BENEFITS OF DRY FIRING AND FEEDBACK IN BIATHLON STANDING SHOOTING PRACTICE

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Johdanto: Ampumahiihdon pystyammunnan hallitseminen vaatii paljon harjoittelua, ja samanaikaiset nopeuden ja tarkkuuden vaatimukset fyysisesti kuormitettuna ovat vastakkaisia. Ampumahiihdon tutkimusartikkeleista löytyy hyvin vähän harjoitteluun liittyviä interventiotutkimuksia, joissa on tutkittu ampumaharjoitusten tai kuivaharjoittelun ja palautteen vaikutuksia ampumahiihdon ammuntaan. Kuivaharjoittelun ja palautteen vaikutuksen ymmärtämiseksi on mitattava ampujan, alustan ja kiväärin välillä vaikuttavia voimia. Tämän tutkimuksen tavoitteena oli tutkia palautemenetelmää, jolla parannetaan ampumahiihdon pystyammuntataitoja ja motivoidaan ampumahiihtäjät kuivaharjoittelemaan ammuntaa kotona. Toisena tavoitteena tutkittiin kuivaharjoittelun määrän vaikutusta pystyammuntasuoritukseen. Lopuksi, laboratoriossa ja ampumaradalla suoritettujen pystyammuntatestien vertailulla selvitettiin korreloivatko kuiva- ja kovapanosammuntatestien tulokset, koska tällaisia tietoja ei löydetty aiemmista tutkimuksista.
Menetelmät: Kuusitoista kansainvälisen ja kansallisen tason ampumahiihtäjää suoritti pystyammunnan kuivaharjoittelua kahdeksan viikon ajan, kahdeksan koehenkilöä (MANTIS-ryhmä, $n = 8$) Mantis X10 Elite -ampumaharjoittelulaitteen (Mantis Tech, LLC, USA) kanssa ja kahdeksan koehenkilöä ilman Mantis-laitetta (CONTROL-ryhmä, $n = 8$). Laboratoriossa ja ampumaradalla suoritettiin 30 laukauksen testit ennen interventiota ja heti kahdeksan viikon harjoittelun jälkeen. Yhteensä analysoitiin 1920 laukausta 64:stä pystyammuntatestistä. Laboratoriossa tehtiin samalla myös tasapainoon, tähtäykseen ja liipaisun liittyviä ammuntateknisten muuttujien mittauksia. Harjoitusinterventio koostui 2-6 viikoittaisesta kuiva-ammuntaharjoituksesta, jotka suoritettiin urheilijan itse valitsemana ajankohtana. Muut harjoitukset suoritettiin normaalien harjoitusohjelmien mukaisesti. Mantis ampumaharjoittelulaite antoi MANTIS-ryhmän urheilijoille välitöntä palautetta äänen ja kuvaajien avulla, sekä pitkän aikavälin tilastoja kuiva-ammuntaharjoituksista. Kuivaharjoittelun kokonaismäärän vaikutusta tutkittiin jakamalla koehenkilöt kahteen ryhmään keskimääräisen kuivaharjoittelun määrän perusteella. Koko ryhmälle ($N = 16$) laskettiin kuiva- ja kovapanosammuntakokeiden väliset korrelaatiot, jotta voitiin tutkia rekyylin ja pamahduksen vaikutusta ampumasuoritukseen.
Tulokset ja päätelmät: MANTIS-ryhmä paransi pystyammuntatulostaan enemmän sekä ampumarata-, että laboritoriotesteissä pienemmällä harjoittelumäärällä kuin CONTROL-ryhmä. Kehon tasapainon (painekeskipisteen sijainnin keskihajonta 0-0,6 s ennen laukausta) ampumasuuntaan nähden kohtisuorassa tapahtuva koko kehon huojunta (SDX), sekä takimmaisen (SDX_R) ja etummaisen jalan (SDX_F) huojunta pienenivät merkitsevästi MANTIS-ryhmässä ($p < .05$). Kuivaharjoittelukertojen suuri määrä oli yhteydessä parempiin pystyammuntatuloksiin sekä laboratoriossa että ampumaradalla, ja myös suurempaan ampumarataharjoittelun määrään. Pieni harjoitusmäärä osoitti suurempaa vaihtelua testituloksissa. Ampumaradan tulokset eivät korreloineet laboratorion ampumatulosten tai teknisten muuttujien muutosten kanssa. Ampumaradan ja laboratorion ampumatulokset korreloivat vain jälkitesteissä ($p < .001$), mikä osoittaa, että tulokset voivat vaihdella uudella testausmenetelmällä, ja taitojen oppiminen vakauttaa tulokset laboratoriotesteissä. Tulevissa tutkimuksissa tulisi verrata laboratorio- ja ampumaratatestien tuloksia ja teknisiä muuttujia.

Avainsanat: ampumahiihto, pystyammunta, kuivaharjoittelu, tasapaino, palaute, Mantis X10

ABSTRACT

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Introduction: Mastering biathlon standing shooting takes a lot of practice and the simultaneous demands of accuracy and speed when physically extorted are contrary requirements. There are very few training intervention studies found in biathlon research papers that studied the effects of shooting exercises or dry firing and feedback on biathlon shooting performance. To understand the effects of dry firing practice and feedback, the different forces acting between the shooter, the base and the rifle have to be assessed. The aim of this study was to investigate a feedback method for improving biathlon standing shooting skills and to motivate biathletes to practice dry firing at home. The second objective was to investigate the effects of the amount of dry firing practice on standing shooting performance. Finally, a comparison of standing shooting tests performed in the laboratory and on the shooting range was carried out to determine whether the results of dry and live shooting tests correlate, as no such data have been found from previous studies.
Methods: Sixteen international- and national level biathletes were asked to perform standing shooting dry fire practice drills for eight weeks, eight subjects (MANTIS group, n = 8) with a Mantis X10 Elite (Mantis Tech, LLC, USA) shooting training device and eight subjects (CONTROL group, n = 8) without the Mantis device. A total of 1920 shots from 64 standing shooting tests were analyzed. The 30-shot standing shooting tests were performed both in the laboratory and on the shooting range before and immediately after the 8-week intervention period. Technical shooting parameters related to postural balance, aiming and triggering were also measured in the laboratory shooting tests. The training intervention consisted of 2 to 6 weekly dry firing exercises, performed at a time of the athlete's own choice. Other exercises were performed according to normal training programs. The Mantis shooting training device provided instant augmented feedback with sound and graphs, and long term statistics from the dry fire exercises to the MANTIS group athletes. The effects of the total amount of dry fire practice was examined by dividing the subjects into two groups based on the average amount of performed dry fire training. Correlations between dry and live fire tests were calculated for the whole group (N = 16) to investigate the effects of live fire recoil and sound on shooting performance.
Results and Conclusions: The MANTIS group demonstrated more improvement with less training in live and laboratory standing shooting scores than the CONTROL group. Postural balance (standard deviation of the center of pressure location 0-0.6 s before firing) of the whole body in cross-shooting direction (SDX) and postural balance for rear (SDX_R) and front leg (SDX_F) decreased significantly ($p < .05$) in the MANTIS group. A high number of dry fire practice sessions was associated with better standing shooting performance both in the laboratory and on the range, and also with a higher amount of live fire training A small number of dry fire exercises showed greater variation in test results. Improvements in shooting range scores did not correlate with changes in laboratory shooting scores or technical variables. Range and laboratory shooting scores correlated only in post-tests ($p < .001$), indicating that results may vary with a new testing method, and skills learning stabilizes scores in laboratory tests. Future studies should compare laboratory and range tested scores and technical variables.

Key words: biathlon, standing shooting, dry fire, postural balance, feedback, Mantis X10

ABBREVIATIONS

ATS	ANOVA-type statistics
CEP	Circular Error Probability
COG	Mean aiming accuracy distance from center of target
COP	Center of Pressure
DevX	Horizontal stability of hold of the rifle
DevY	Vertical stability of hold of the rifle
F	Front
HighDT	High dry fire training amount group
IBU	International Biathlon Union
IQR	Interquartile range
ISSF	International Sport Shooting Federation
LabPTS	Laboratory 30-shot shooting test score
LowDT	Low dry fire training amount group
MV	Mean velocity of aiming point trajectory (200/600 ms) before triggering
nparLD	Non-parametric longitudinal
NPO	Natural point of aim
VO_{2max}	Maximal oxygen consumption
XC	Cross Country
r_s	Spearman's rho correlation coefficient
R	Rear
RangePTS	Biathlon range 30-shot shooting test score
SD	Standard deviation
SDX	Whole-body postural balance in cross-shooting direction
SDY	Whole-body postural balance in shooting direction
SDX_F	Front leg postural balance in cross-shooting direction
SDY_F	Front leg postural balance in shooting direction
SDX_R	Rear leg postural balance in cross-shooting direction
SDY_R	Rear leg postural balance in shooting direction
$Target_{2/3}$	Relative aiming accuracy distance from hit point
TF	Trigger force relative to shot break, before triggering or 200 ms after
$TIRE_6$	Timing of triggering index
WD	Weight distribution

CONTENTS

1 INTRODUCTION

Biathlon is a fascinating and challenging winter sport, which combines freestyle cross-country skiing and small bore rifle marksmanship. Having to master two totally different types of sport disciplines, a biathlete needs to practice a lot, since training needs to be focused on rifle shooting and cross-country skiing. According to Laaksonen et al. (2018b), Swedish national team coaches recorded the total amount 700 to 900 hours of endurance training for an Olympic level biathlete annually and around 22000 shots fired during approximately 210 shooting sessions. This means the combined total physical training hours and sessions for a biathlete could be slightly less than 800 to 900 hours for a cross-country skier (Sandbakk et al. 2014), due to the ~7000 shots added in shooting training at rest (Laaksonen et al. 2018b). The best biathletes can compete in international cross-country skiing events at an elite level since the aerobic capacity requirements and skiing speeds and are roughly the same (Laaksonen et al. 2018). Training for biathlon also includes posture building, speed of preparation for the first shot and overall minimizing the time spent on the shooting range. Specifically shooting times and accuracy have improved in the resent years, which emphasizes training in competition like conditions, under time pressure and against other athletes (Laaksonen et al. 2018). There are many ways to practice biathlon shooting related tasks even at home, in order to automate those and minimize the time spent on the range in competitions.

Most biathlon shooting research projects have been focusing on testing the performance and separating the technical components of a shot (Ihalainen et al. 2018; Köykkä et al. 2020; Sattlecker et al. 2017). In addition, recent studies have been investigating the differences between shots from rest and shots after different levels of intensive physical exercise (Ihalainen et al. 2018; Heinrich et al. 2020; Hoffmann et al. 1992; Zak et al. 2020). Recent studies have shown that physical stress and exertion may not have a huge impact in biathlon shooting accuracy nor rifle stability in the prone position, but rather the time spent on the range, as concluded by Heinrich et al. (2020). Hoffmann et al. (1992) found that the stability of hold was mostly affected in standing shooting, if exercise intensity was high just before shooting. In effect, total time to finish the race is the only thing that matters in a biathlon race, of course adding the penalties from shooting during the race. It is important to minimize the time spent on the range, and that seems to require better stance stability and postural balance.

The demands of biathlon include time related requirements; skiing time, shooting time and penalty time, which have been researched in several studies (Luchsinger et al. 2018; Björklund et al. 2022), and shooting related requirements (Gallicchio et al. 2016; Žák et al. 2020). The time and shooting requirements are interconnected with tactical, environmental and physical variables, which have been researched in various other studies (Stöggl et al. 2015; Laaksonen et al. 2018; Ihalainen et al. 2018; Köykkä et al. 2020). There are very few training intervention studies found in biathlon research papers that studied the longer term effects of specific shooting exercises in biathlon standing shooting performance (Groslambert et al. 2003; Laaksonen et al. 2011; Zak et al. 2017), thus providing great opportunities to design longitudinal research studies in this field to complement the various other researches.

Moreover, in addition to practicing at the biathlon shooting range, various dry firing drills, mental and relaxation practice (Laaksonen et al. 2011) and some form of augmented feedback (Mononen et al. 2003) have been practiced to improve standing shooting performance. Dry firing and holding exercises are practiced by the Swedish Olympic biathletes up to 130 sessions per year (Laaksonen et al. 2018b) and it is recommended in target rifle shooting as well (Maksimovic ISSF, 2022). Laaksonen et al. (2011) found that dry firing 4-12 x 5 shots per week, combined with holding exercises and autogenic and imaginary training (ATR) showed improved shooting precision in biathlon. Dry firing exercises were performed in a manner, which simulated the usual live fire biathlon shooting in a competition, or in a shooting training.

Biomechanical evaluation of standing shooting in the University of Jyväskylä's biathlon shooting laboratory in Vuokatti allows testing of many technical shooting related parameters. The fully synchronized test data include hit point, aiming point trajectory, triggering and postural balance related factors, measured with modern wireless equipment and presented in graphical plots. Since there is also a biathlon shooting range close by, there is a possibility to perform comparisons of laboratory tests of technical shooting variables and live fire tests on the biathlon shooting range on the same day or week. The year round availability of international and national level biathletes for testing the effects of various training interventions simplifies logistics and adds value to the training center.

2 DEMANDS OF BIATHLON

2.1 General requirements

The total race time in a biathlon competition consists of skiing time, shooting accuracy and shooting time. Penalties are given for every miss in shooting, which increases skiing time and distance, or adds one minute to total course time in individual competition. The International Biathlon Union (IBU) authorizes seven types of biathlon competition events; individual, sprint, relay, pursuit, mass start, mixed relay and single mixed relay. Range time and shooting time become more important when a biathlete is fighting for podium positions in the world cup sprint races, nevertheless skiing time and shooting performance remain the most important contributors according to Luchsinger et al. (2019). Skiing speed has steadily increased due to better tracks, better skis, better waxing and better training, such as upper body strength, power and endurance (Laaksonen et al. 2018). Luchsinger et al. (2018) studied the effects of performance determining factors in sprint competitions, where course time explains the 3% to 5% difference between top ten performers and those finishing on places 21 to 30. Shooting accuracy (penalty time) and course time were the determining factors and accounted all together for 94% of performance differences in a sprint race. The conclusion was that generally coaches and athletes should try to improve skiing speed and shooting performance, rather than shooting time in order to finish in the top 10 in a Biathlon World cup sprint (Luchsinger et al. 2018). Other race types have slightly different demands, but for example in an individual race with four shootings (4x5 shots), a 1 minute penalty per missed target is extremely hard to catch up by faster skiing, and according to a recent study by Björklund et al. (2022) shooting accuracy is more important than skiing speed in biathlon pursuit and mass start competitions.

2.2 Shooting requirements

Standing shooting in Biathlon is for most biathletes more demanding than prone shooting, even the target size is scaled up to 115 mm from the 45 mm used as prone target. This can be verified from the IBU data center (2023) statistics, which typically indicates 3% to 8% worse hit rate for standing shooting than prone shooting for most individual biathletes. Luchsinger et al. (2018) found that world cup sprint races standing shooting hit percentages are 90%, while prone shooting percentages are around 95% for the whole season average shooting results. This may depend on many factors, but one major reason is that standing shooting is always the last shooting in a biathlon race and the athletes are extremely strained physically and stressed mentally.

A biathlete is not necessarily always trying to attempt to shoot all center shots at the target in a biathlon competition, since the purpose is only a hit that makes the target fall. The diopter sight on the biathlon rifle (figure 1) enables aiming and timing the shot so that a hit is possible on the black target dot 50 meters away. When the front sight aperture is small enough, it is possible to hit the target, even if the target is not perfectly centered in the sights.

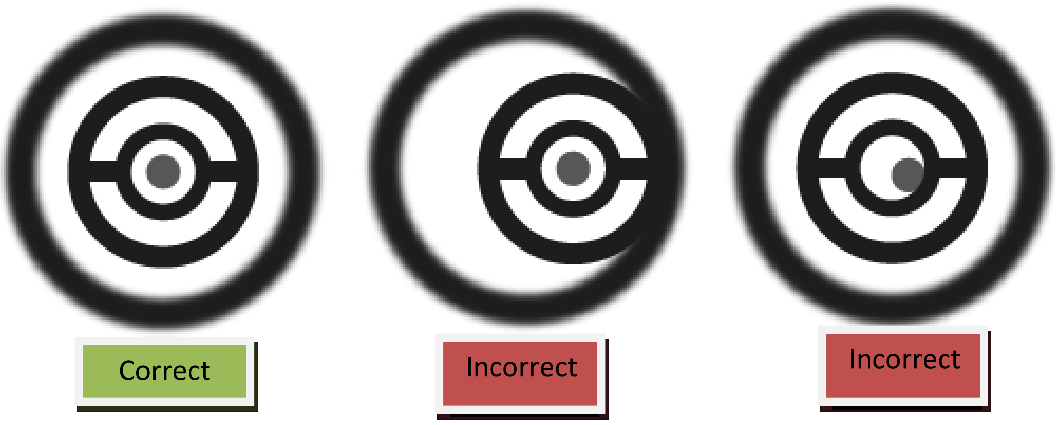

FIGURE 1. A target dot at 50 meters, as seen through a biathlon rifle's diopter sight (Finnish Biathlon Association, modified).

A hit means no penalty and a miss causes a 1 minute time penalty, or a 150 meter penalty loop skiing, depending on race type. Hoffman et al. (1992) decided that for scientific purposes, also other shooting performance factors than hit or miss should be recorded. Also Ihalainen et al. (2018) and Köykkä et al. (2020) have been studying various biathlon shooting performance determinants, which in a more complete way can describe the different performance factors in a biathlon shooting event. Various sorts of measurements and equipment have been developed in these research projects to quantify these variables and will be discussed in more detail in the next chapter. Žák et al. (2020) presented a so called "pyramid of biathlon shooting" (figure 2), which illustrates the three key factors of biathlon shooting; stance stability, aiming process and clean triggering. Triggering on the top of the pyramid means that if an athlete masters the trigger press and timing, he/she is not automatically a great shooter. All shooting components need to be mastered and harmonized together (Žák et al. 2020).

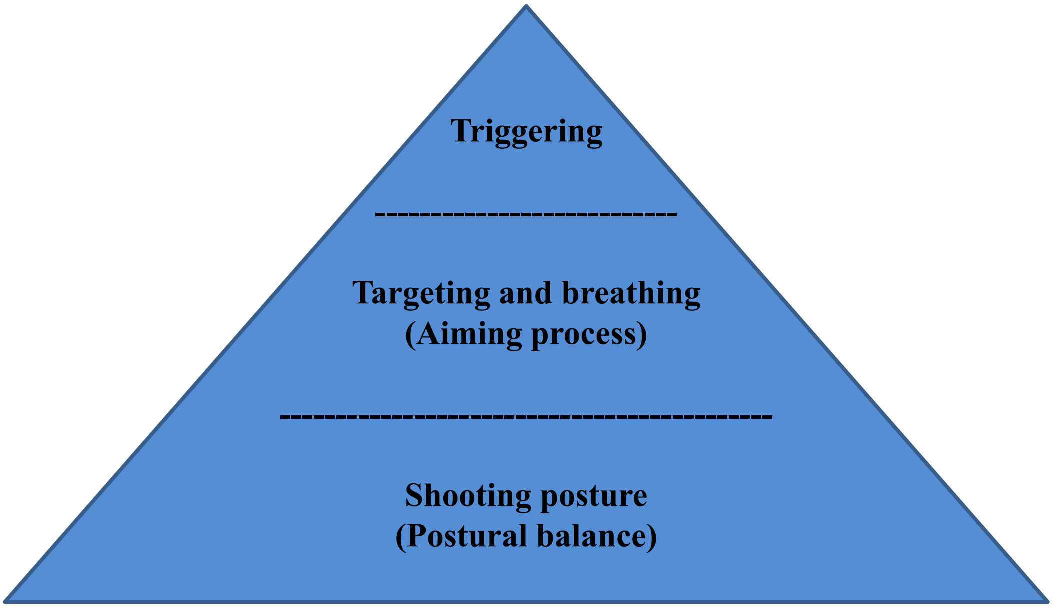

FIGURE 2. Pyramid of biathlon shooting showing the key factors of biathlon shooting which should be mastered together from bottom to top (Žák et al. 2020, modified).

In the aiming and target acquisition process, at least two different major strategies are used, the other is timing and the other holding strategy. Köykkä et al. (2020) studied these strategies, and came to the conclusion that some biathletes do not even try to aim at the center or hold the rifle still during the time period close to triggering and firing, so it seems likely that aiming accuracy and holding time are not representative of their technical skill level. It was suggested that there was no real difference in shooting performance between these two aiming strategies. The more time an athlete has to complete the five shots, the more tempting it may become to play it safe and use the holding strategy, if the stance and rifle stability will allow a clean shot. The balance and aiming point trajectory differences in shooting at rest may be smaller, especially when using holding strategy, but the tests are designed so that even the small differences can be detected (Köykkä et al. 2020).

The effects of intensive exercise immediately prior to shooting has shown only minimal or no impact on shooting performance of experienced biathletes according to Gallicchio et al. (2016) and Luchsinger et al. (2016). Rest condition and sub-maximal exercise condition seemed to reveal same level of standing shooting accuracy results (Heinrich et al. 2020; Gallicchio et al. 2016, Vickers & Williams. 2007), but shooting time increased after intense cardiovascular load. Controversially, a number of other studies have shown decreased postural balance and shooting performance after intense physical loading (Ihalainen et al. 2018; Hoffmann et al. 1992; Zak et al. 2020; Sattlecker et al. 2017).

When intense physical load decreases a biathlete's monitoring capacity, all irrelevant non-shooting actions are neglected by experienced biathletes. By putting all focus on the shooting, elite biathletes can maintain rest level shooting accuracy under sub-maximal physical load (Gallicchio et al. 2016; Vickers & Williams 2007). Biathletes with same training background have a much greater possibility to be better shooters in a race, if they are better shooters at rest. Ihalainen et al. (2018) showed that shooting technical variables measured at rest correlated with the corresponding variables measured under physical stress. Hit percentage and postural stability declined from rest to race, and especially stability of hold in shooting direction and cleanness of triggering were affected negatively by physical load (Ihalainen et al. 2018).

Accuracy and precision directly affect biathlon shooting scores, penalties and total course time. High precision is required from the shooter, ammunition and rifle combination to precisely position the shots in small groups, and high accuracy is required from the shooter to be able to place the shot group to the center of the target (figure 3). The highest precision is only needed in prone shooting, but it is beneficial also in standing shooting.

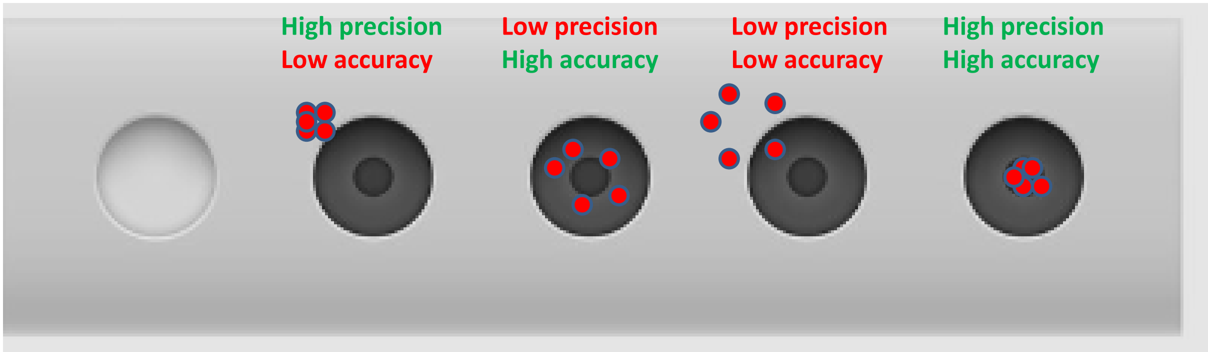

FIGURE 3. A classical illustration of accuracy and precision.

2.3 Tactical and environmental requirements

Athletes tend to slow down their skiing 15 to 30 seconds before the shooting and start preparing mentally for the shooting by checking the wind, selecting the shooting lane on the range and preparing the stance, so heart rate generally drops before shooting (Laaksonen et al. 2018b). In laboratory testing it may be difficult to determine an exercise intensity level, which would serve as optimal for all subjects, to simulate shooting in a race. Tactics, including skiing speed, vary heavily in different competition types, and depends on the immediate situation between competitors. Björklund et al. (2022) found overall shooting accuracy the most important factor in pursuit and mass start types of competitions. In sprint competitions however, skiing speed and standing shooting performance are more important (Luchsinger et al. 2018).

Pacing, drafting and tactics are also important in mass start, pursuit and the individual races, where there are four shooting events and a longer total skiing distance. Varying environmental conditions may need different tactics than ideal racing conditions, and accounting for wind, temperature, snow fall or fog for example, needs attention and training in those kind of highly varying conditions and finding out specific weaknesses and strengths. There is a lack of scientific studies from the field of biathlon tactics and varying shooting conditions.

2.4 Physical requirements

The best biathletes can compete in international cross-country skiing events at an elite level, and it has been verified that aerobic VO_{2max} capacity requirements are roughly the same in biathlon and XC skiing competitions (see table 1 in the article: Laaksonen et al. 2018). The start-and-stop nature of biathlon may resemble sprint skiing more than distance skiing, and anaerobic capacity requirements have become more crucial due to uphill sections and increasing speeds (Laaksonen et al. 2018).

Carrying the 3.5 kg rifle has been reported to increase oxygen consumption, blood lactate concentration and metabolic efforts, especially for female biathletes (Laaksonen et al. 2018). Probably due to greater rifle mass relative to body mass in women. Stöggl et al. (2015) did not find any major gender differences in the effects of carrying a rifle, but they reported significant increases in leg work and cycle rates for both genders, and potential upper body performance development requirements for female biathletes.

An international level cross-country skier trains 800 to 900 hours annually on average (Sandbakk et al. 2014), and an Olympic level biathlete may do the same amount of endurance training according to Laaksonen et al. (2018b), but these volumes are very individual, and there is a trend to focus more on intensive power training, strength training and sprint type skiing training.

3 BIOMECHANICAL EVALUATION OF BIATHLON STANDING SHOOTING

In rifle shooting, it is important to form and maintain a stable and, but relaxed position throughout the shooting process. Many other factors also need to be perfected in concert with the shooting posture. For this reason, the different forces acting between the shooter, the base, and the weapon are interesting to study.

3.1 Force measurement technologies

Biomechanical force measurements use force plates, pressure sensors and balance plates. In these, different types of sensors are used to express force, the most important of which are strain gauges, piezo sensors and capacitors. A force sensing resistor (FSR) is a device which exhibits a decrease (or increase) in resistance with an increase in the force applied to the active surface. This resistance change can then be curve fitted and calibrated for greater accuracy and converted into a voltage output. Its force sensitivity is optimized for use in human touch control of electronic devices (Interlink, FSR 400 Integration guide). The sensor usually used for force plate measurements is a resistive strain gauge strip. Pressure sensors based on capacitance and conductance have two electrically conductive membranes, between which there is either a non-conductive (capacitance) or an electrically conductive (resistive) material. When pressure is applied to the capacitive sensor, the non-conductive material is compressed, the electrically conductive membranes converge, and this causes a change in electrical charge. In a resistive sensor, on the other hand, the electrical conductance changes when the pressure is applied to the sensor (Interlink, FSR 400 Data Sheet; Paukkonen, 2013). In general, measurements of motion are more difficult to implement and calibrate, but the reduction in sensor sizes and wireless measurements provide the desired freedom to perform measurements under field conditions. Although measurements are performed without moving around, additional equipment and wiring often interfere with performance and concentration. Next chapters will form an overview of some critical technical determinants of biathlon standing shooting and the measurement possibilities of those.

3.2 Trigger control

Triggering (force, timing and cleanness) is a major predictor of biathlon shooting performance according to Laaksonen et al. (2018) and Ihalainen et al. (2018), however there have been very few studies examining it. The minimum trigger resistance for a biathlon rifle is 500 grams (IBU, Event and competition rules, 2022), and many athletes use a trigger setting slightly above that, because it is measured carefully before every competition. Minimal threshold on the trigger makes breaking of the shot less detectable, and this can improve shooting by not giving the shooter a chance to anticipate the breaking of the shot. Even a perfect hold and aiming can be ruined by poor triggering, as the rifle barrel moves during breaking of the shot. Ihalainen et al. (2018) studied the technical determinants of biathlon standing shooting and they found out that the two most influencing parameters were cleanness of triggering (the cumulative distance travelled by the aiming point during the last 200 ms before the shot breaks) and postural balance. In every shooting sport, performance depends on the ability to keep the aiming point during triggering. Köykkä et al. (2020) studied holding and timing strategies in biathlon standing shooting, which both work better, if the aiming point movement is minimized during triggering. Both strategies benefits heavily from a stable posture, which affects rifle muzzle movement during aiming. This is difficult to control in biathlon since physical exertion makes muscle and balance control hard to maintain in a static shooting position. Maksimovic (2022) recommends gradual 3 phase triggering (figure 4) with a dedicated second stage of about 80 percent pressure during the aiming process for standing rifle shooting.

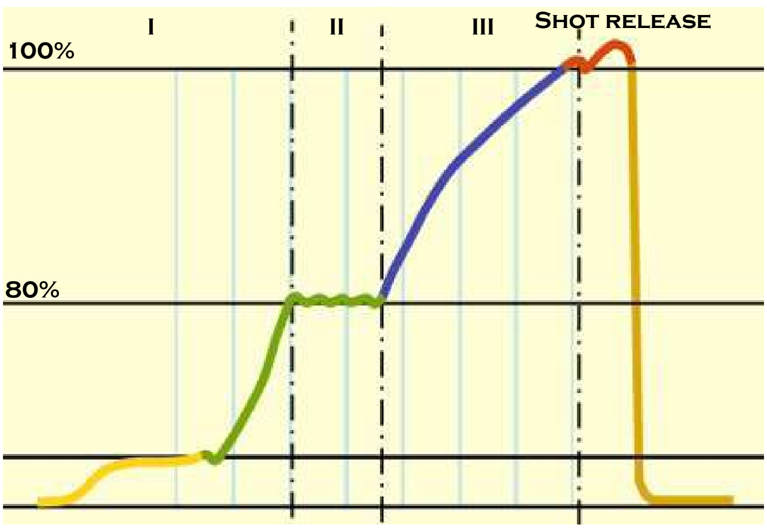

FIGURE 4. Trigger force curve for standing shooting (Maksimovic, G. ISSF, modified).

Any additional abnormalities, jerks, jumps or stops in the curve can be considered poor triggering. Figure 5 shows measured triggering profiles in biathlon standing shooting, where the second phase is clearly seen in the shooting without physical load. Galay et al. (2021) found that trigger pressure 0.5 to 1 second before shot release is lower in a physically loaded condition, leading to destabilization of the rifle during target acquisition.

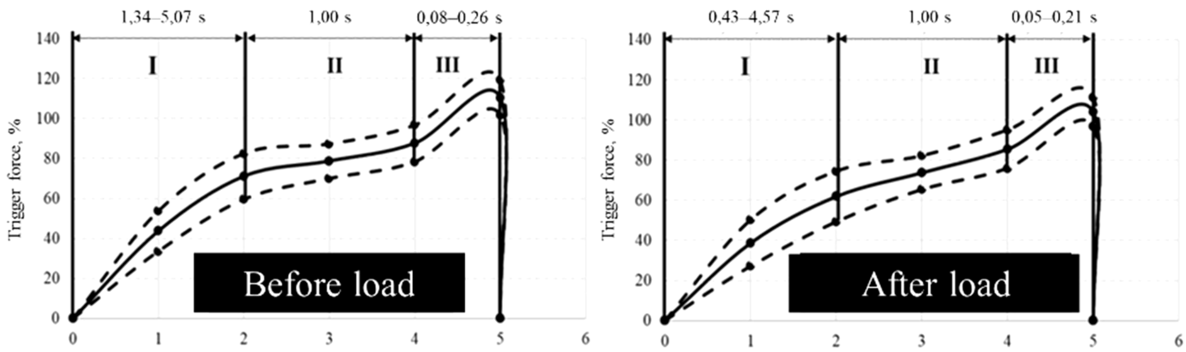

FIGURE 5. Trigger force curves from biathlon standing shooting (Galay et al. 2021).

Eventually, there has to be a good feel for the trigger and one should be extremely well acquainted with the trigger that one is intending to use in competitions. Sattlecker et al. (2017) showed that there is no correlation between trigger coefficients (force curves) and shooting performance, but Ihalainen et al (2018) found that cleanness of triggering had the strongest relation with both shooting performance in rest and under physical load. The relationship between trigger pressure and the movement of the aiming point during the last 200 ms should probably be investigated more closely in future studies. Trigger force has a tendency to decrease from rest to fatigued condition (Galay et al. 2021) and elite shooters use higher trigger forces one second before firing (Sattlecker et al. 2013). Higher trigger forces 0.5-1 second before firing seem to have a connection with higher aiming stability during the last second before firing (Žák et al., 2020). In the same study they proved that increasing the pressure during targeting on the trigger has a negative impact on rifle stability, especially during the last second. To improve rifle stability during aiming, the pressure on the trigger should be as high as possible and constant in time one second or more before breaking the shot (Köykkä et al, 2022; Žák et al., 2020). Many studies have found triggering parameters among the most determining factors of shooting performance in biathlon (Ihalainen et al. 2018; Sattlecker et al. 2017; Žák et al., 2017).

There are a couple of measurement options for trigger force measurements, such as strain gauges and pressure sensors. However, due to the small size of the triggers and low triggering forces, pressure sensors are often used (Paukkonen, 2013). Force Sensing Resistors (FSR) are devices that produce a decrease in electrical resistance as more physical force or pressure is applied to them, putting them in the broader category of piezoresistive devices. Figure 6 shows a typical pressure sensor used for triggering measurements (FSR 402, Interlink Electronics Inc, CA, USA).

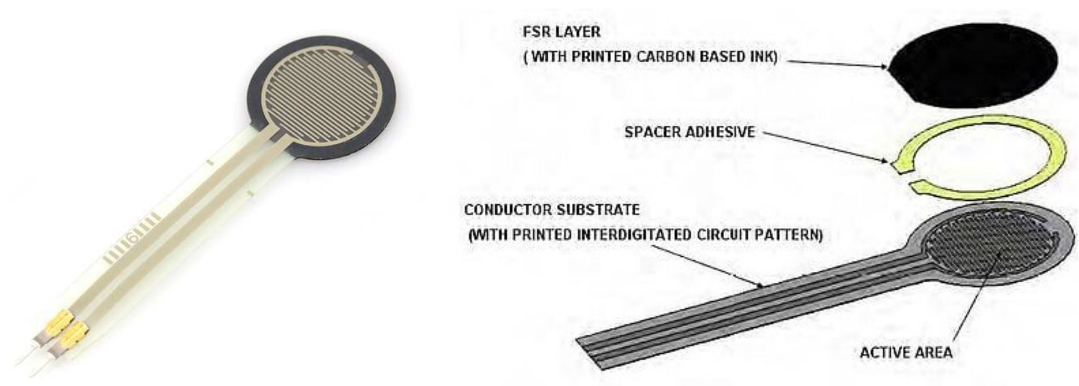

FIGURE 6. Interlink FSR 402 pressure sensor (www.interlinkelectronics.com).

It would be best to integrate the sensor into the trigger, which would require structural changes to the triggers to install the sensors inside the trigger. The sensor can also be taped or glued on the trigger, or it can be integrated into a glove, for example, but in these cases the measurement results may be erroneous as the sensor moves in relation to the trigger and the finger. Absolute force values are normally not measured, because normally triggering profiles (figure 4) and timing are of interest. In the case of trigger profiles, voltage values are used instead of force. Measuring absolute force value with an inexpensive pressure sensor would require constant calibration of the sensor and a solid mechanical housing.

It is generally desired to see if there are errors in the trigger control, such as a jerking the trigger, that would appear as a rapid increase in force in the trigger profile. Pure triggering plays a very important role in all types of shooting, as errors and jerks at critical moments of aiming may lead to bad hits. According to Anschütz, the world's biggest manufacturer of biathlon rifles, the rifle strikers are built to be very light and fast so that the bullet can leave the barrel quickly after being triggered. This so-called lock-time is, for example, in a biathlon rifle about 4 ms from the time the trigger is breaking until the bullet comes out from the barrel

(ANSCHÜTZ J.G., Ulm, Germany). All trigger jerks and rifle barrel movements during this time will change the hit point and can cause a miss. Figure 7 illustrates an Anschütz triggering mechanism (ANSCHÜTZ J.G., Ulm, Germany) to which a force sensing pressure sensor should be attached for biathlon shooting measurements. This is a somewhat cumbersome task, since biathletes should be using their own trigger and familiar feel for it.

FIGURE 7. A typical biathlon rifle trigger and firing mechanism (www.anschütz.com).

3.3 Postural balance and body sway

The data of multiple studies and several papers on shooting indicates that postural balance and rifle stability (holding) are related to each other and to the shooting score in standing shooting (Sattlecker et al. 2014, Sattlecker et al. 2017, Ihalainen et al. 2018, Köykkä et al. 2020). After a lap of intensive skiing, during the last standing shooting, physical exertion makes the balance control worse and body sway larger. Hoffman et al. (1992) reported that intense exertion significantly affected standing shooting performance by its effect on the stability of the hold. With excessive physical load, clean and smooth triggering becomes more difficult due to body and rifle sway, as the aiming point trajectory and muzzle movement seem to grow in amplitude and velocity quite uncontrollably during aiming. However, there are no commonly agreed protocols on how to introduce the physical load when testing in a laboratory, nor how to arrange and control the shooting phase. Figure 8 shows the set-up used by Ihalainen (2018), when testing balance and aiming accuracy of biathletes in the laboratory of biomechanics of Jyväskylä University in Vuokatti, Finland. Separate force plates are set underneath each ski, to independently measure balance variation from both legs.

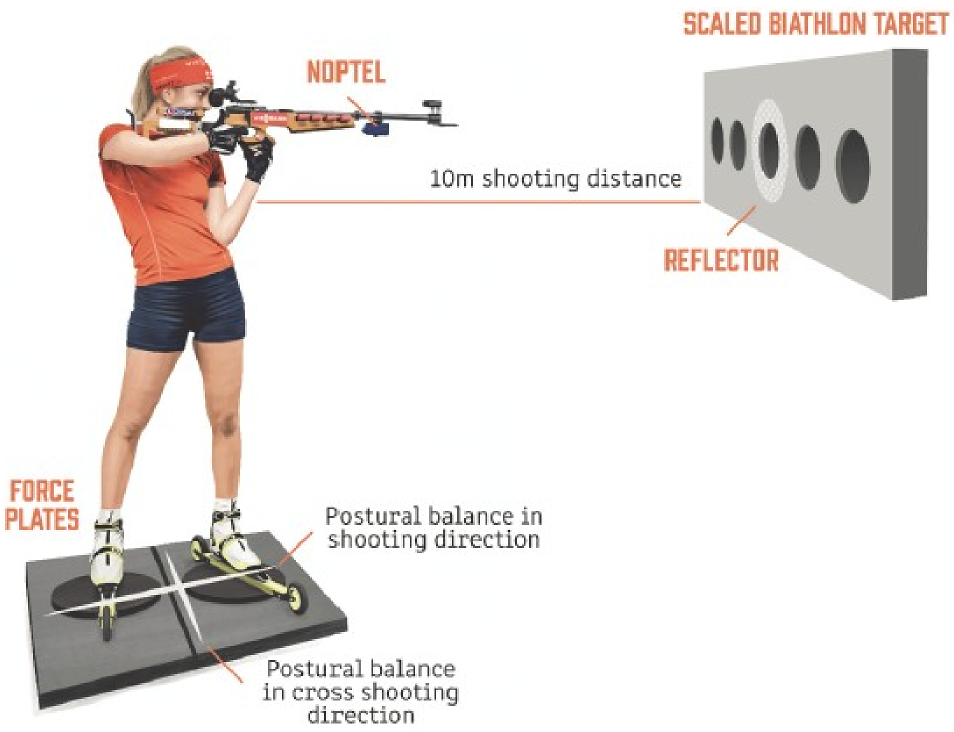

FIGURE 8. Measurement of postural balance and biathlon shooting in a laboratory (Ihalainen, 2018).

Equilibrium is generally measured with force plate sensors placed under the shooter, and balance is an important measure of shooting performance and posture stability. Mononen et al. (2007) used a triangular Good Balance plate manufactured by the Finnish Metitur Oy to measure balance. In addition, ready-made software is available for balance measurements, which filters and processes movements in the x- and y-coordinates before, during and after the trigger pull. From these coordinates, the COP or pressure center and its variation, speed and distance during execution are then calculated (Mononen et al. 2007). So far, the results between the different studies on the effect of balance on shot accuracy vary considerably. The balance would be expected to directly affect the sway of the weapon, but there are other compensating forces that can control the movement of the rifle muzzle. In addition, the timing and cleanness of the triggering play a crucial role in peak performance (Ihalainen, 2018).

Sadowska et al. (2019) found that rifle and pistol shooters have significantly better balance characteristics in the standing position both with eyes open and eyes closed, than untrained control groups. The gaze cannot be used to control balance while shooting in the same way as without a rifle, as the one eye follows the target through the sights, so proprioceptive senses must be used and practiced. Changes in shooting performance during training or competition are most clearly related to changes in horizontal hold ability. Changes in horizontal hold, on the other hand, are associated with changes in balance (Sadowska et al. 2019). The stability of the balance is one clear factor influencing the different aspects of shooting technique and thus the accuracy of the hit, and various balance exercises are likely to improve shooting technique (Ihalainen, 2018). A good postural balance is a prerequisite of good standing shooting, whether at rest or strained and independent of aiming strategy (Köykkä et al. 2020). Future biathlon research should evaluate postural balance, rifle stability and shooting performance together (Sadowska et al. 2019), and in order to find correct postural balance effects on biathlon standing shooting scores, skis and boots should be on during the testing.

3.4 Aiming point trajectory and hit

All control of the body's biomechanical forces in shooting are condensed into a hit, so the final assessment of shooting performance is only obtained from the hit or shooting score, regardless of the variation of other parameters. Optoelectronic measurement of aiming point trajectory and hit has become a common standard for laboratory measurement of shooting. The Noptel ST-2000 Sport laser system (Noptel, Oulu, Finland) is probably the most common of these, since it has been on the market since the 80's. The Noptel equipment simulates a 50 meter shooting range indoors on a 5 or 10 meter range and is used to measure shooting accuracy, stability of hold and aiming accuracy. When dry firing with optoelectronic devices indoors, the recoil caused by a rifle shot can normally not be taken into account in biomechanical measurements, but some indoor live fire ranges exist which can accommodate also recoil effects. Recoil has a significant physical and mental impact on shooting performance, and specifically in biathlon, where a series of five shots is fired. Noptel equipment is also suitable for outdoor use on a track up to about 50 meters, but the weather conditions limit its use to cloudy days, and the cable prevents skiing and position practice. Another commonly used system is the SCATT shooter training system (SCATT Electronics LLC, Moscow, Russia), which is based on a camera device that detects and monitors the target. The SCATT system is also sometimes used outdoors with a variety of rifle types because it allows the use of the real ammunition and can withstand recoil. It may be the most sophisticated commercial system for shooting research at present.

The rifle muzzle can sway in 3 dimensions (x, y and z) in the standing shooting, but most significant increase in deviation was found in the y-axis vertical direction in the study by Ihalainen et al. (2018), and x-axis horizontal direction in studies by Sattlecker et al. (2014) and Köykkä et al. (2020). Different study methods, seem to give different results in terms of most significant technical determinants in biathlon shooting. Due to the various target approaching angles and aiming strategies in biathlon shooting, the sway in any direction can happen randomly, so movement speed in general should be minimized and controlled. Figure 9 shows how the movement of the aiming point before firing is remarkably small for top-level shooters and the acceleration of the movement is also small or close to zero. A small movement of the aiming point like this provides good prerequisite for successful trigger maneuver and excellent shooting scores.

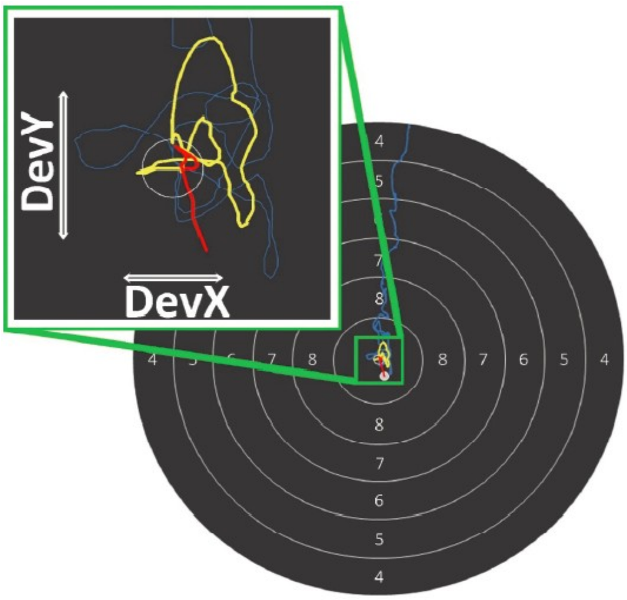

FIGURE 9. Aiming point trajectory of an elite level air rifle shooter measured with Noptel laser system (Ihalainen, 2018).

3.5 Forces on the butt plate

The pressure between rifle and shoulder is measured with strain gauge sensors mounted under the rear plate of the rifle stock (figure 10). These measurements give varying results due to different firing positions and different placement of the butt plate on the shoulder as reported by Grebot et al. (2007).

FIGURE 10. The butt section of a rifle with a force sensor attached (Tanskanen, 2013).

In the measurement of butt forces, the absolute force values are not as important as the variance between shots and shooting sessions of the shooter. Butt forces also most often change when the length of the stock of a rifle is adjusted, and the forces seem to drop after intense exercise (Grebot et al. 2007). The design of the butt plate of a rifle varies considerably between the rifles of different shooters, which poses challenges to the placement of the sensor. In prone and standing shooting, different parts of the butt plate touch the shooter's shoulder depending on the position, so measuring the butt force provides information about the stability of the pull and the position of the butt plate on the shoulder. The shape of the butt plate can thus be optimized to suit each shooter (Grebot et al. 2007). The differences between the butt plates, the shooters and the firing positions and the sensors are probably so significant that, despite many searches, no particularly interesting research measurement results were found. There may be a need to find a repeatable way to measure rifle-shoulder forces during biathlon shooting, especially when physically strained in a race type situation.

4 SHOOTING TRAINING

Winning an Olympic medal in Biathlon under normal weather conditions, not one single miss is allowed in sprint races and no more than one penalty in the four shootings in the other individual events. Olympic level athletes shoot around 20000 shots per year while practicing shooting, which takes hundreds of hours of time and effort (Laaksonen et al. 2018). Shooting is best learned by shooting and immediate feedback during training is extremely valuable, since the athlete cannot see other than the target and sights of the rifle during a shot. A coach is unable to identify the pressure value on the trigger and movement of the rifle by looking at the finger of the biathlete and the rifle barrel during the shooting, so the utilization of diagnostic tools in training can be recommended to biathlon trainers. If a trainer is not available, utilizing video recording and diagnostic tools in shooting practice is useful when trying to find systematic errors. Additionally, varying different types of shooting practice, makes it more fun and motivates the shooter.

4.1 Dry firing practice

Important technical factors in shooting, such as postural stability, stance building, rifle holding, aiming, triggering and many more variables can be improved at home with focused training methods. This is where dry firing (practice shooting without ammunition) exercises come to play and can offer substantial benefits with less effort than going to the shooting range. Dry firing may not be a preferred training method by some athletes, since there is hardly any feedback during the training, but it can still improve shooting skills and consistency. Even without monitoring devices, dry firing can reveal trigger control problems, as the aiming point should remain the same even if the trigger is pulled (ISSF, 2022). There are some training devices with feedback available for indoor use, such as Noptel and Scatt, but they are quite expensive.

Mantis (Mantis Tech, LLC, USA) has developed a small device called "MantisX10 Elite" which has inertial sensors to detect the tiny movements of a rifle barrel before, during and after triggering. The simple and inexpensive device only weighs 13 grams, has no cables and is easy to attach, detach and use. Additionally, the user interface for mobile phones or laptops includes a training diary, shot feedback and various shooting training programs (Mantis Tech, LLC, USA). Thanks to monitoring technical shooting factors, the trigger control and the aiming point movement and long-term systematic training of these parameters, improvements in shooting performance can be expected (Žák et al. 2020).

Top biathletes in the Swedish Olympic team dry fired 120-130 sessions per year before the Pyongyang Olympic Games 2018 (Laaksonen et al. 2018b). Dry firing is intended to help minimize body and rifle sway (holding) by improving postural balance, correct trigger control and to improve the aiming process (Groslambert et al. 2003), therefore it is utilized extensively in rifle shooting practice by all levels of shooters (ISSF, 2022). Mantis Tech LLC claims that dry firing with MantisX shooting training system "will improve your grip, trigger control, shooting accuracy and shooting speed".

4.2 Live fire practice

Live fire practice makes up for most of the shooting practice, more than 20000 shots per year for an experienced athlete, but it is not an absolute requirement to shoot live ammo in every practice session. However, outdoor practice with skis on in a real competition environment is essential to learn the effects of the environment, especially to read the wind conditions (Laaksonen et al. 2018b). These external, challenging effects include: wind, rain, lighting, gun recoil, external noise, temperature variations etc. The list is almost never ending.

There are extremely few biathlon research studies, which have included real live ammunition shooting in the study, and those that have tried most probably got overwhelmed by the external and environmental variables making the test results highly unrepeatable. Most live fire practice sessions include posture and stance practice and timing of various shooting range actions to minimize the time spent on the range and while shooting (Laaksonen et al. 2018b). It is generally recommended by shooting coaches to shoot at paper targets before engaging in real biathlon targets, to find systematic errors, and also learn how to call the shots. Biathlon steel targets can mask some problems, especially in standing shooting practice, because the falling target hides the exact placement of the hit and, so it is useful to practice on paper targets. Live firing should also include ammunition testing, in order to find the best ammunition for cold weather, competitions and practice (ISSF, 2022). Rifle precision is highly dependent on the quality of ammunition.

4.3 Mental and relaxation practice

Mental and relaxation techniques can be combined with dry firing and live firing training, but can also be practiced alone. Laaksonen et al. (2011) found that 10 weeks of combined applied tension release, holding and shooting training intervention enhances the shooting performance of biathletes in a biathlon race simulated laboratory test. Before the intervention, the experimental group and control group had similar shooting accuracy, but after 10 weeks intervention the experimental group had an overall better shooting ability. Groslambert et al. (2003) also observed improved shooting accuracy and stability of hold in standing shooting after 6 weeks of combined autogenic and imagery training and Solberg et al. (1996) showed that specific meditation techniques performed ones a week for seven weeks, significantly improved national level rifle shooters competition scores compared to control group.

Relaxation and visualization techniques have shown to improve performance in many different sports, and should be taught to junior biathletes early on, so they learn to utilize their full mental capacities and possibly get control over the psychophysiological effects during shooting. Assessment of psychophysiological effects has long traditions in competitive rifle marksmanship studies, and it has been found that rifle shooters achieve their best scores with individually very different heart rates (Hatfield et al. 1983), but in biathlon shooting this is under-researched (Laaksonen et al. 2018). Vickers & Williams (2007) showed that mental pressure during competition simulation does not have a great negative effect on shooting performance if compensated by more focused concentration and a longer fixation with the eye. Competition anxiety and mental pressure is much harder to simulate in a test environment, than physical exertion.

4.4 Effects of augmented feedback

Augmented feedback from an optoelectronic shooting training system (Noptel ST-2000 Sport, Noptel Inc., Finland) improved shooting accuracy in a study by Mononen et al. (2003), but the 4-week training effects disappeared for the most part after 10 days. It was suggested that in order to achieve more permanent learning effects, the duration of the feedback training period should probably have been longer. Even though shooting scores did improve with kinematic feedback, rifle stability did not, therefore there would be a need to investigate the effects of feedback on postural stability and rifle movements during the trigger pull (Mononen et al. 2003). Mullineaux et al. (2012) studied the effects of real-time auditory biofeedback on rifle stability and postural balance in a group of elite rifle shooters during a 4-week intervention. Exactly like Mononen et al. (2003), they found that the group that received feedback during practice improved their scores compared to a control group who received no feedback. Their conclusion was that biomechanical biofeedback is proposed to have improved performance, possibly through training better decision making just before triggering, but the actual cause requires further research, since no differences between groups were found in the actual feedback parameters (Mullineaux et al. 2012). It is therefore important that future shooting intervention studies aim to find the shooting technical parameters that improve with specific trainings and with specific feedback. Specific technical training sessions, their duration and frequency should be recorded in a training diary to get more feedback on the effects of various training methods. Mantis X10 Elite feedback system includes barrel trajectory movement during holding and triggering, cleanness of triggering score of every shot, average score of the series of shots, movement direction of the barrel during the last 250ms before triggering and rifle cant at the triggering moment. In addition to visual feedback, Mantis has the possibility to provide auditory feedback with speech and/or beeps.

4.5 Motivation

Motivation for shooting practice should be high, since biathlon shooting requires difficult fine motor skills usage during physical extortion. Without proper motivation these skills will not be properly practiced and mastered in variable conditions. Matikka et al. (2020) divides motivation in internal and external motivation, and emphasizes the role of the coach in strengthening the athletes internal motivation towards training. External motivation can be efficient only in short term. Setting clear and achievable short and long term goals in shooting training can be a great internal motivator for practice sessions. First a long term result goal should be set and then a clear process and training program should be created to achieve this long term result. Short term goals can then be set to make the progress easier to monitor and gives the athlete feelings of success (Matikka et al. 2020). These short term goals in shooting practice can be small technical improvements in each session and each week, instead of recording only the shooting score.

A study with novice running target shooters concluded that knowledge of performance (KP) and knowledge of results (KR) modes of augmented feedback improved shooting scores after a 12-week shooting training. However, KR and KP together did not improve shooting scores more than KR alone (Viitasalo et al. 2001). This suggests that knowledge of results is enough feedback and training motivation for shooters with limited shooting experience. The constantly improving shooting scores are a short term motivator giving able feelings of success for the novice shooter. Motivation is all about feelings of competence, but if the athlete is too self oriented, the internal motivation may disappear in the long run and lead to less commitment in training and anxiety in competitions. Therefore coaching should strengthen the athletes task orientation with less criticism and with meaningful training sessions (Matikka et al. 2020).

5 RESEARCH PROBLEMS AND HYPOTHESIS

The aim of this study was to investigate a feedback method for improving biathlon standing shooting skills and to motivate biathletes to dry fire practice at home. Dry firing is practiced extensively by athletes in small-bore rifle shooting (Maksimovic, ISSF, 2022), so its importance should not be underestimated in biathlon shooting practice either, as the rifle type and ammunition are the same. Additionally, this study tested the hypothesis that dry firing drills may enhance shooting technical skills of biathlon athletes. The technical effects of dry fire practice were assessed in the laboratory, and the Mantis X10 Elite feedback shooting training system (Mantis Tech, LLC, USA) was evaluated. Shooting skills of 16 biathletes (Junior, National and International level Finnish biathletes) were assessed before and after an 8-week dry fire intervention. Shooting tests were completed in rest condition in a laboratory and outside on a biathlon shooting range. A benefit from doing the same basic standing shooting tests in the lab and on the shooting range will reveal, if there are any differences in shooting performance between dry firing and live firing.

Research question 1:
What are the effects of dry fire practice and feedback from the Mantis training system on shooting performance and technical variables?

Hypothesis 1:
Mantis feedback group will improve shooting performance and improve certain technical skills more than the control group without a feedback system. According to Mantis: grip, trigger control, shooting accuracy, and shooting speed will improve (Mantis Tech LLC, 2022).

Research question 2:
What are the effects of dry fire practice on biathlon standing shooting, and does the amount of dry fire training correlate with changes in scores?

Hypothesis 2:
Standing shooting test score and shooting technical factors will improve with dry firing. Positive effects on standing shooting performance were found in some of the few experimental biathlon shooting intervention studies with 4 weeks kinematic feedback

(Mononen et al. 2003), 6 weeks autogenic and imagery training (Groslambert et al. 2003) and 10 weeks relaxation, holding and dry shooting exercises (Laaksonen et al. 2011). Stability of hold (Sattlecker et al. 2014, 2017; Ihalainen et al. 2018), postural balance in cross-shooting direction SDX (Sattlecker et al. 2014 and 2017) and cleanness of triggering (Ihalainen et al. 2018) have been previously reported to be related to biathlon standing shooting performance. Ihalainen et al. (2018) also found that postural balance in shooting direction (SDY) is related to vertical stability of hold and cleanness of triggering.

Research question 3:
Is there a correlation between the live fire and dry fire test results?

Hypothesis 3:
Lack of recoil and an audible shot sound when dry firing vs. live firing will have an impact on average shooting scores. Dry firing is expected to give better scores than live fire due to lack of recoil and sound, and stable lab conditions. Rifle sight adjustments, ammunition and wind does not have an effect on dry fire scores, but are of great significance in live firing. According to Heinrich et al. (2020), the recoil in real shooting likely affects the motor system (i.e. less stability) thereby perhaps resulting in changes to gaze behavior and attentional processes, and the loud bang-sound may result in an auditory distraction of (visual) attention from the target.

6 MATERIALS AND METHODS

6.1 Participants

This study took place at the University of Jyväskylä sport testing facilities in Vuokatti, Finland. A total of 16 biathletes from the National Biathlon Team of Finland and Vuokatti-Ruka Sports Academy volunteered for this study. They were 16 to 26 years old and had 2 to 18 years of experience in systematic biathlon training and were competing on a national or international level. During the initial shooting pre-testing, the participants were randomized into MANTIS (Mantis Elite X10 users) and CONTROL subgroups with a random number generator (Excel-function "*RAND*"; Microsoft Excel, version 2007, Microsoft Corp., Redmond, USA). Prior to the start of the intervention, a two hour information session was held to install the Mantis equipment and applications and to demonstrate the different dry fire drills and share paper targets with distance and height recommendations. The last few tested subjects were manually allocated to reduce the differences in the shooting performance between the groups. The groups were not completely homogenous in terms of laboratory shooting test results, although the range shooting results were very similar between the MANTIS and CONTROL groups.

Dry fire training amount (HighDT vs. LowDT) was determined after the intervention by calculating above average and below average training session counts, and the second subgroup comparison was made based on the amount of dry fire training completed. The MANTIS group consisted of two MEN and six WOMEN and the CONTROL group of five MEN and three WOMEN. The HighDT group consisted of three WOMEN and five MEN, and of three MANTIS and five CONTROL group participants. All subjects were informed of the purpose, nature and potential risks of the study, and they gave their written informed consent prior to participating the measurements. The study was conducted according to the Declaration of Helsinki, and a formal ethical approval process was not needed according to the University of Jyväskylä Ethical Committee. Data are presented as mean ± standard deviation (*SD*), or median and inter quartile range (*IQR*), as appropriate. A detailed description of participants is shown in table 1.

TABLE 1. Descriptive characteristics of the participants and subgroups.

Group	***n***	**Age [years]**	**Biathlon training experience [years]**	**Height [cm]**	**Weight [kg]**
MEN	7	19.1 ± 2.8	7.7 ± 3.5	178.3 ± 3.5	69.0 ± 7.0
WOMEN	9	18.3 ± 3.3	7.4 ± 4.9	167.6 ± 4.4	62.3 ± 6.3
MANTIS	8	19.1 ± 3.7	7.4 ± 5.3	170.3 ± 6.8	62.0 ± 6.6
CONTROL	8	18.3 ± 2.3	7.8 ± 3.1	174.3 ± 6.5	68.5 ± 6.7
HighDT	8	20.4 ± 3.4	9.3 ± 4.5	173.4 ± 7.2	66.3 ± 8.4
LowDT	8	17.0 ± 1.2	5.9 ± 3.3	171.1 ± 6.5	64.3 ± 6.2
Total	16	18.7 ± 2.9	7.6 ± 4.0	172.3 ± 6.5	65.3 ± 7.0

HighDT, high dry fire training amount; LowDT, low dry fire training amount. Data are presented as mean ± *SD*.

6.2 Experimental design

The experiment started in May 2022 during the biathlon summer training period with an initial questionnaire about shooting training and dry firing for all participants. All subjects performed the same test protocol in the laboratory by standing upright on force platforms and firing 6x5 shots at a single target. The target was scaled to 10 meters distance so that it resembled the size of a standing shooting biathlon target on the 50 meter range. Then the subjects performed the same 6x5-shot standing shooting test at the Vuokatti biathlon range. The shooting test was the same that many Finnish biathletes perform weekly or biweekly on a biathlon range in a rest condition, the so called "30+30 test", 30 shots prone and 30 shots standing. In this study, only the standing shooting results were of interest. Standing shooting was selected, because biathletes generally need more practice in standing shooting, especially the junior ones, who have been practicing almost solely prone shooting. Shooting times were not recorded in this study, because shooting was performed in a rest condition.

During initial testing, the subjects were randomized into two equal size subgroups, the MANTIS experimental group (n = 8), who would use the Mantis device and application in dry firing practice, and a CONTROL group (n = 8) who continued their dry fire training without feedback. Both groups were advised to complete the same dry fire drills and regular live fire trainings for 8 weeks (table 2). The biathletes were given a package for a dry fire training program with six different drills (appendix 1), which were varied during the intervention. The dry fire drills were not requested to be followed to the letter, as only the amount of drills was important. Immediately after the 8-week training intervention period, the 30-shot laboratory and 30-shot range shooting tests were repeated. After the shooting tests, a final dry fire questionnaire was completed, in order to see any changes in training routines.

A shooting training diary was kept for the daily recording of all dry firing and live firing practice during the 8-week intervention. The specific training drill completed in dry firing and live fire drills and number of shots and/or training duration was recorded from each session. One whole dry fire training session was specified as 15 minutes training or 50 shots, and sessions could be divided in multiple daily sessions and performed any time of the day, when preferred. Post intervention analysis was made between Mantis and non-Mantis groups, and between most trained (HighDT) and least trained (LowDT) groups.

TABLE 2. Experimental protocol.

Study Phase	**Pre-test**		**Intervention period**								**Post-test**
Week	**< 0**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Call for subjects	X										
Review Inclusion/Exclusion Criteria	X										
Signing Informed Consent		X									
Height and Weight											X
Laboratory shooting test 6x5 shots		X									X
Dry fire questionnaire		X									X
Range shooting test 6x5 shots		X									X
Randomization into groups		X									
Instructions and Mantis training session		X									
Dry fire exercises:											
1. Basic biathlon position exercise			X	X			X		X	X	
2. Triggering and breathing exercise			X	X	X	X			X	X	
3. Balance exercise				X		X	X		X	X	
4. Slow shooting exercise			X	X		X	X		X	X	
5. Fast shooting exercise			X	X		X	X	X	X	X	
6. Interval shooting exercise					X		X	X	X	X	
Holding exercises			X	X	X	X	X	X	X	X	
Live fire practice			X	X	X	X	X	X	X	X	
Shooting diary			X	X	X	X	X	X	X	X	

6.3 Apparatus

The Coachtech (Ohtonen et al. 2015) shooting test system with two force plates, a trigger sensor and a radio unit with an integrated microphone, A/D converter and amplifier (figure 11). The microphone was used to assist in synchronizing data from the trigger mechanism click, the PASCO force plates (figure 11) and Noptel ST-2000 (figure 12). The Coachtech software was used for storing and analyzing data of the shots. The biathletes used their own competition biathlon rifles and sports attire with running shoes.

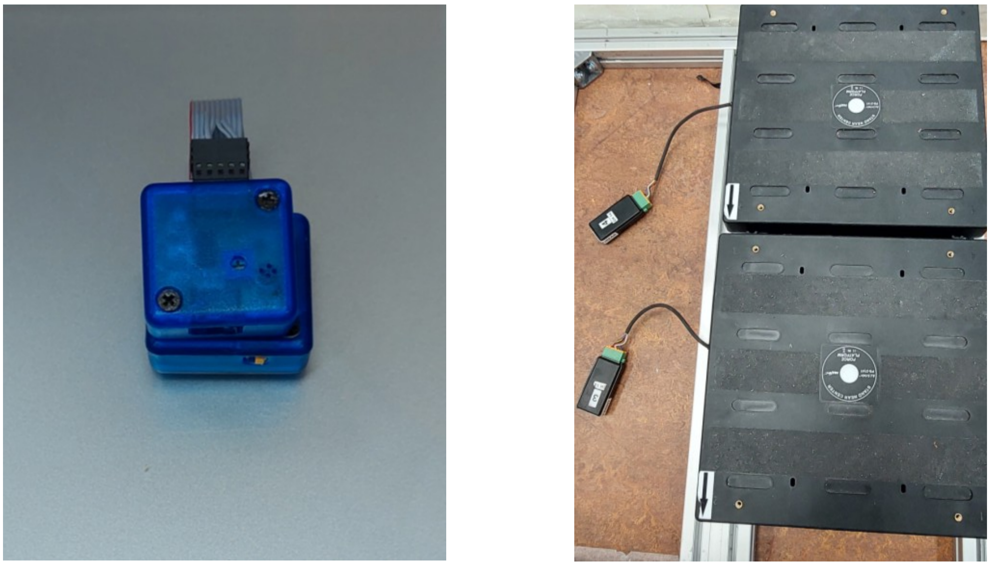

FIGURE 11. Coachtech radio unit and A/D converter (left) and force plates with wireless Coachtech transceivers (right) (University of Jyväskylä, Vuokatti, Finland).

The Noptel ST-2000 Sport II laser system (Noptel Inc., Oulu, Finland) and software was used in the laboratory for aiming point trajectory and hit point identification. The Noptel NOS4 system has previously been used by Sattlecker et al. (2017), Ihalainen et al. (2018) and Köykkä et al. (2020) in their biathlon research. The system consisted of an infrared optical transmitter-receiver unit attached to the rifle barrel, a reflector next to the scaled target dot at 10 meters and a computer (figure 16 and figure 17). The Noptel transmitter-receiver unit (weight 120 g) was attached under the rifle barrel (figure 12), next to the stock and connected to the serial port of a computer for data display, analysis and storage. Measurements and storing of the shooting data was carried out with NOS4-software at a sample rate of 67 Hz and an aiming point measurement accuracy of 0.3 mm (90% Circular Error Probability, CEP) at 10 meters distance (Noptel Inc., Oulu, Finland).

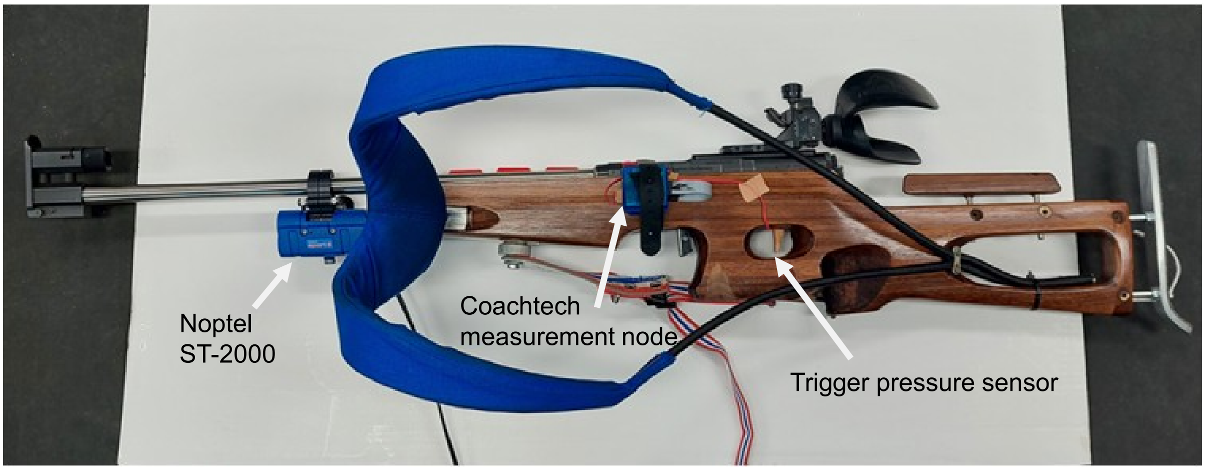

FIGURE 12. Noptel, trigger sensor and Coachtech measurement node attached to a rifle.

Triggering pressure was measured by attaching two FSR 402 (Interlink Electronics Inc., Irvine, CA, USA) piezoresistive pressure sensors connected in parallel for more accuracy and better coverage of the trigger (figure 12). The pressure signal was amplified and sampled at 400 Hz using the 43 gram wireless Coachtech device (University of Jyväskylä, Vuokatti, Finland), and the trigger break was identified using microphone data, which was collected with the same system and synchronized to the triggering moment detected by the Noptel system. The pressure signal values for each shot were normalized with the Coachtech software to the individual trigger force (weight > 500 g according to *IBU event and competition rules*, 2023) of each rifle, and the pressure value at the shot break moment (identified by a microphone) was used as the 100% trigger force value. Shots that were incorrectly detected by the Noptel system (e.g. reload clicks of the rifle) were excluded by including only the shots during which the triggering finger was placed on the trigger and some pressure applied. Data visualization, analysis and storage were performed using the Coachtech system.

Laboratory shooting scores (LabPTS) and 12 shooting technical variables were analyzed from each shot in the laboratory (table 3). These variables represent shooting performance and various technical shooting parameters related to stability of hold, aiming accuracy and triggering. The aiming trajectory deviations, describing movement of the rifle barrel was divided separately for the horizontal and vertical axis by the means of the x- deviation and the y-deviation, respectively.

TABLE 3. Shooting technical variables.

Variable [unit]	Definition
Shooting performance	
RangePTS	30 shots standing shooting total score on the shooting range
LabPTS	30 shots standing shooting total score in the laboratory
Aiming accuracy	
COG [mm]	Distance of the aiming point mean location to the center of the target during the last 0.6 s before triggering.
$Target_{2/3}$ [%]	Relative contribution of the last 0.6 s before triggering during which the aiming point distance was ≤ ⅔*57.5 mm (i.e., two thirds of the edge of the hit area).
Timing of triggering	
$TIRE_6$ [index]	Time sector with the smallest distance of the aiming point mean location to the centre of the target: 1 = −0.6…−0.5 s, 2 = −0.5…−0.4 s, 3 = −0.4…−0.3 s, 4 = −0.3…−0.2 s, 5 = −0.2…−0.1 s, 6 = −0.1…0.0 s.
Stability of hold and Cleanness of triggering	
DevX [mm]	Horizontal standard deviation of the aiming point during the last 0.6 s before triggering.
DevY [mm]	Vertical standard deviation of the aiming point during the last 0.6 s before triggering.
MV_{200} [mm/s]	Mean total velocity of the aiming point trajectory during the last 0.2 s before triggering (the total distance travelled by the aiming point/time).
MV_{600} [mm/s]	Mean total velocity of the aiming point trajectory during the last 0.6 s before triggering (the total distance travelled by the aiming point/time).
COG2Hit [mm]	Distance of the hit point to aiming point mean location during the last 0.6 s before triggering.
Trigger force	
TF_{-1000} [%]	Trigger force % compared to the final shot breaking force 1000 ms before triggering
TF_{-600} [%]	Trigger force % compared to the final shot breaking force 600 ms before triggering
TF_{-200} [%]	Trigger force % compared to the final shot breaking force 200 ms before triggering
TF_{+200} [%]	Trigger force % compared to the final shot breaking force 200 ms after triggering

Note: modified from Ihalainen et al. 2018; Köykkä et al. 2020.

Postural balance was measured with two 35x35 cm PASCO PS-2141 force platforms (PASCO Inc., California , USA), with the center of one force plate under each foot during shooting as shown in figure 13. The platforms were movable to fit individual stance widths. The force plate data were collected at 400 Hz synchronously with a trigger signal from a microphone using the wireless Coachtech system and software. The triggering moment was synchronized with the force plate data based on the microphone time stamp recorded from the trigger mechanism.

FIGURE 13. PASCO force platforms and Coachtech wireless transmitter devices.

Center of pressure (COP) location under both feet was calculated from the force plates separately, and a combined whole body COP location was calculated by combining both force plates data. The COP coordinates were filtered with a 4th-order Butterworth low-pass filter with 7 Hz cutoff frequency, which has been optimized to reduce noise and use with the PASCO PS-2141 force platforms when testing biathlon standing shooting. The 7 Hz cutoff is smaller than the 10 Hz general recommendation for cutoff frequency by Schmid et al. (2002) and Ruhe et al. (2010), but asequate, since frequency content of COP displacement has been shown to only extend up to 2.5 Hz in a very fast oscillation of COP (Yamamoto et al. 2015). Postural balance was calculated as standard deviations of the computed COP location data in the shooting direction (SDY) and cross-shooting direction (SDX) during the last 0.6 s before triggering. Postural balance variables analyzed from the force and COP data are described in table 4.

TABLE 4. Postural balance technical variables.

Variable [unit]	Description
Weight distribution	
WD_F [%]	Percentage weight on the front leg (F_Front / (F_Front + F_Rear) x 100)
WD_R [%]	Percentage weight on the back leg (100% - WD_F). (Not used in analyses, as it is redundant)
Postural balance	
SDX [mm]	Standard deviation of the computed whole body COP location in cross-shooting direction during the last 0.6 s before triggering.
SDY [mm]	Standard deviation of the computed whole body COP location in shooting direction during the last 0.6 s before triggering.
SDX_F [mm]	Standard deviation of the front leg COP location in cross-shooting direction during the last 0.6 s before triggering.
SDY_F [mm]	Standard deviation of the front leg COP location in shooting direction during the last 0.6 s before triggering.
SDX_R [mm]	Standard deviation of the rear leg COP location in cross-shooting direction during the last 0.6 s before triggering.
SDY_R [mm]	Standard deviation of the rear leg COP location in shooting direction during the last 0.6 s before triggering.

Note: modified from Ihalainen et al. 2018; Köykkä et al. 2020.

For the dry fire practice sessions the Mantis-group attached the Mantis Elite X10 shooting training device below the barrel and installed Mantis Rifle training application on their cellular phones. The Mantis Elite X10 device (figure 14) weighs only 13 grams (Mantis Tech LLC, 2022), so it can be left attached to the barrel at all times without interference with normal training. The Jyväskylä University scale measurement showed 11 grams for the device and 36 grams for rifle attachment, totaling 47 grams for the whole Mantis set-up.

FIGURE 14. Mantis Elite X10 shooting training device attached to a rifle barrel.

The Mantis X10 Elite mobile application shows the technical score of the series of shots, barrel movement trajectory during holding and triggering, and cleanness of triggering and holding of every shot. Screenshot examples from MantisX mobile application feedback are shown in figure 15.

FIGURE 15. Mantis X10 Elite mobile application feedback examples.

6.4 Training methods

Six different dry fire practice drills were designed (appendix 1) and the subjects were asked to follow the training program as closely as possible, but also to select drills that would help any individual goals and progress. Drills were assigned two to six times per week, varying the amount each week, and a drill lasting 15 minutes or 50 shots fired was perceived as a single completed dry fire session. The dry firing training was done by aiming on a paper target 1 to 5 meters away from the front sight, which was scaled to fit the target height and size at 50 meters distance. For example, aiming from 4 meters distance (front sight to wall), the scaled target diameter would be exactly 0.92 cm and the for the average height athlete (172.3 ± 6.5 cm), the eye height would be on average 162 cm, which would set the target dot at 6 cm below the center of the front sight. The height of the target dot should be verified with the athletes natural point of aim (NPO), which should feel most comfortable and reflect the normal stance and aiming at the biathlon range. A training diary was filled by checking a box in a spreadsheet from each completed dry fire drill. Regular live fire trainings were conducted as planned in the training programs and training camps and those were also recorded in the training diary.

6.5 Data collection

The total amount of analyzed shots was 1920 shots from 64 tests, consisting of 960 live fire rounds on the range and 960 dry fire shots in the shooting laboratory. All shots were performed in standing position and fired in five shot series in a resting condition. Dry fire, live fire and range test data were collected in a spread sheet diary. Shooting test data in the laboratory was collected with the Coachtech system on a PC (University of Jyväskylä, Vuokatti, Finland). For each biathlete, a one hour time slot was reserved for questionnaire filling and completing the standing shooting test.

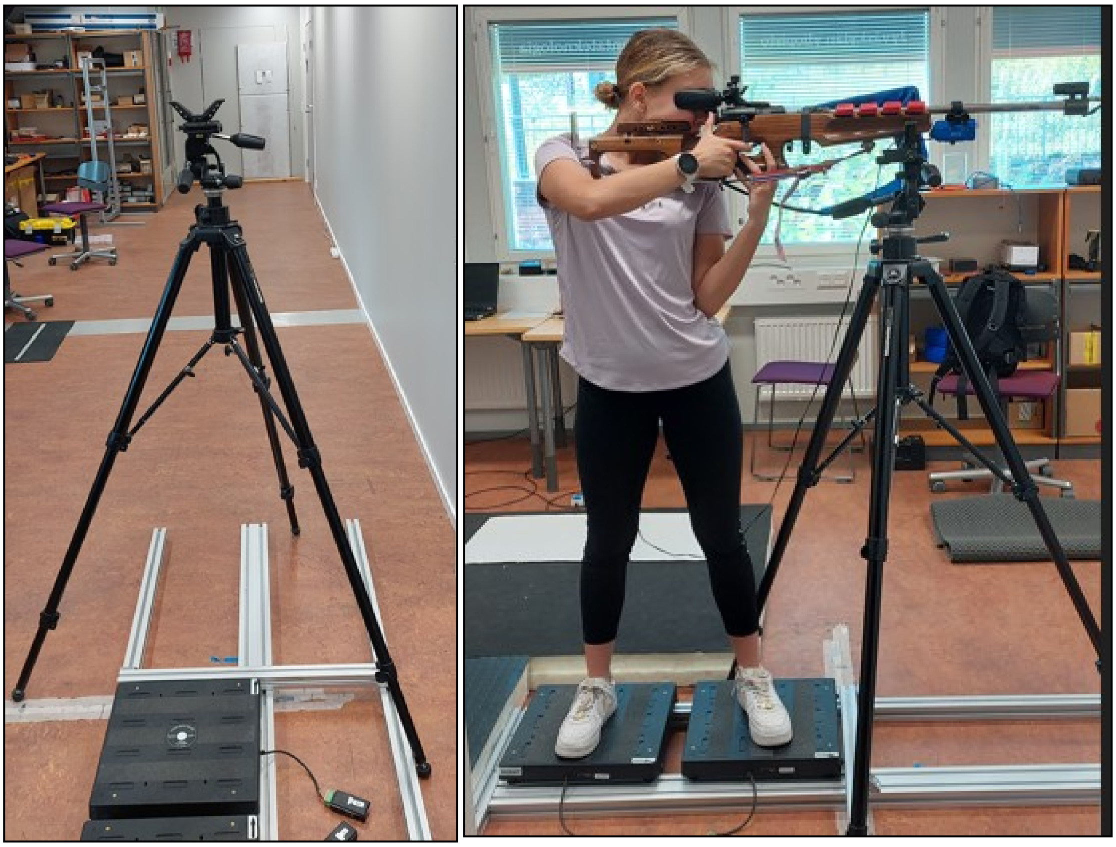

FIGURE 16. Rifle and Noptel zeroing with a tripod.

The shooter first completed a five minute zeroing from standing shooting position using a stable tripod as a rest for the rifle (figure 16), and then completed a 30-shot test in 6x5-shot series. The standing shooting test (figure 17) was done at rest and in a fairly slow and relaxed pace. Between each 5-shot series the shooter was asked to step back and relax while the series data check was made. No feedback was provided during the shooting test, but an average score and a single interesting technical parameter was discussed after the test. Immediately after the 8-week training intervention, the shooting test was repeated exactly the same way as in the pre-testing, including a post questionnaire. Data from pre- and post tests were stored on a data server for comparison and analysis. Similar pre-post live range shooting tests were completed during the same week as the lab tests and the total 30-shot scores were recorded from those tests as well. The shooting data of each subject was averaged for every pre-post shooting session, presenting each technical shooting variable as 30-shot mean value from pre- and post-test.

FIGURE 17. Laboratory standing shooting test.

6.6 Statistical analysis

Mean values of the measured shooting variables were calculated for each participant for each session (pre and post) and used as the dependent measure. Then mean ± *SD* and median(*IQR*) values of the measured values were calculated for all groups (table 1) and then data was arranged in one row for each subject, having totally 16 rows of mean pre- and post data. Change scores, labeled as delta-variables, were calculated from the mean post-pre data for each variable. Shapiro-Wilk's tests of normality were performed for the total population and subgroup data (pre-, post- and difference score data). Many data did not fulfil pre-requisites for parametric tests (e.g. normal distribution, similar variance). Mundry et al. (1998) recommended non-parametric (exact significance) tests for data with small sample size and non-normal distribution. Data transformation methods did not fix the distribution (skewness and outliers), so non-parametric tests were used in the analysis. As software packages offer p-values for both asymptotic and exact tests, the preference is to use exact tests, since asymptotic tests may lead to incorrect p-values with small sample sizes and ties in the data (Neuhäuser et al. 2009; Mundry et al. 1998). All non-parametric statistical tests; Mann-Whitney, Wilcoxon and Spearman were performed as 2-tailed, exact significance tests.

Repeated measurements data analysis was performed with the nparLD R-package (Noguchi et al. 2012). This package offers mixed ANOVA-type statistics (*ATS*) for rank-based non-parametric longitudinal data analysis. Within the F1-LD-F1-model group (Mantis, Control, HighDT, LowDT) was defined as whole-plot factor and time (pre-test, post-test) as sub-plot factor. The analysis provides an ANOVA-type statistic for group, time and the interaction (group x time). In case of significant main or interaction effects, post hoc tests were performed separately for that specific shooting variable with Wilcoxon signed-ranks and Mann-Whitney *U*-tests for comparison of treatment groups and within group changes.

According to Lord (1967) and Wright (2006), a *t*-test and ANCOVA test can lead to different conclusions depending on the study design and randomization of the subjects. A full random allocation into groups based on initial test scores was impractical and there were some initial differences in shooting performance and experience between groups. Also, the measured technical shooting variables could not be evaluated before group allocation, and the effect of treatment on those was considered similar for all skill levels, so there was a chance of Lord's paradox to occur. Therefore, after the nparLD ANOVA-type tests, an independent sample Mann-Whitney *U*-test and Wilcoxon signed-ranks tests were performed for comparing MANTIS vs. CONTROL group and HighDT vs. LowDT group change scores.

With the Mann-Whitney *U*-test, the pre-post difference scores (RangePTSdelta and LabPTSdelta) were compared between groups and subsequently a Wilcoxon signed-ranks tests was used to analyse the absolute score changes in each group. The main interest was on the difference in the amount of gain of the treatment between the groups.

The independent samples Mann-Whitney *U*-test was used to investigate pre-test shooting score differences between groups in MANTIS vs. CONTROL and HighDT vs. LowDT groups. Shooting performance difference between MEN and WOMEN was not analyzed because of the difference in sample distribution between the groups, and since recent studies by Luchsinger et al. (2018) and Ihalainen et al. (2018) did not show statistically meaningful differences in shooting performance between MEN and WOMEN. A 2-tailed Wilcoxon signed-ranks test was used to investigate within group differences between pre-test and post-test shooting scores.

Two-tailed Spearman correlation coefficients were computed for the whole subject group to examine relationships between shooting performance on the range (RangePTS) and in the laboratory (LabPTS), both pre- and post-test. Spearman correlation was also used to examine relationships between absolute shooting performance change (RangePTSdelta and LabPTSdelta) and pre-post change (delta) in shooting technical variables for all groups separately (MANTIS, CONTROL, HighDT and LowDT) and for the whole population (N = 16).

Data gathering and processing was performed with Microsoft Excel (version 2007, Microsoft Corp., Redmond, USA). Data and results have been reported as the mean ± *SD*, and Median(*IQR*) and statistical significance was set at $p < 0.05$. Statistical analyses were performed with IBM SPSS Statistics 28.0 software (IBM Corp., Armonk, NY, USA), and R-package (64-bit version 3.6.3, https://www.r-project.org/).

7 RESULTS

7.1 Shooting variables analysis for all subjects combined

A Wilcoxon matched pairs signed-rank test indicated that RangePTS post-test ranks were statistically significantly higher than pre-test ranks ($p < .05$). Standard deviation of the front leg COP location in cross-shooting direction SDX_F ($p < .05$) and standard deviation of the front leg COP location in shooting direction SDY_F ($p < .05$) post-test ranks were statistically significantly lower than pre-test ranks. The results of the analysis for all subjects are presented in table 5.

TABLE 5. The median and interquartile range (*IQR*) of the pre-post shooting score changes and shooting technical variables for all subjects ($N = 16$).

	ALL subjects			Wilcoxon	
Variable [unit]	Pre	Post	% change	*Z*-score	*p*-value
Shooting performance					
RangePTS	184.5(21.8)	192.5(27.5)	**4**	-2.017	**.043***
LabPTS	184.5(35)	185.5(38.8)	1	-0.483	.648
Aiming accuracy					
COG [mm]	31.3(18.7)	29.4(10.9)	-6	-1.034	.323
$Target_{2/3}$ [%]	53.4(33.0)	58.5(22.9)	10	-0.336	.754
Timing of triggering					
$TIRE_6$ [index]	4.25(0.62)	4.37(0.49)	3	-0.595	.571
Stability of hold and cleanness of triggering					
DevX [mm]	19.0(4.8)	18.0(3.3)	-5	-1.551	.130
DevY [mm]	17.5(5.0)	17.1(4.5)	-2	-1.189	.252
MV_{200} [mm/s]	273.6(50.0)	254.2(58.4)	-7	-1.189	.252
MV_{600} [mm/s]	273.1(38.3)	258.5(39.7)	-5	-1.448	.159
COG2Hit [mm]	34.8(11)	33.8(6.5)	-3	-0.569	.587
Trigger force					
TF_{-1000} [%]	83.3(17.2)	76.1(13.6)	-9	-0.414	.706
TF_{-600} [%]	88.9(16)	86.7(8.5)	-2	-0.207	.860
TF_{-200} [%]	93.6(11.9)	92.9(5.0)	-1	-0.207	.860
TF_{+200} [%]	63.8(34.1)	83.3(35.1)	31	-0.879	.404
Weight distribution					
WD_F [%]	60.2(5.1)	58.4(2.8)	-3	-0.052	.980
WD_R [%]	39.9(5.1)	41.6(2.8)	4	-0.052	.980
Postural balance					
SDX [mm]	0.77(0.24)	0.64(0.24)	-16	-1.913	.058
SDY [mm]	0.49(0.18)	0.46(0.09)	-4	-0.982	.348

TABLE 5 (continued).

Variable [unit]	ALL subjects Pre	Post	% change	Wilcoxon *Z*-score	*p*-value
SDX_F [mm]	0.74(0.28)	0.66(0.22)	**-11**	-20.017	**.044***
SDY_F [mm]	0.25(0.17)	0.20(0.19)	**-22**	-2.069	**.037***
SDX_R [mm]	0.82(0.24)	0.72(0.25)	-12	-1.396	.175
SDY_R [mm]	0.15(0.08)	0.16(0.12)	10	-0.259	.811

RangePTS, range shooting score; LabPTS, lab shooting score; COG, mean aiming accuracy distance from center; $Target_{2/3}$, relative aiming accuracy distance from hit; $TIRE_6$, timing of triggering index; DevX, horizontal stability of hold; DevY, vertical stability of hold; MV_{200}, mean velocity 200 to 0 ms before triggering; MV_{600}, mean velocity 600 to 0 ms before triggering; COG2Hit, distance of hit point to aiming mean; TF_{-200} to TF_{-1000}, Trigger force 200 to 1000 ms before triggering; TF_{+200}, Trigger force 200 ms after triggering; WD_F, percentage weight on the front leg. Postural balance (standard deviation of the center of pressure location 600 to 0 ms before triggering) of the whole body in shooting (SDY) and cross-shooting (SDX) direction, and postural balance of each leg separately (F, front; R, rear). Pre-post difference: * p < .05.

A 2-tailed Spearman correlation computed for whole subjects group between all shooting variables indicated that none of the changes in the technical delta-variables had a statistically significant correlation with the change in range shooting scores (RangePTSdelta). There was a negative correlation between change in lab shooting scores (LabPTSdelta) and changes in DevY (figure 18), MV_{200} (r_s = -0.513, p = .042) and MV_{600} (figure 19).

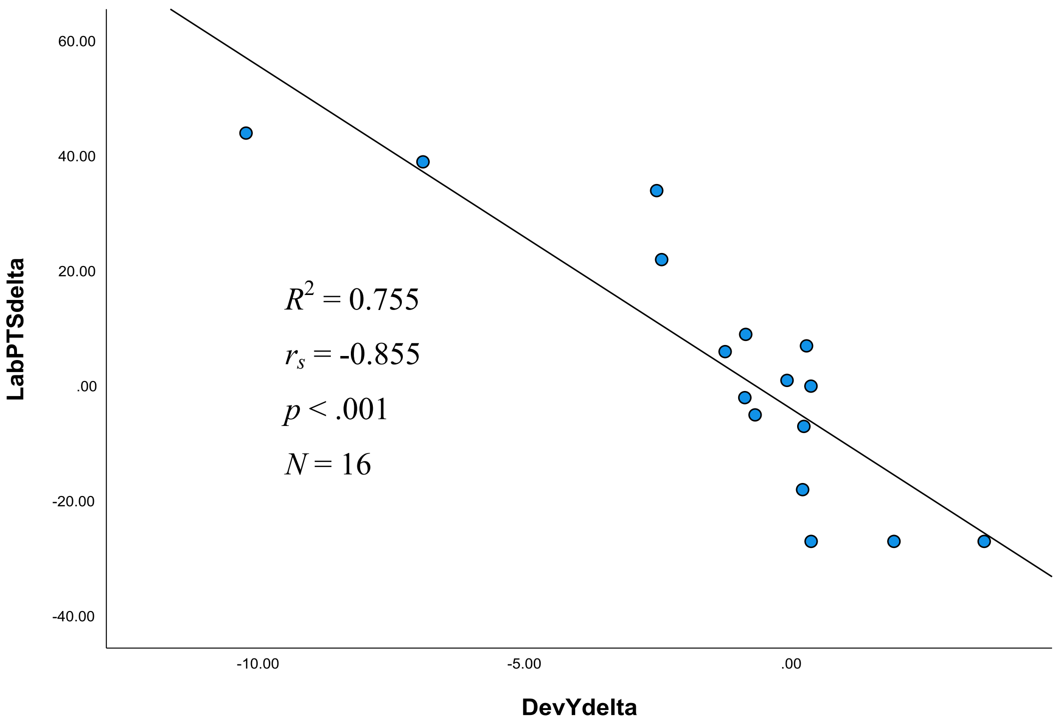

FIGURE 18. Spearman correlation between pre-post laboratory shooting score change (LabPTSdelta) and change in vertical standard deviation of the aiming point movement (DevYdelta) for all subjects.

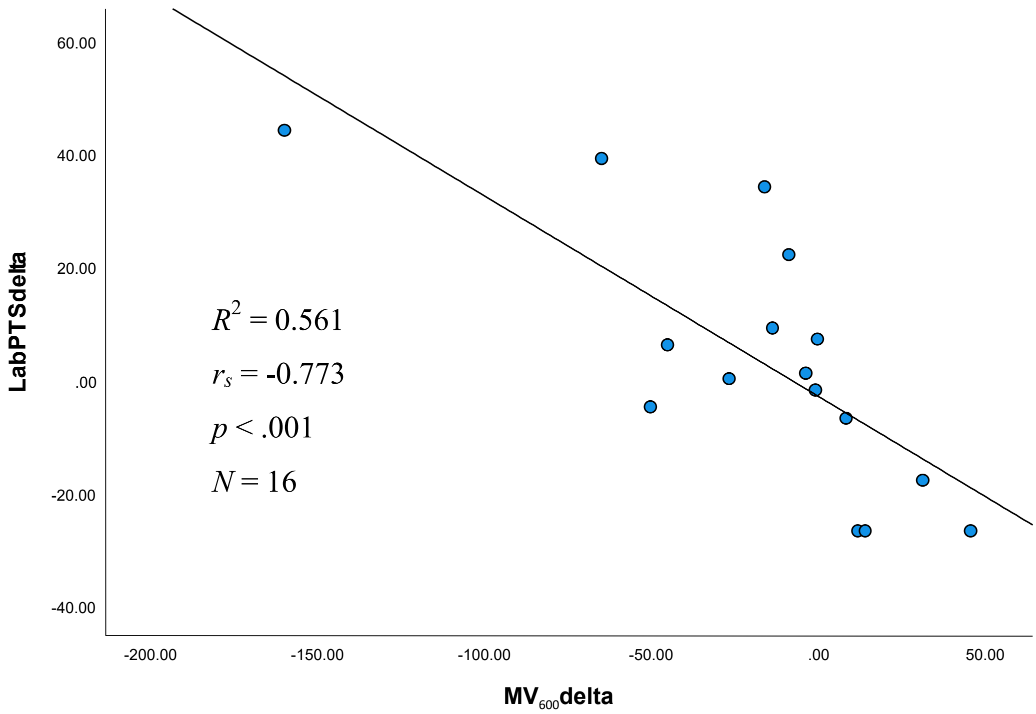

FIGURE 19. Spearman correlation between pre-post laboratory shooting score change (LabPTSdelta) and change in mean total velocity of the aiming point trajectory (MV_{600} delta) for all subjects.

A negative correlation was found between change in lab shooting scores (LabPTSdelta) and changes in and postural balance variables SDX ($r_s = -0.617$, $p = .011$), SDY ($r_s = -0.605$, $p = .013$), SDX_R (figure 20) and SDY_R ($r_s = -0.732$, $p = .001$). Change in aiming accuracy ($Target_{2/3}$delta) had a positive correlation with LabPTSdelta ($r_s = 0.596$, $p = .015$).

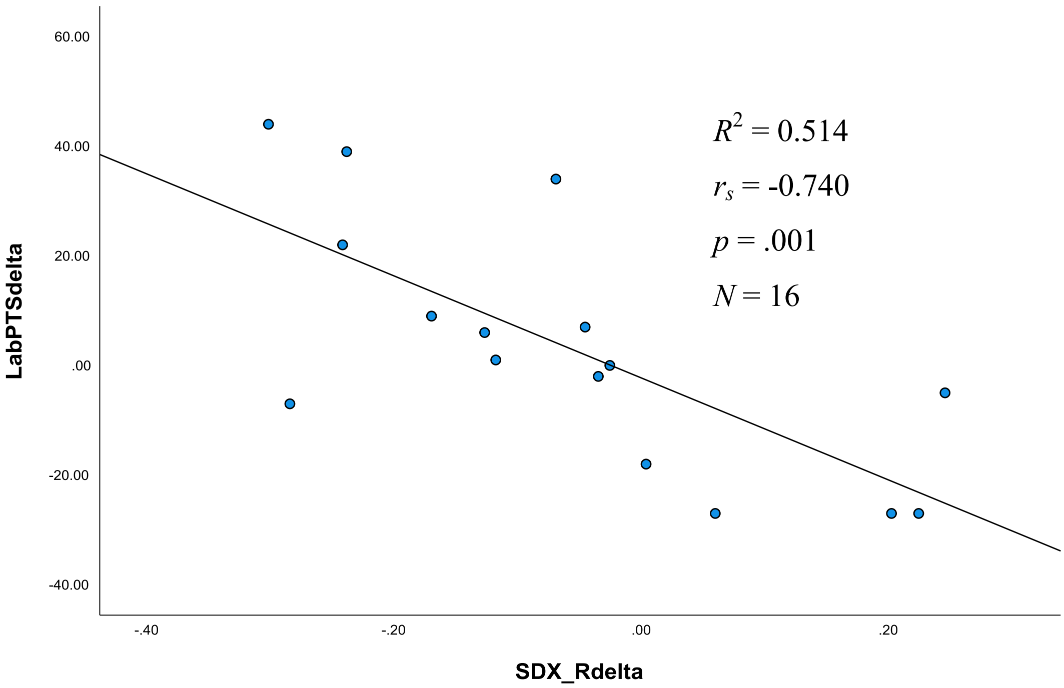

FIGURE 20. Spearman correlation between pre-post laboratory shooting score change (LabPTSdelta) and change in standard deviation of the rear leg center of pressure location in cross-shooting direction (SDX_Rdelta) for all subjects.

7.2 Shooting technical variables analysis in MANTIS and CONTROL groups

An independent samples Mann-Whitney *U*-test was performed for the pre-test variables between MANTIS and CONTROL groups showed that the groups did not differ significantly from each other in any of the analyzed pre-test variables. An ANOVA-type repeated measurements analysis (table 6) indicated significant interaction effects (Group x Time) for MV_{600} ($p < .05$), SDX ($p < .05$) and SDY_F ($p < .05$). Significant main effects were indicated for Group in WD_F ($p < .05$), and for Time in SDX ($p < .05$), SDY_F ($p < .05$) and SDX_R ($p < .05$).

Post hoc tests were performed for MV_{600} (figure 21), SDX (figure 22 and figure 23), SDY_F, SDX_F (figure 24), WD_F and SDX_R variables, as the ANOVA-type tests or percentage changes indicated significant effects. Percentage changes in mean ± *SD* and median(*IQR*) values of pre-post shooting variables in MANTIS and CONTROL groups are presented in appendix 2.

TABLE 6. Median(*IQR*) pre-post test values, and nparLD ANOVA-type statistic (*ATS*) of the shooting technical variables for MANTIS (n = 8) and CONTROL (n = 8) groups.

	MANTIS		**CONTROL**		***ATS*(1,∞) (*p-value)***		
Variable [unit]	Pre	Post	Pre	Post	*Group*	*Time*	*Interaction*
Shooting performance							
RangePTS	184.5(22.3)	192.5(12.8)	184.0(14.3)	181.0(31.0)	0.129 *NS*	**3.493 (.062)**	1.584 *NS*
LabPTS	171.5(35.5)	185.5(31.3)	190.0(27.5)	178.0(45.5)	0.118 *NS*	0.148 *NS*	1.771 *NS*
Aiming accuracy							
COG [mm]	34.4(15.7)	27.2(12.2)	27.0(20.5)	31.0(8.6)	0.001 *NS*	0.276 *NS*	0.729 *NS*
$Target_{2/3}$ [%]	49.1(32.6)	57.6(27.1)	57.7(29.7)	58.5(13.5)	0.003 *NS*	0.237 *NS*	0.237 *NS*
Timing of triggering							
$TIRE_6$ [index]	4.3(0.4)	4.2(0.6)	4.3(0.7)	4.5(0.4)	0.535 *NS*	0.176 *NS*	0.560 *NS*
Stability of hold and cleanness of triggering							
DevX [mm]	18.5(4.5)	17.7(3.2)	19.2(3.7)	18.8(3.2)	0.457 *NS*	1.834 *NS*	1.834 *NS*
DevY [mm]	17.5(5.1)	15.5(4.2)	17.5(4)	17.2(2.9)	0.092 *NS*	1.441 *NS*	1.277 *NS*
MV_{200} [mm/s]	273.6(28.1)	237.1(49.5)	268.6(76.7)	265.6(48.1)	0.490 *NS*	2.553 *NS*	0.524 *NS*
MV_{600} [mm/s]	282.8(41.7)	246.9(31.9)	265.5(32.9)	274.1(42.1)	0.601 *NS*	3.265 *NS*	**3.906 (.048)***
COG2Hit [mm]	36.6(9.1)	32.2(7.1)	34(11.9)	33.8(5.5)	0.119 *NS*	0.812 *NS*	0.203 *NS*
Trigger force							
TF_{-1000} [%]	83(23)	81(15)	83(12)	74(9)	0.113 *NS*	0.665 *NS*	0.746 *NS*
TF_{-600} [%]	87(21)	87(9)	89(5)	86(7)	0.003 *NS*	0.471 *NS*	0.337 *NS*
TF_{-200} [%]	89(14)	93(4)	94(6)	93(6)	0.029 *NS*	0.119 *NS*	0.119 *NS*
TF_{+200} [%]	59(50)	77(54)	68(19)	83(15)	0.028 *NS*	2.752 *NS*	0.052 *NS*
Weight distribution							
WD_F [%]	57.8(7.6)	57.7(3.2)	60.6(3.8)	60.2(3.6)	**5.035 (.025)***	0.512 *NS*	0.194 *NS*
Postural balance							
SDX [mm]	0.80(0.22)	0.63(0.12)	0.77(0.26)	0.77(0.25)	0.003 *NS*	**4.520 (.034)***	**3.972 (.046)***
SDY [mm]	0.47(0.08)	0.47(0.03)	0.56(0.17)	0.45(0.19)	0.451 *NS*	1.481 *NS*	0.396 *NS*
SDX_F [mm]	0.81(0.18)	0.66(0.12)	0.63(0.27)	0.69(0.39)	0.722 *NS*	2.437 *NS*	**3.756 (.053)**
SDY_F [mm]	0.28(0.23)	0.22(0.23)	0.23(0.18)	0.20(0.13)	0.594 *NS*	**6.153 (.013)***	**5.208 (.022)***
SDX_R [mm]	0.78(0.21)	0.63(0.25)	0.84(0.25)	0.79(0.32)	1.045 *NS*	**5.257 (.022)***	2.264 *NS*
SDY_R [mm]	0.15(0.06)	0.15(0.10)	0.15(0.11)	0.17(0.09)	0.011 *NS*	0.008 *NS*	1.744 *NS*

ATS, ANOVA-type statistics; *IQR*, interquartile range; *NS*, non-significant; RangePTS, range shooting score; LabPTS, lab shooting score; COG, mean aiming accuracy distance from center; $Target_{2/3}$, relative aiming accuracy distance from hit; $TIRE_6$, timing of triggering index; DevX, horizontal stability of hold; DevY, vertical stability of hold; MV_{200}, mean velocity 200 to 0 ms before triggering; MV_{600}, mean velocity 600 to 0 ms before triggering; COG2Hit, distance of hit point to aiming mean; TF_{-200} to TF_{-1000}, Trigger force 200 to 1000 ms before triggering; TF_{+200}, Trigger force 200 ms after triggering; WD_F, percentage weight on the front leg. Postural balance (standard deviation of the center of pressure location 600 to 0 ms before triggering) of the whole body in shooting (SDY) and cross-shooting (SDX) direction, and postural balance of each leg separately (F, front; R, rear). * $p < .05$.

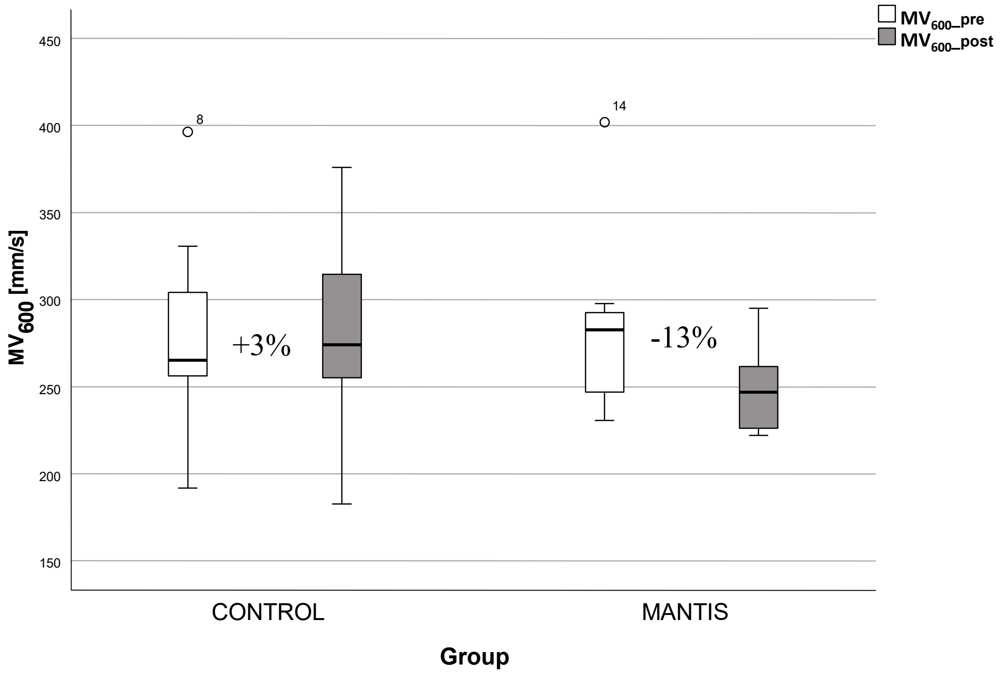

FIGURE 21. A pairwise comparison of mean velocity of the aiming point trajectory (MV_{600}) between MANTIS (n = 8) and CONTROL (n = 8) groups showed no statistically significant effects, though the interaction effect was significant. The CONTROL group total variance increased pre-post and MANTIS group median MV_{600} decreased (z = -1.820, p = .078).

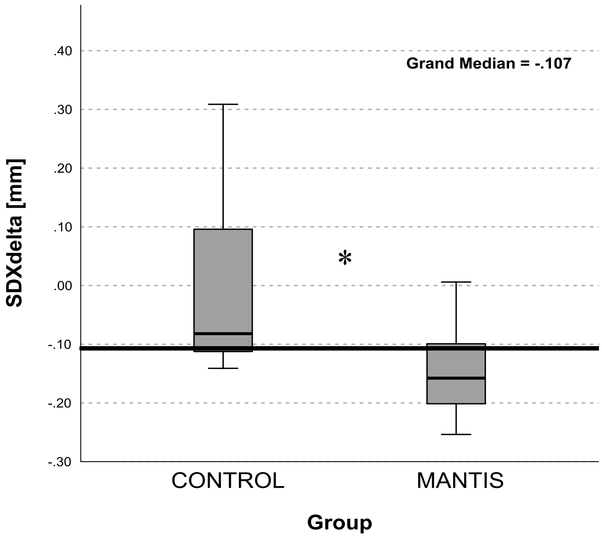

FIGURE 22. An independent sample Mann-Whitney *U*-test indicated significant between group difference in MANTIS (n = 8) and CONTROL (n = 8) groups standard deviation of the center of pressure location in cross-shooting direction change (SDXdelta) ranks calculated from post-pre test change values (z = -2.100, p = .038).

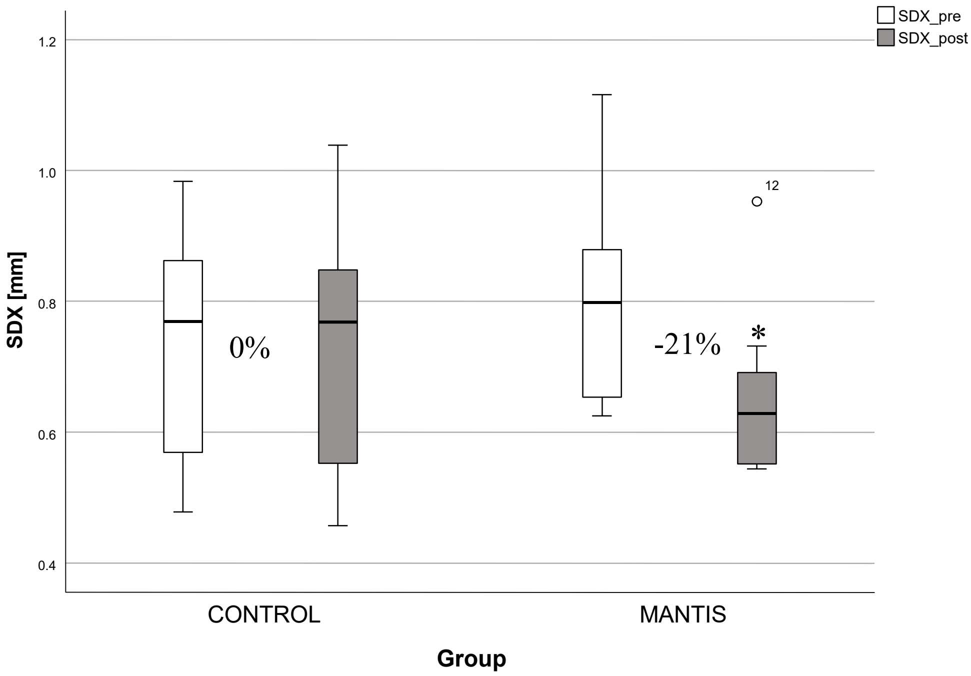

FIGURE 23. A Wilcoxon matched pairs signed-ranks test showed a significant decrease in pre-post total cross-direction postural balance (SDX) for MANTIS group (*n* = 8) from 0.80(0.22) to 0.63(0.12) mm (*z* = -2.380, *p* = .016), as the CONTROL group (*n* = 8) didn't have a significant change in SDX.

SDY_F decreased 21% In the MANTIS group from pre- to post-test (*z* = -2.100, *p* = .039), whereas in the CONTROL group the 13% decrease was non-significant (*z* = -0.560, *p* = .641). In WD_F there were no significant within group changes in either MANTIS nor CONTROL group, but A Mann-Whitney *U*-test indicated significant between group difference in the post test ranks (*z* = -2.100, *p* = .038). SDX_R had a statistically significant decrease in the MANTIS group (-20%, *z* = -2.100, *p* = .039), as the CONTROL group experienced only a non-significant -6% decrease.

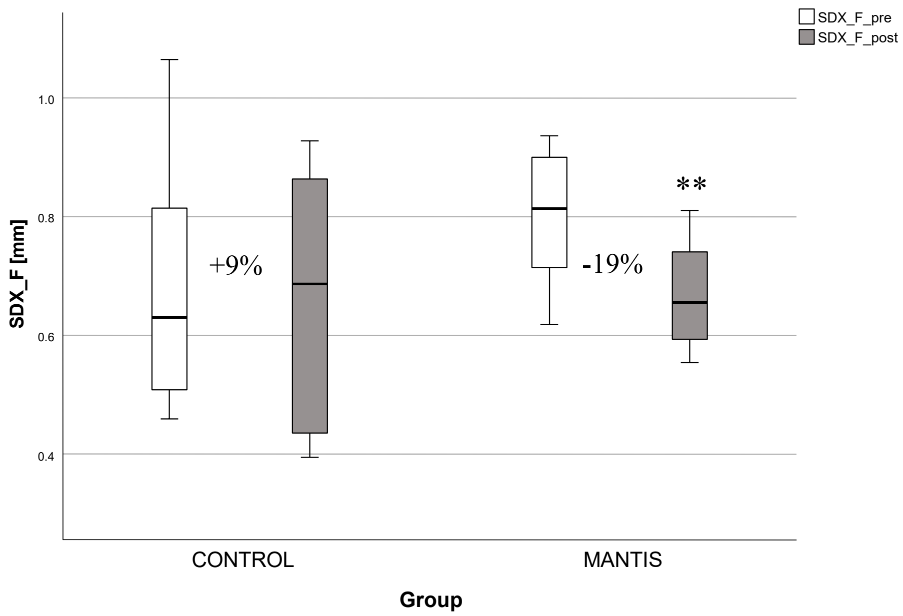

FIGURE 24. Front leg cross-direction postural balance (SDX_F) had a significant pre-post test decrease in MANTIS group (n = 8) (z = -2.521, p = .008), which was non-significant in the ANOVA-type test (interaction effect p = .053), because variance in CONTROL group (n = 8) was high.

A 2-tailed Spearman correlation was computed separately for MANTIS group and CONTROL group between all technical laboratory shooting variable changes. No statistically significant correlations were found between RangePTSdelta and other variables. LabPTSdelta correlations are presented in table 7.

TABLE 7. Spearman correlations between LabPTSdelta and technical variable changes for MANTIS (n = 8) and CONTROL (n = 8) groups.

	LabPTSdelta MANTIS group		**LabPTSdelta CONTROL group**	
Variable [unit]	Correlation r_s (8)	p-value	Correlation r_s (8)	p-value
RangePTSdelta	-0.119	.779	0.169	.690
DevXdelta [mm]	-0.810*	.015		
DevYdelta [mm]	-0.833*	.010	**-0.922****	**.001**
MV_{200}delta [mm/s]	-0.762*	.028		
MV_{600}delta [mm/s]	-0.810*	.015	-0.719*	.045
$Target_{2/3}$delta [pp]	0.762*	.028		
SDYdelta [mm]	-0.605*	.013	-0.755*	.031
SDX_Rdelta [mm]	**-0.740****	**.001**	-0.778*	.023
SDY_Rdelta [mm]	**-0.732****	**.001**		

Note: Statistically significant correlation to LabPTSdelta *p < .05, **p < .01. delta; change between pre-post test; LabPTS, lab shooting score; RangePTS, range shooting score; DevX, horizontal stability of hold; DevY, vertical stability of hold; MV_{200}, mean velocity 200 to 0 ms before triggering; MV_{600}, mean velocity 600 to 0 ms before triggering; $Target_{2/3}$, relative aiming accuracy distance from hit; pp, percentage points; Postural balance (standard deviation of the center of pressure location 600 to 0 ms before triggering) of the whole body in shooting (SDY) and cross-shooting (SDX) direction, and postural balance of each leg separately (F, front; R, rear).

7.2.1 Shooting scores comparison between MANTIS and CONTROL groups

A two-tailed Wilcoxon signed-ranks tests indicated that RangePTS post-test ranks were statistically significantly higher than pre-test ranks in MANTIS group ($Z = -2.521$, $p = .008$, figure 26). The MANTIS group had 8 positive ranks (rank-sum 36) versus CONTROL groups 4 positive ranks (rank-sum 16) in shooting change score improvement shown in figure 25. Laboratory shooting scores (LabPTS) did not have a statistically significant improvement in any group, though the percentage change in MANTIS group shown in figure 27 shows substantial improvement in lab shooting scores.

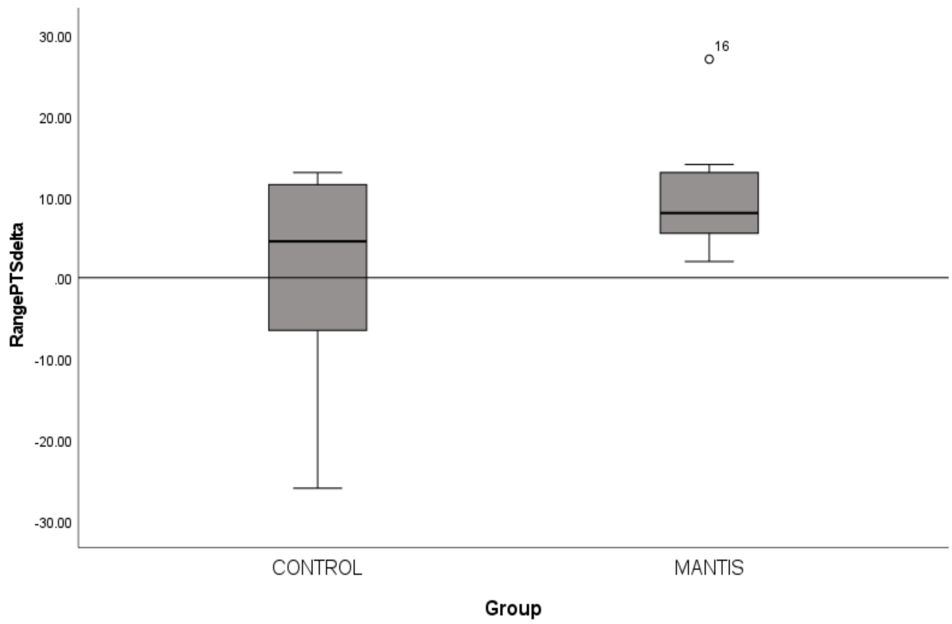

FIGURE 25. Difference in change scores of pre - post mean range shooting scores (RangePTSdelta) in MANTIS (n = 8) and CONTROL (n = 8) groups. High variation is seen in CONTROL group change scores.

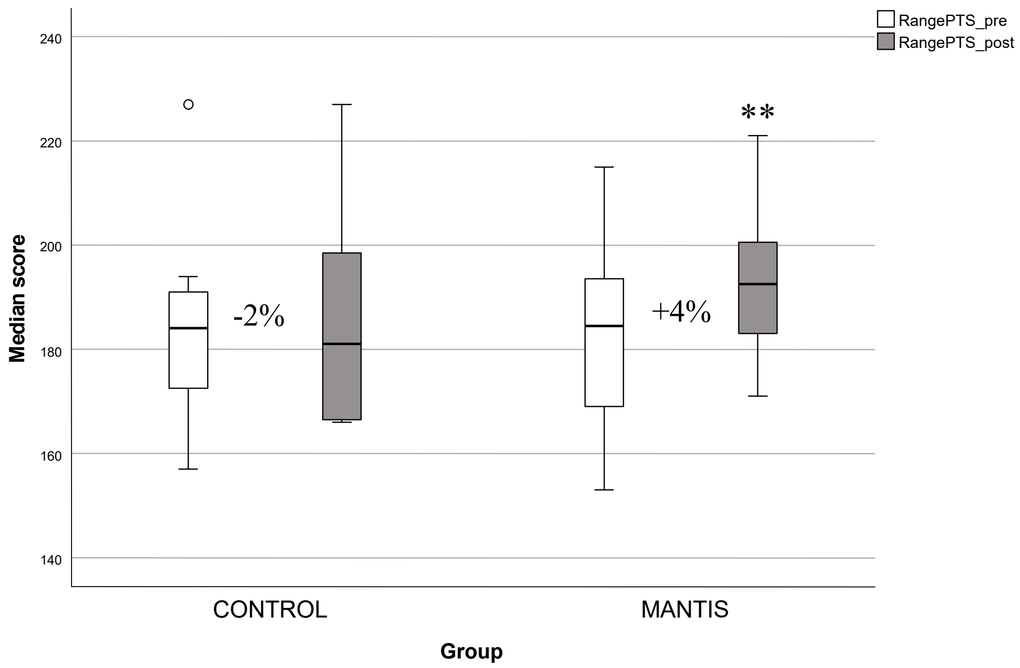

FIGURE 26. Change in median range shooting scores (RangePTS) in MANTIS (n = 8) and CONTROL (n = 8) groups. MANTIS group improved significantly at the $p < 0.010$ - level.

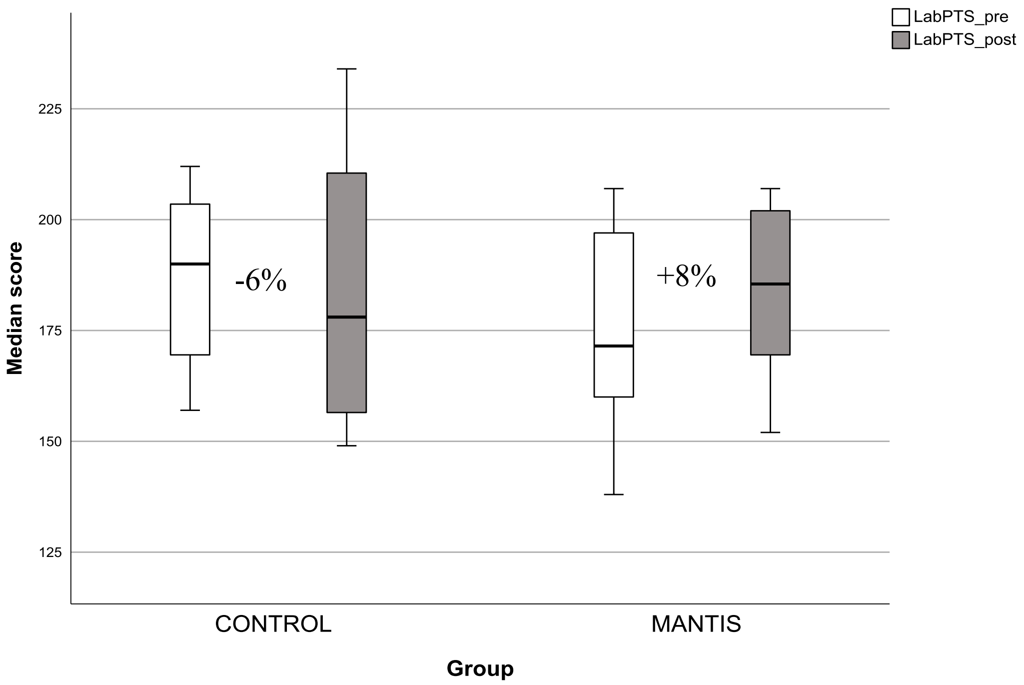

FIGURE 27. Change in median laboratory shooting scores (LabPTS) in MANTIS (n = 8) and CONTROL (n = 8) groups. There was not enough evidence to reject the null hypothesis for LabPTS pre-post change, possibly due to small sample size, or too high variability.

All MANTIS group athletes improved their mean shooting scores on the range (RangePTS +4%) and in the lab (LabPTS +8%) throughout the training sessions, while the CONTROL group athletes scored worse in post-tests on the range (RangePTS -2%) and in the lab (LabPTS -6%) (appendix 2).

7.3 Shooting technical variables analysis in HighDT and LowDT groups

An independent samples Mann-Whitney *U*-test was performed for the pre-test variables, the groups did not differ significantly from each other in any of the analyzed variables. There were no significant interaction effects (Group x Time) found in the ANOVA-type repeated measurements analysis. Significant main effects were indicated for Time in postural balance variables SDX ($p < .05$), SDY_F ($p < .05$) and SDX_R ($p < .05$). Significant Group main effect was indicated only in SDY_F ($p < .05$). Table 8 displays outcomes from the ANOVA-type analysis between HighDT and LowDT groups.

TABLE 8. Median(*IQR*) pre-post test values, and nparLD ANOVA-type statistic (ATS) of the shooting technical variables for HighDT (n = 8) and LowDT (n = 8) groups.

	HighDT		**LowDT**		***ATS*(1,∞) (*p*-value)**		
Variable [unit]	Pre	Post	Pre	Post	*Group*	*Time*	*Interaction*
Shooting performance							
RangePTS	184.5(29.3)	195.5(29.3)	184.5(13.3)	185.5(23.8)	1.024 *NS*	**3.168 (.075)**	0.132 *NS*
LabPTS	192.0(20.5)	200.0(29.0)	162(34.5)	169.5(23.5)	**3.465 (.063)**	0.131 *NS*	0.028 *NS*
Aiming accuracy							
COG [mm]	27.0(18.9)	26.8(16.2)	34.4(15.7)	31.2(9.2)	0.281 *NS*	0.263 *NS*	0.037 *NS*
$Target_{2/3}$ [%]	57.7(31.8)	62.1(29.7)	49.1(32.0)	55.5(16.5)	0.218 *NS*	0.233 *NS*	0.019 *NS*
Timing of triggering							
$TIRE_6$ [index]	4.1(1.1)	4.4(0.7)	4.3(0.4)	4.3(0.5)	0.535 *NS*	0.174 *NS*	0.471 *NS*
Stability of hold and cleanness of triggering							
DevX [mm]	17.7(2.9)	17.0(3.2)	20.4(5.6)	18.6(1.8)	2.732 *NS*	1.640 *NS*	0.155 *NS*
DevY [mm]	15.8(3.7)	15.0(4.0)	19.7(4.4)	17.8(3.0)	2.401 *NS*	1.325 *NS*	0.041 *NS*
MV_{200} [mm/s]	259.8(38.7)	252.1(65.7)	276.2(63.3)	254.2(40.9)	0.365 *NS*	2.553 *NS*	0.524 *NS*
MV_{600} [mm/s]	265.5(33.3)	255.3(39.6)	287.2(64.3)	265.0(36.7)	1.743 *NS*	2.609 *NS*	0.308 *NS*
COG2Hit [mm]	31.4(11.0)	31.1(6.2)	36.7(8.5)	34.7(4)	2.078 *NS*	0.809 *NS*	0.155 *NS*
Trigger force							
TF_{-1000} [%]	84(18)	76(17)	81(15)	79(13)	0.001 *NS*	0.658 *NS*	0.583 *NS*
TF_{-600} [%]	90(11)	85(15)	86(14)	87(5)	0.003 *NS*	0.550 *NS*	2.737 *NS*
TF_{-200} [%]	95(9)	92(11)	89(11)	93(3)	0.003 *NS*	0.137 *NS*	2.189 *NS*
TF_{+200} [%]	69(24)	78(46)	62(44)	87(32)	0.305 *NS*	2.914 *NS*	0.878 *NS*

TABLE 8 (continued).

	HighDT		**LowDT**		***ATS*(1,∞) (*p*-value)**		
Variable [unit]	Pre	Post	Pre	Post	*Group*	*Time*	*Interaction*
Weight distribution							
WD_F [%]	60.5(2.2)	59.4(4.6)	56.1(5.4)	58.0(1.7)	2.777 *NS*	0.521 *NS*	0.444 *NS*
Postural balance							
SDX [mm]	0.78(0.23)	0.67(0.22)	0.76(0.25)	0.64(0.22)	0.001 *NS*	**3.948 (.047)***	1.700 *NS*
SDY [mm]	0.49(0.16)	0.45(0.09)	0.48(0.13)	0.47(0.07)	0.001 *NS*	1.618 *NS*	1.732 *NS*
SDX_F [mm]	0.77(0.16)	0.59(0.25)	0.67(0.32)	0.69(0.20)	0.008 *NS*	2.204 *NS*	2.054 *NS*
SDY_F [mm]	0.30(0.12)	0.29(0.15)	0.16(0.18)	0.11(0.12)	**5.567 (.018)***	**4.781 (.029)***	0.926 *NS*
SDX_R [mm]	0.84(0.18)	0.76(0.25)	0.78(0.26)	0.67(0.33)	0.080 *NS*	**4.531 (.033)***	0.018 *NS*
SDY_R [mm]	0.15(0.21)	0.17(0.09)	0.15(0.05)	0.14(0.09)	0.714 *NS*	0.007 *NS*	1.068 *NS*

ATS, ANOVA-type statistics; *IQR*, interquartile range; *NS*, non-significant; RangePTS, range shooting score; LabPTS, lab shooting score; COG, mean aiming accuracy distance from center; $Target_{2/3}$, relative aiming accuracy distance from hit; $TIRE_6$, timing of triggering index; DevX, horizontal stability of hold; DevY, vertical stability of hold; MV_{200}, mean velocity 200 to 0 ms before triggering; MV_{600}, mean velocity 600 to 0 ms before triggering; COG2Hit, distance of hit point to aiming mean; TF_{200} to TF_{1000}, Trigger force 200 to 1000 ms before triggering; TF_{+200}, Trigger force 200 ms after triggering; WD_F, percentage weight on the front leg. Postural balance (standard deviation of the center of pressure location 600 to 0 ms before triggering) of the whole body in shooting (SDY) and cross-shooting (SDX) direction, and postural balance of each leg separately (F, front; R, rear). * $p < .05$.

Post hoc tests were performed for SDX, SDY_F and SDX_R variables, since the ANOVA-type tests indicated significant main effects. Percentage changes in mean ± *SD* and median(*IQR*) values of pre-post shooting variables in HighDT and LowDT groups are presented in appendix 3.

An independent samples Mann-Whitney *U*-test didn't show any statistically significant between group (LowDT vs. HighDT) differences in postural balance changes SDXdelta, SDY_Fdelta and SDX_Rdelta, which also didn't have interaction effects in the ANOVA-type test. A Wilcoxon matched pairs signed-ranks test showed a statistically significant decrease in pre-post total cross-direction postural balance SDX for HighDT group ($z = -2.521$, $p = .008$) is illustrated in figure 28, and figure 29 shows significant between groups difference in front leg postural balance in shooting direction SDY_F post test values ($z = -2.415$, $p = .015$).

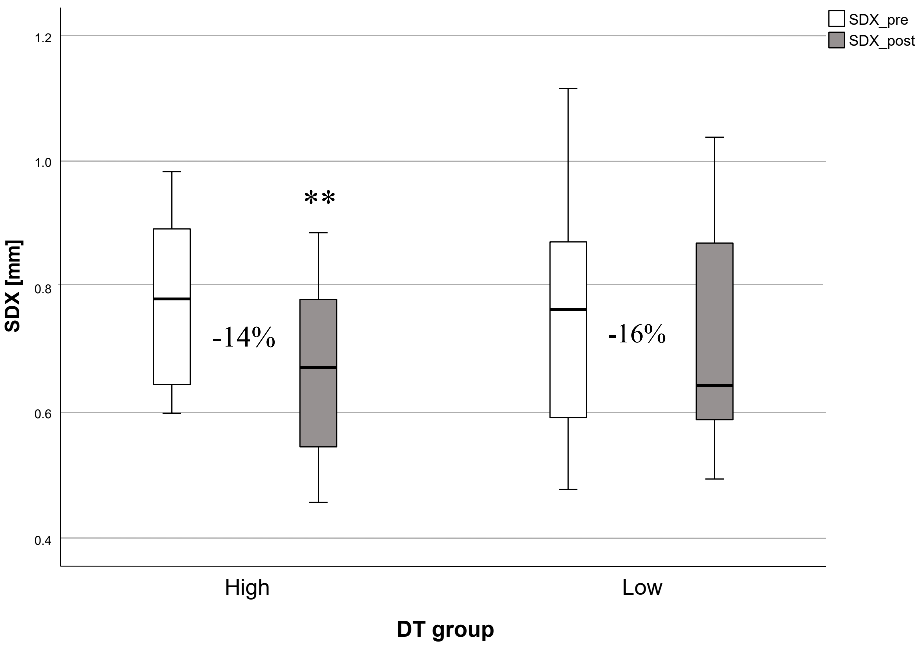

FIGURE 28. A Wilcoxon matched pairs signed-ranks test showed a significant decrease in pre-post total cross-direction postural balance (SDX) for HighDT (high amount of dry fire training) group ($p < .01$), and the LowDT (low amount of dry fire training) group didn't have a statistically significant change in SDX, possibly due to high variance.

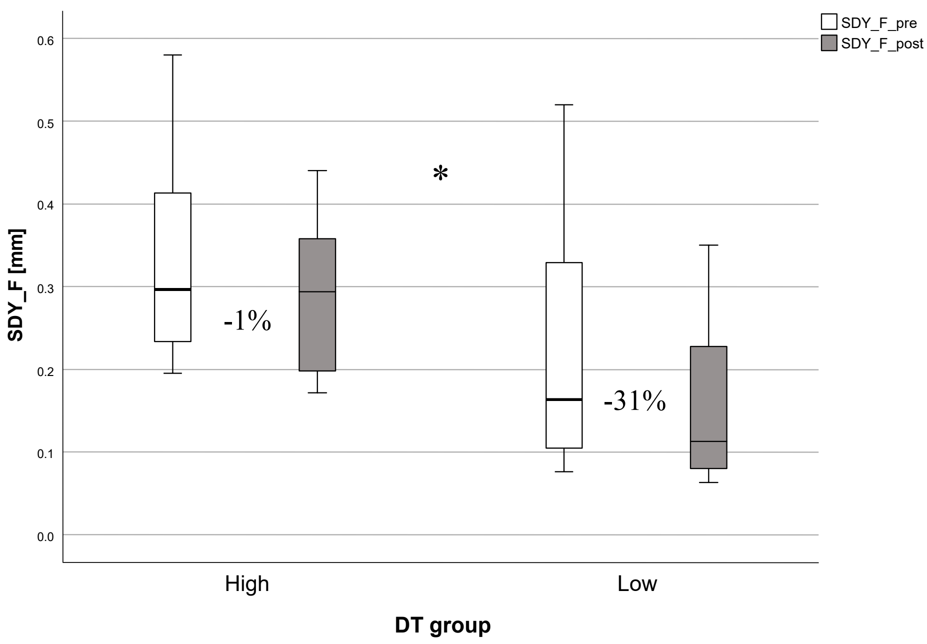

FIGURE 29. Front leg postural balance in shooting direction (SDY_F) decreased only in LowDT (low amount of dry fire training) group from pre- to post-test ($z = -1.823$, $p = .068$), and the only statistically significant between groups difference (*$p < .05$) was SDY_F post-test values between HighDT (high and low amount of dry fire training) and LowDT groups.

A 2-tailed Spearman correlation was computed separately for HighDT and LowDT groups between all technical laboratory shooting variable changes. No statistically significant correlations were found between RangePTSdelta and other variables. LabPTSdelta correlations are presented in table 9. The horizontal standard deviation of aiming point change DevXdelta and rear leg postural balance COP location in X- and Y- directions (SDY_Rdelta and SDX_Rdelta) had a negative correlation ($p < .05$) with laboratory shooting score change (LabPTSdelta) in the high dry fire amount group HighDT.

TABLE 9. Spearman correlations between LabPTSdelta and technical variable changes for HighDT ($n = 8$) and LowDT ($n = 8$) groups.

	LabPTSdelta HighDT group		**LabPTSdelta LowDT group**	
Variable [unit]	Correlation r_s (8)	*p*-value	Correlation r_s (8)	*p*-value
RangePTSdelta	0.143	.736	-0.036	.933
DevXdelta [mm]			**-0.898****	**.002**
DevYdelta [mm]	-0.738*	.037	**-0.970*****	**< .001**
MV_{600}delta [mm/s]			**-0.898****	**.002**
$Target_{2/3}$delta [pp]			**0.946*****	**< .001**
SDX_Rdelta [mm]	-0.786*	.021		
SDY_Rdelta [mm]	-0.810*	.015	-0.719*	.045

Note: Statistically significant correlation to LabPTSdelta *$p < .05$, **$p < .010$, ***$p < .001$. delta; change between pre-post test; LabPTS, lab shooting score; RangePTS, range shooting score; DevX, horizontal stability of hold; DevY, vertical stability of hold; MV_{600}, mean velocity 600 to 0 ms before triggering; $Target_{2/3}$, relative aiming accuracy distance from hit; pp, percentage points; Postural balance (standard deviation of the center of pressure location 600 to 0 ms before triggering) of the rear leg in shooting (SDY_R) and cross-shooting (SDX_R) direction.

7.3.1 Shooting scores comparison between HighDT and LowDT groups

An independent samples Mann-Whitney U-test didn't show significant statistical differences in pre-test shooting score ranks between HighDT and LowDT groups (LabPTS_pre, $p = .130$ and RangePTS_pre, $p = .574$). Wilcoxon signed-ranks tests were performed to find out if shooting score had improved in the intervention from pre- to post tests in any group. A two-tailed Wilcoxon signed-ranks tests indicated that RangePTS post-test ranks were statistically significantly higher than pre-test ranks in HighDT group (z = -2.197, p = .031) (figure 30). The HighDT group had less negative ranks than LowDT in RangePTS. Laboratory shooting scores LabPTS did not have a statistically significant improvement in any group. There was not enough evidence to reject the null hypothesis for LabPTS pre-post change, possibly due to small sample size, or too high variability.

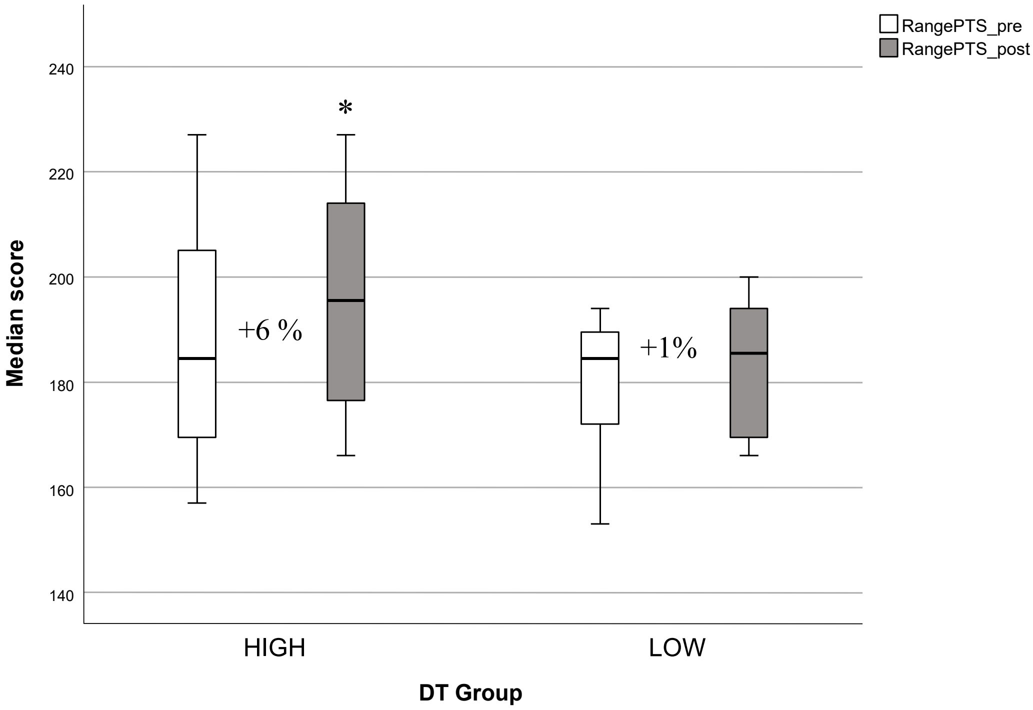

FIGURE 30. Change in median range shooting scores (RangePTS) in HighDT (high dry fire amount) group had a statistically significant positive change ($p < .05$), and LowDT (low dry fire amount) group did not improve RangePTS significantly.

7.4 Correlations of Range and Laboratory shooting tests scores

A two-tailed Spearman correlation was computed for all subjects (N = 16), which showed significant positive correlation of post-test shooting scores Range_post and Lab_post (table 10 and figure 31). Correlation between pre-test results Lab_pre and Range_pre was non-significant (figure 32).

TABLE 10. Spearman correlation matrix for pre-post shooting test scores for all subjects (N = 16) from the laboratory (LabPTS pre-post) and shooting range (RangePTS pre-post).

		RangePTS_pre	RangePTS_post	LabPTS_pre	LabPTS_post
RangePTS_pre	Spearman's rho	—			
	p-value	—			
RangePTS_post	Spearman's rho	0.756 ***	—		
	p-value	< .001	—		
LabPTS_pre	Spearman's rho	**0.366**	0.587 *	—	
	p-value	**0.163**	0.017	—	
LabPTS_post	Spearman's rho	0.479	**0.752 *****	0.606 *	—
	p-value	0.061	**< .001**	0.013	—

Note: **p* < .05, ***p* < .010, ****p* < .001. pre-post test; LabPTS, lab shooting score; RangePTS, range shooting score.

The pre-post changes in shooting scores, LabPTSdelta and RangePTSdelta did not have a statistically significant correlation. In the CONTROL group (n = 8) all shooting tests correlated significantly at least at the level *$p < .05$, however in the MANTIS group (n = 8) only Range_pre and Range_post had a significant correlation (r_s = 0.970, p < .001). In the HighDT group (n = 8) all shooting tests correlated significantly at least at the level *$p < .05$, and in the LowDT group (n = 8) no statistically significant correlations were found, indicating individually highly variable test results.

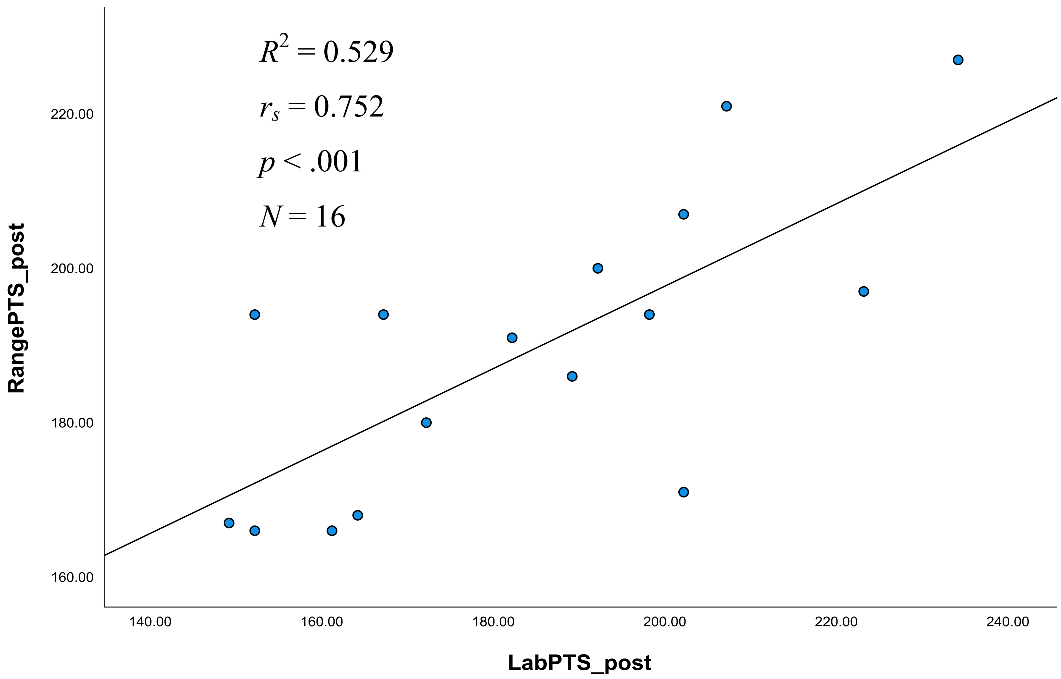

FIGURE 31. Spearman correlation between post-test laboratory (LabPTS_post) and range (RangePTS_post) shooting scores for all subjects was statistically significant.

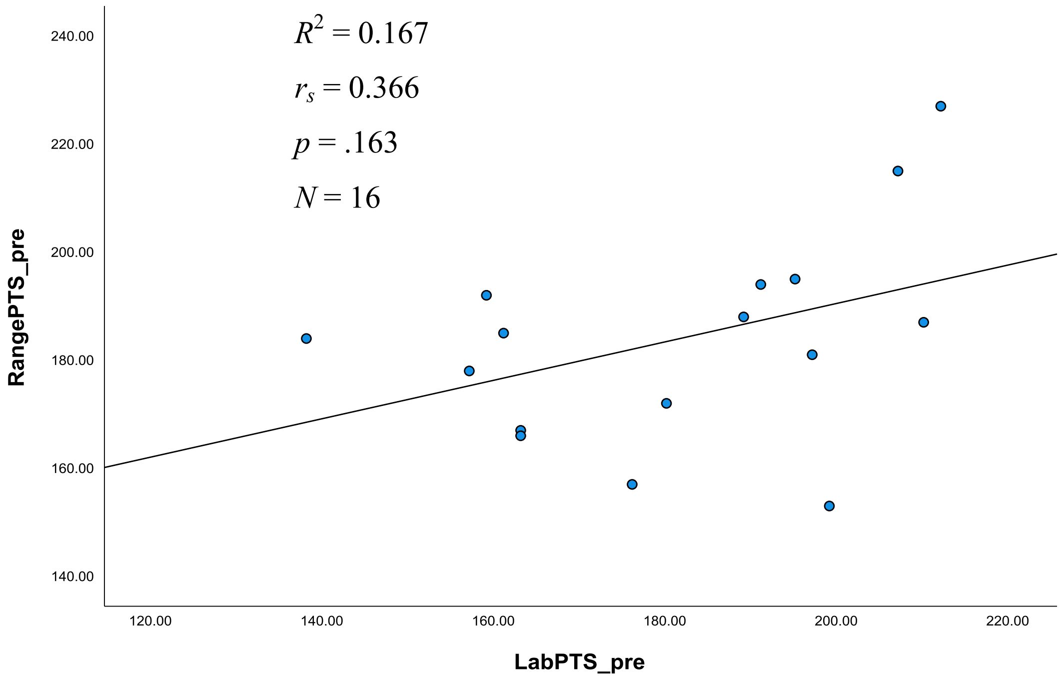

FIGURE 32. Non-significant Spearman correlation between pre-test laboratory (LabPTS_pre) and range (RangePTS_pre) shooting scores for all subjects.

8 DISCUSSION

The purpose of this study was to examine how dry firing practice and feedback affects biathlon standing shooting performance. Live and dry fire shooting tests were conducted at the biathlon shooting range and in the laboratory before and after the training intervention to investigate the effects of live fire recoil and sound on shooting performance. Subgroups were formed and also compared based on the amount of dry fire practice the athletes had performed.

The main findings from the study were: (1) The MANTIS group demonstrated more general improvement in standing shooting scores with less training than the CONTROL group who practiced conventional dry fire training. This supports the first hypothesis H1. (2) High amount of dry fire practice sessions showed higher post-test standing shooting scores both in the laboratory and on the range. This partially confirms the second hypothesis H2. (3) Range shooting scores did not correlate with laboratory tested technical variables. Range and lab shooting scores only correlated in post-tests, indicating that unfamiliar testing method may initially give variable results and skills learning stabilizes scores in the laboratory tests. Contrary to the third hypothesis H3, laboratory shooting scores were worse than range shooting scores at post-test. In the next three chapters, all the research questions and hypotheses are discussed in more detail.

8.1 Effects of dry fire practice and feedback with the Mantis training system

Hypothesis 1: *Mantis feedback group will improve shooting performance and improve certain technical skills more than the control group without a feedback system.* The MANTIS group improved the median RangePTS (+4%)** and LabPTS (+8%), while the CONTROL group showed a decline in the pre-post shooting performance for both RangePTS (-2%) and LabPTS (-6%) (appendix 2). However, possibly due to the small sample size or too large differences between individual athletes' shooting scores, the only statistically significant ($p < .01$) change in shooting performance was observed in the pre-post RangePTS improvement of the MANTIS group. Postural balance variables SDX, SDX_R and SDX_F decreased significantly in the MANTIS group, and a statistically significant between group difference was found in the change SDXdelta ($p < .05$), which indicates improvement in whole body postural balance in cross-shooting direction for the MANTIS group. These findings indicate a positive effect of the Mantis feedback training on shooting performance and postural balance, which supports hypothesis 1.

The variation (*IQR* and *SD*) in shooting scores decreased in the MANTIS group, whereas in the CONTROL group the variation increased, which indicates positive learning effects from the feedback system. Indeed, it is widely known that the variability of an outcome is decreased as a function of practice and improvements in skill (Cohen & Sternad. 2009; Mononen et al. 2003), though variability can never be fully eliminated, since the nervous system is inherently noisy. Manley et al. (2014) showed that awareness of the critical dimension during motor learning is the key factor which allows learning from arbitrary rewards and that explicit, binary feedback about success or failure was only sufficient for learning when participants were aware of the dimension along which motor behavior had to change. It was suggested that higher-order moments of outcome signals are likely to play a significant role in skill learning in complex tasks, and that without such awareness, learning was only present when extrinsic noise was added to the feedback (Manley et al. 2014). This suggests that instant feedback and awareness of the critical dimensions is important for learning, and that the simple binary feedback from a biathlon target might not provide enough information for skills learning.

The MANTIS group participants completed on average (mean ± *SD*) 23 ± 8 dry fire and 23 ± 9 live fire practice sessions during the 8 weeks training period, as the CONTROL group trained much more, on average 32 ± 10 dry fire and 26 ± 11 live fire sessions. This is showing even a more important effect of the Mantis feedback system, which would indicate that less training using the Mantis feedback leads to higher improvement in shooting performance than a higher training amount without feedback.

Figure 33 shows a comparison between Noptel and Mantis barrel movement tracking and shot detection, which look quite similar. However, the shot placement is different, and hit point direction estimate was correct approximately 80% of the time in several range shooting tests with the Mantis. This may or may not have an effect on the correctness of the feedback from the Mantis application. Anyhow it is suggested, to follow long term trends only, with hundreds of shots instead of individual shots or five shot series when using the Mantis training system. The shooting training systems from various suppliers should be compared and validated in future studies, so the correct feedback would be available at home and on the range. Moreover, a feedback device with an IMU unit and no knowledge of an actual hit point, may provide feedback for postural balance correction, as was evident in this study. Especially cross-shooting direction postural balance (SDX) improved in the MANTIS group, which was easily detected with the Mantis device and reported to the user as barrel movement during holding and triggering.

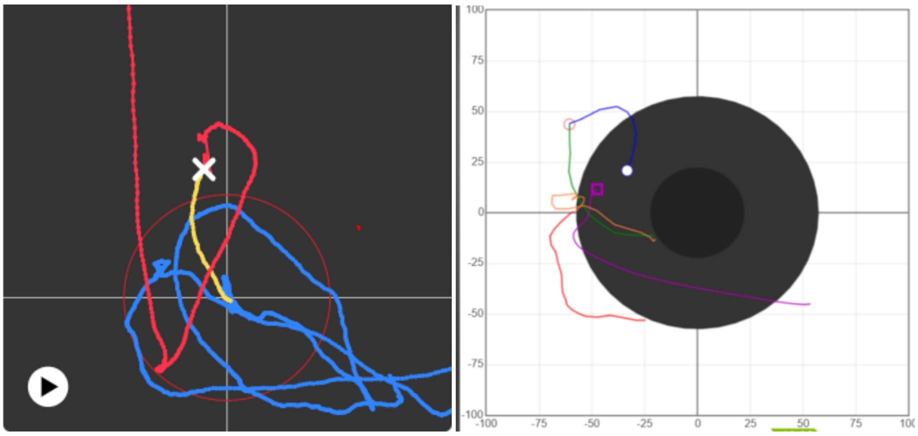

FIGURE 33. Comparison of Mantis (left) and Noptel aiming point trajectory from the same shot. Mantis shows different readings 250 ms before hit (white X), as it centers the triggering time curve to a hypothetical center of a target (yellow line). The hit point placement is different with Noptel (white dot), though the aiming point trajectory is similar.

A motivating effect of the Mantis training system was not obvious, as five subjects of the MANTIS group also belonged to the LowDT group. Only one subjects increased his dry fire training amount substantially with the Mantis feedback and his shooting scores improved more than average amount. Many athletes commented that the Mantis system too often reported a "great shot", even if the athlete felt uncertain about a good shot. Possibly the feedback needs to have different levels for shooters with varying skills, so the reporting level could be adjusted to suite a more stable hold and smaller aiming point and barrel movement.

8.2 Effects of dry fire practice in biathlon standing shooting performance

Hypothesis 2. *Standing shooting test score and shooting technical factors will improve with dry firing.* Laboratory shooting score improvement LabPTSdelta for all subjects ($N = 16$) had a negative correlation with postural balance in cross-shooting direction SDXdelta ($r_s = -0.617$, $p = .011$) and SDX_Rdelta ($r_s = -0.740$, $p = .001$), which is in line with multiple previous studies. Sattlecker et al. (2014 and 2017) found that standing shooting performance is correlated with postural balance, mainly in cross-shooting direction SDX, and Sadowska et al. (2019) showed that changes in horizontal hold were associated with changes in balance. Ihalainen et al. (2018) found that postural balance in shooting direction (SDY) is related to vertical stability of hold (DevY) and cleanness of triggering. As well as in the present study, laboratory shooting score improvement LabPTSdelta had strong correlations with SDYdelta ($r = -0.605$, $p = .013$) and DevYdelta ($r_s = -0.855$, $p < .001$). Standard deviation of the rear leg COP location in cross-shooting (SDX_R) and shooting direction (SDY_R) had a strong correlation with laboratory shooting score improvement, which also could be a potential lead for future studies, considering that weight distribution (WD_F) did not correlate with any of the tested technical variables or shooting scores.

The HighDT group participants completed on average 35 ± 6 (mean ± *SD*) dry fire and 32 ± 6 live fire practice sessions during the 8 weeks intervention period, and the LowDT group trained much less, on average 19 ± 6 dry fire and 17 ± 9 live fire sessions. No statistically significant correlations were found between the amount of dry fire or live fire sessions and the shooting performance (pre-, post- or delta scores), indicating that the high amount of shooting training will not guarantee a better shooting performance. Indeed, Laaksonen et al. (2011) also found that the autogenic and imaginary training group enhanced shooting performance more with less regular shooting training than the control group, which was the same conclusion as for the MANTIS group in this study.

The HighDT and LowDT groups had initially identical median RangePTS shooting scores (184.5 pts), however, initial median LabPTS scores differed 19% between the groups (HighDT 192 pts vs. LowDT 162 pts), which was a indication of positive effects of dry firing on laboratory shooting results. HighDT group improved median RangePTS (+6%) and LabPTS (+4%), where as the LowDT group improved median RangePTS (+1%) and LabPTS (+5%). Both groups improved laboratory shooting scores, which may indicate dry firing skills learning and reduced outcome variability even with a small amount of dry fire practice. Interestingly, the HighDT group also practiced 88% more shooting on the range, which explains the higher enhancement in RangePTS compared to the LowDT group. HighDT groups median post intervention shooting scores were substantially higher than the LowDT groups scores, which was due to higher number of senior athletes in the group. A statistically significant -14% change in SDX ($p < .01$), was found in the HighDT group, which indicates that larger amount of dry firing can improve shooting performance through postural balance, which has earlier been confirmed by Sattlecker et al. (2014 and 2017).

8.3 Correlation between live fire and dry fire test results

Hypothesis 3: *Lack of recoil and an audible shot sound when dry firing vs. live firing will have an impact on average shooting scores. Dry firing is expected to give better scores than live fire due to lack of recoil, sound and stable lab conditions.* A significant correlation was found between the range and laboratory shooting scores only in the post-tests ($r_s = 0.752$, $p < .001$), which is in line with the earlier observation of outcome variability reduction as a function of practice and improvements in skill (Cohen & Sternad. 2009). When four of the most inexperienced laboratory shooters were omitted ($n = 12$) from the Spearman correlation calculation, also the pre-test shooting scores between the lab and the range correlated at the level $r_s = 0.706$, $p = .013$. Interestingly, there were no significant correlations found between range shooting score change RangePTSdelta and change in any laboratory measured technical shooting or postural balance variables. This finding suggests that range and laboratory shooting skills development may develop independently of each other in terms of shooting technical variable development, and also indicating very different technical determinants for shooting performance for each individual athlete and individual shooting event. Similarly, Ihalainen et al. (2016) also found that, although the test shooting scores with a Noptel device in the laboratory improved, there were no statistically significant changes in the competition shooting scores.

Moderate correlation ($r = 0.50$ to 0.55, $p < .05$) was found between live and dry fire scores in two studies by Smith et al. (2000 and 2003), in which soldiers were tested for marksmanship qualifications at the shooting range and indoors with a laser device. The aim for these studies was to detect needs for additional shooting training and find marksmanship qualification limits with dry firing, instead of having to go to a shooting range. The studies concluded that soldiers most in need for remedial training can be identified with a dry firing test, when an outdoor range is not available. A recommendation was made to have previous years qualification scores as a prerequisite when selecting participants in future research. The shooting score correlation between live and dry fire varied depending on the skill level of the subjects and the shooting range and conditions, so predictions for expert level qualification were not very good (Smith & Hagman. 2000 and 2003).

A good topic for future biathlon shooting research would be a study in which the same technical variables are measured on the shooting range and in the laboratory on the same day and the results are compared. Shots could also be fired sequentially, such as five shots dry fire, five shots live fire, five shots dry fire, etc. Contrary to the suggestions of Heinrich et al. (2020) and the last hypothesis from the present study, the recoil and sound from real shooting didn't seem to distract the biathletes, as median post-test scores were 4% higher on the range than in the laboratory. For all subjects combined (N = 16), the median pre-test scores (184.5) were identical in the laboratory and on the shooting range.

8.4 Sample size and statistical analysis effects

The reason for some of the statistically non-significant changes between and within groups were most probably due to small sample size and large differences in individual shooting skills in pre- and post-tests. The individual shooting scores varied from 153 to 227 points in RangePTS and from 138 to 234 points in LabPTS, which introduced high variance in statistical analyses and thus small statistical effect sizes. The extreme low and high results are true measures of individual shooting performance, and thus cannot be treated as extreme outliers and removed from analysis. The median RangePTS scores for MANTIS and CONTROL groups were identical at pre-test (184.5 vs. 184.0), and in median LabPTS there was a 11% difference between group pre-scores (171.5 and 190.0), therefore the group allocation was kept for the study, based on negligible RangePTS score differences at pre-test. After all, range shooting performance is a more important measure of skills, than a laboratory dry shooting test.

Post hoc tests with shooting scores were performed, even if ANOVA-type tests did not show statistically significant between or within group main effects, since those tests had been decided before the intervention started. Most of the collected data did not meet the assumptions of a normal distribution, therefore non-parametric tests were chosen. Due to Lord (1967) paradox effects, both Wilcoxon t-tests and nparLD ANOVA-type tests were performed, to see if the initial hypothesis of change score improvement in groups was found. Percentage change in mean and median shooting scores may be more indicative of actual progress, than any statistical test in this study. Individual shots would need to be analyzed, if more detailed relationships between technical variables and shot scores were desired, because there are several variables that can affect each individual shot. Thus, improvement in some variable may cause another parameter to be more dominating and misleading conclusions may occur. Spancken et al. (2021) concluded that the wide range shooting technical variables and possible influence on shooting performance also show that shooting performance is composed of multifaceted processes running simultaneously and sequentially.

8.5 Limitations of the study

There was no formal control over how the athletes performed the dry firing drills or regular live fire training, but a weekly motivational dry fire reminder was sent to all participants by email. The practice sessions were reported in a diary, and only the amount of training sessions was extracted, which does not explain the effects of individual dry fire drills on the results. To study the effects of a particular exercise, the sample size would need to be substantially larger and individual drills would need to be performed at least once a week throughout the intervention.

Small sample size (n = 8) in the experimental groups complicated statistical analysis and may not give enough statistical power in all cases. This is an inherent problem in many experimental studies in the field of expertise research and therefore data have to be carefully interpreted. The small sample size also highlights differences in laboratory shooting test experience, and since the initial test results have large variation between individuals the skills learning for the test is vastly different, which introduces a clear limitation in evaluating individual test results.

Shooting in a rest condition prevents the complicated procedure of determining a proper physical stress level for various individuals at race pace, and the strenuous shooting test procedure associated with maintaining the proper physical stress level during the test. However, although the athletes were not physically stressed, competition anxiety and mental pressure is much harder to simulate in a test environment than physical exertion and should also be accounted for, if possible. Moreover, the present study allowed for wearing running shoes or similar, however biathlon shooting tests should preferably be arranged with ski boots and skis on, in order to have correctness in postural balance measurements. The lack of commonly agreed protocols for biathlon shooting testing makes every laboratory use different equipment and settings, which makes inter-laboratory comparison almost impossible, most possibly leading to different findings. Even in the same laboratory, test results may vary with different operators and slightly differing procedures. The test procedure development and standardization would need careful consideration in future research projects. An extra practice and test session for all athletes would be highly recommended in order to reduce the learning effect of the repeated test situation between the pre- and post-test.

8.6 Coaching and training perspectives

Standing shooting is not only learned by shooting on the shooting range, but also requires frequent dry fire training and holding exercises. Also, for those biathletes who have been practicing shooting for a longer time, balance exercises with the rifle are good for the supporting muscles of standing shooting. In the present study, dry firing with augmented feedback improved biathlon standing shooting performance with less training sessions than conventional dry fire practice. The amount of biathlon standing shooting practice does not seem to have direct correlation with outcome improvement, and general recommendations vary from one training session per week to daily practice. Since good postural balance is an important factor and is highly correlated with standing shooting performance, the quality and focus in the training can be improved with dry firing and augmented feedback.

Careful interpretation of laboratory shooting test results is particularly necessary when the test method is new to the athlete or a long time has passed since the last test. Dry firing test results may not resemble range shooting test results, when an athlete is unfamiliar with the laboratory test or dry firing in general. An inexperienced shooter may show a huge improvement or deterioration in laboratory test results in a short period of time, which is not reflected in actual live fire shooting. The differences found between laboratory and range tests certainly require more research, and possibly a better parameter to evaluate is the size of the shot group (precision) rather than the total score. Small groups of shots at the target are always a sign that you have mastered the technical and postural balance variables, as well as the right equipment and adjustments.

When performing dry fire training, it is important to remember the correct shooting techniques with breathing, aiming and triggering. Dry fire practice can also help to speed up shooting and reduce total range time and to find a suitable shooting rhythm. For juniors who are new to standing shooting, holding and dry firing is extremely important for mastering shooting posture and building the supporting muscles, in order to find a more relaxed stance. A guideline for all biathlon shooting athletes is special training in holding and dry fire training, at least on days when there is no actual live shooting training. For athletes in the early stages of their biathlon career, daily holding and dry fire practice is highly recommended.

8.7 Conclusions

The results of the present study indicate that standing shooting practice with a Mantis X10 device has a positive effect on biathlon standing shooting performance both on the range and in the laboratory. Shooting scores of the MANTIS group improved more with less training sessions compared to the CONTROL group. The main parameters, that had statistical significant changes were postural balance variables in cross shooting direction (SDX), which have also been found in several other studies to be strongly related to shooting performance and shooting technical factors. The interpretation of direct effects of postural balance on shot accuracy may still be misleading, since the body COP movements affect the rifle with a delay and somewhat independently of holding, aiming and triggering. A systematic review by Spancken et al. (2021) also showed that body sway can not be used as a performance determinant to discriminate between shot scores, but rather a performance requirement to compete at an elite level. This supports the findings in the present study that postural balance variable improvements did not correlate with range shooting scores.

Furthermore, since no statistically significant correlations were found between RangePTS change score and any of the laboratory tested technical variables, it would be reasonable to conclude that the range test scores are not directly related to laboratory tested technical variables. Range vs. laboratory shooting tests and variables will require further investigation in future studies with larger sample sizes and a greater number of tests and shots. Every shot has its signature technical variable measures and no other shot can be exactly same, so more detailed single shot analysis should be included and also correlations with multiple shot groups.

Since no statistically significant correlations were found between the amount of shooting training (live or dry fire) and the improvements in shooting performance, it can be concluded that the groups were already biased on training amounts before the intervention. Generally, lower amount of training introduced higher amount of variance in measured shooting technical variables, confirmed also by Cohen & Sternad. (2009).

Elite-level biathletes must be consistently very fast, precise and accurate in biathlon shooting. Dry firing gives self confidence and better zeroing before competition, and even if practiced only five minutes per day, dry firing builds muscle memory and improves postural balance and triggering.

REFERENCES

ANSCHÜTZ J.G. GmbH & Co.KG, Jagd- und Sportwaffenfabrik Ulm / Germany. (accessed on 08/15/2022). http://jga.anschuetz-sport.com/.

Björklund, G., Dzhilkibaeva, N., Gallagher, C., Laaksonen, M. S. (2022). The balancing act between skiing and shooting – the determinants of success in biathlon pursuit and mass start events, Journal of Sports Sciences, 40:1, 96-103, DOI:10.1080/02640414.2021.1976493.

Cohen, R.G., Sternad, D. (2009). Variability in motor learning: relocating, channeling and reducing noise. Exp Brain Res 193, 69–83. https://doi org.ezproxy.jyu.fi/10.1007/ s00221-008-1596-1.

Finnish Biathlon Association (Suomen Ampumahiihtoliitto). Ampumahiihtoammunnan tekniikat- juliste. Accessed on August 18th 2022. http://www.biathlon.fi/.

Galay, N., Vasyuk, V., Bykov, D., Vasilyeva, V., & Bakayev, V. (2021). Evaluation of the Dynamics of the Pressure Applied to the Trigger When Shooting In Biathlon. Sport Mont, 19(3), 9-13. doi: 10.26773/smj.211002.

Gallicchio, G., Finkenzeller, T., Sattlecker, G., Lindinger, S., Hoedlmoser, K. (2016). Shooting under cardiovascular load: Electroencephalographic activity in preparation for biathlon shooting, International Journal of Psychophysiology, Volume 109, Pages 92-99, ISSN 0167-8760, https://doi.org/10.1016/j.ijpsycho.2016.09.004.

Grebot, C., Burtheret, A. (2007). Forces exerted on the butt plate by the shoulder of the biathlete in biathlon shooting, Computer Methods in Biomechanics and Biomedical Engineering, 10:sup1, 13-14.

Groslambert, A., Candau, R., Hoffman, M. D., Bardy, B., & Rouillon, J. D. (1999). Validation of simple tests of biathlon shooting ability. International journal of sports medicine, 20(3), 179–182. https://doi.org/10.1055/s-1999-970286.

Groslambert, A., Candau, R., Grappe, F., Dugue, B., and Rouillon, J. D. (2003). Effects of autogenic and imagery training on the shooting performance in biathlon. Res. Q. xerc. Sport 74, 337–341. doi: 10.1080/02701367.2003. 10609100.

Hatfield, B.D., Landers, O.M. (1983). Psychophysiology - a new direction for sport psychology. J Sport PsychoI1983;5:243- 59.

Heinrich, A., Hansen, D. W., Stoll, O., & Cañal-Bruland, R. (2020). The impact of physiological fatigue and gaze behavior on shooting performance in expert biathletes. Journal of science and medicine in sport, 23(9), 883–890. https://doi.org/10.1016/j.jsams.2020.02.010.

Hoffman, M. D., Gilson, P. M., Westenburg, T. M. & Spencer, W. A. (1992). Biathlon shooting performance after exercise of different intensities. International Journal of Sports Medicine 13 (3), 270–273.

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. https://doi.org/10.1123/ijspp.2015-0211.

Ihalainen, S., Laaksonen, M. S., Kuitunen, S., Leppävuori, A., Mikkola, J., Lindinger, S. J. & Linnamo, V. (2018). Technical Determinants of Biathlon Standing Shooting Performance Before and After Race Simulation. Scandinavian Journal of Medicine and Science in Sports 28 (6), 1700–1707.

Ihalainen, S. (2018). Technical determinants of competitive rifle shooting performance. Doctoral Thesis. University of Jyväskylä, Faculty of Sport and Health Sciences, Finland. http://urn.fi/URN:ISBN:978-951-39-7468-8.

Interlink Electronics. FSR 400 Data Sheet. Interlink Electronics, Inc. Interlink 402 Force sensing Resistor. http://www.interlinkelectronics.com/fsr-400. (accessed on 08/19/2022).

Interlink Electronics. FSR 400 Integration guide. https://www.interlinkelectronics.com/request-integration-guides. (accessed on 05/03/2023).

International Biathlon Union, IBU. (2022). Event and competition rules. (accessed on 08/19/2022). http://res.cloudinary.com/deltatre-spa-ibu/image/upload/nk93tbz7syaoj02qmjod.pdf.

International Biathlon Union. (2022). Datacenter (IBU). (accessed on 08/19/2022). http://biathlonresults.com/.

Köykkä, M., Ihalainen, S., Linnamo, V., Ruotsalainen, K., Häkkinen, K., Laaksonen, M.S. (2020). Aiming strategy affects performance-related factors in biathlon standing shooting. Scand J Med Sci Sports. 2020;00:1–13.

Köykkä, M., Laaksonen, M. S., Ihalainen, S., Ruotsalainen, K., & Linnamo, V. (2022). Performance-determining factors in biathlon prone shooting without physical stress. Scandinavian Journal of Medicine and Science in Sports, 32(2), 414-423. https://doi.org/10.1111/sms.14087

Laaksonen, M., Finkenzeller, T., Holmberg, H-C., Sattlecker, G. (2018). The influence of physiobiomechanical parameters, technical aspects of shooting, and psychophysiological factors on biathlon performance: A review. Journal of Sport and Health Science. 7. 10.1016/j.jshs.2018.09.003.

Laaksonen, M. S., Jonsson, M. & Holmberg, H.-C. (2018b). The Olympic Biathlon – Recent Advances and Perspectives After Pyeongchang. Frontiers in Physiology 9 (796). doi: 10.3389/fphys.2018.00796.

Laaksonen, M. S., Ainegren, M., and Lisspers, J. (2011). Evidence of improved shooting precision in biathlon after 10 weeks of combined relaxation and specific shooting training. Cogn. Behav. Ther. 40, 237–250. doi: 10.1080/ 16506073.2011.616217.

Lord, F. M. (1967). A paradox in the interpretation of group comparisons. Psychological Bulletin, 72, 304–305.

Luchsinger, H., Sandbakk, Ø., Schubert, M., Ettema, G., Baumeister, J. (2016). A Comparison of Frontal Theta Activity During Shooting among Biathletes and Cross-Country Skiers before and after Vigorous Exercise. PLoS ONE 11(3): e0150461. doi:10.1371/journal.pone.0150461

Luchsinger, H., Kocbach, J., Ettema, G., and Sandbakk, Ø. (2018). Comparison of the effects of performance level and sex on sprint performance in the biathlon world cup. Int. J. Sports Physiol. Perform. 13, 360–366. doi: 10.1123/ijspp.2017- 0112.

Maksimovic, G., International Shooting Sport Federation. ISSF National Coach Course RIFLE SHOOTING. https://www.issf-sports.org/getfile.aspx?mod=docf&pane=1&inst=493&file=Rifle_shooting_theoretical_material.pdf (accessed on 08/19/2022).

Manley H., Dayan P., Diedrichsen J. (2014). When money is not enough: awareness, success, and variability in motor learning. PLoS One. 2014 Jan 28;9(1):e86580. doi: 10.1371/journal.pone.0086580.

Mantis Tech, LLC. 2270 US Hwy 30, Oswego, IL 60543. USA. MantisX-products. (accessed on 08/18/2022). http://www.mantisx.com/.

Matikka, L., Roos-Salmi, M., Arajärvi, P., Nuoramo, T. & Aaltonen, A. (2020). Urheilupsykologian perusteet (3. painos.). Liikuntatieteellinen Seura ry. 50-51, 55, 139.

Mononen, K., Viitasalo, J. T., Konttinen, N. & Era, P. (2003). The effects of augmented kinematic feedback on motor skill learning in rifle shooting. Journal of sports sciences, 21(10), 867-876. https://doi.org/10.1080/0264041031000101944.

Mononen, K., Konttinen, N., Viitasalo, J., Era, P. (2007). Relationships between postural balance, rifle stability and shooting accuracy among novice rifle shooters. Scandinavian Journal of Medicine & Science in Sports.

Mullineaux, D.R., Underwood, S.M., Shapiro, R., Hall, J.W.(2012). Real-time biomechanical biofeedback effects on top-level rifle shooters. Appl Ergon 2012;43:109 -14.

Mundry, R., & Fischer, J. (1998). Use of statistical programs for nonparametric tests of small samples often leads to incorrect P values: Examples from Animal Behaviour. Animal behaviour, 56(1), 256-259. https://doi.org/10.1006/anbe.1998.0756.

Neuhäuser, M., & Ruxton, G. D. (2009). Round your numbers in rank tests: Exact and asymptotic inference and ties. Behavioral ecology and sociobiology, 64(2), 297-303. https://doi.org/10.1007/s00265-009-0843-1.

Newell, K.M. & Corcos, D.M. (1993). Variability and Motor Control. Champaign, IL: Human Kinetics.

Noguchi, K., Gel, Y. R., Brunner, E., and Konietschke, F. (2012). nparLD: an R software package for the nonparametric analysis of longitudinal data in factorial experiments. J. Stat. Softw. 50, 1–23.

Noptel Oy. Noptel Oy - Sport Training Products - Sport II Training System. (accessed on 08/17/2022). http://www.noptel.fi/shooter-training-devices/sport-ii/.

Ohtonen, O., Ruotsalainen, K., Mikkonen, P., Heikkinen, T., Hakkarainen, A., Leppävuori, A., et al. 2015. Online feedback system for athletes and coaches. In: Hakkarainen, A., Lindinger, S., Linnamo, V., editors. 3rd International Congress on Science and Nordic Skiing; Finland: University of Jyväskylä; 2015. p. 35.

Paukkonen, P. (2013). Kivääriammunnan liipaisuvoimien mittausmenetelmän kehittäminen, testaus ja validointi. Pro gradu - tutkielma. Liikuntabiologian laitos. Jyväskylän yliopisto.

Real biathlon. (Accessed on April 22nd 2022). http://www.realbiathlon.com/.

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

Sadowska, D., Sacewicz, T., Lichota, M., Krzepota, J., Ładyga, M. (2019). Static Postural Balance in Modern Pentathletes: A Pilot Study. Int J Environ Res Public Health. 2019;16(10):1760. Published 2019 May 18. doi:10.3390/ijerph16101760.

Sandbakk, Ø. & Holmberg, H. (2014). A reappraisal of success factors for Olympic cross-country skiing. International journal of sports physiology and performance, 9(1), 117-121. https://doi.org/10.1123/ijspp.2013-0373

Sattlecker, G., Buchecker, M., Rampl, J., Müller, E., & Lindinger, S.J. (2013). Biomechanical aspects in biathlon shooting. In Science and Nordic Skiing II. University of Jyväskylä, Finland, p. 33-40.

Sattlecker, G., Buchecker, M., Müller, E., & Lindinger, S. J. (2014). Postural Balance and Rifle Stability during Standing Shooting on an Indoor Gun Range without Physical Stress in Different Groups of Biathletes. International journal of sports science & coaching, 9(1), 171-184. https://doi.org/10.1260/1747-9541.9.1.171.

Sattlecker, G., Buchecker, M., Gressenbauer, C., Müller, E. & Lindinger, S. J. (2017). Factors discriminating high from low score performance in biathlon shooting. Int J Sports Physiol Perform. 2017;12(3):377-384.

SCATT Electronics LLC, 141551 Russia, Moscow Region. (visited on 08/17/2022). http://www.scatt.com.

Schmid, M., Conforto, S., Camomilla, V., Cappozzo, A., D'Alessio, T. (2002). The sensitivity of posturographic parameters to acquisition settings, Medical Engineering & Physics, Volume 24, Issue 9, 2002, Pages 623-631.

Schmitt, L., Bouthiaux, S., Millet, G. (2020). Eleven Years' Monitoring of the World's Most Successful Male Biathlete of the Last Decade. International Journal of Sports Physiology and Performance. 16. 10.1123/ijspp.2020-0148.

Smith, M. D., & Hagman, J. D. (2000). Predicting rifle and pistol marksmanship performance with laser marksmanship training system. U.S. Army Research Institute for the Behavioral and Social Sciences.

Smith, M. D., & Hagman, J. D. (2003). Using the laser marksmanship training system to predict rifle marksmanship qualification. Reserve Component Training Research Unit, U.S. Army Research Institute for the Behavioral and Social Sciences.

Solberg, E.E., Berglund, K.A., Engen, O., Ekeberg, O., Loeb, M. (1996). The effect of meditation on shooting performance. Br J Sports Med. 1996 Dec;30(4):342-6. doi: 10.1136/bjsm.30.4.342. PMID: 9015599; PMCID: PMC1332422.

Spancken, S., Steingrebe, H., & Stein, T. (2021). Factors that influence performance in Olympic air-rifle and small-bore shooting: A systematic review. PloS one, 16(3), e0247353. https://doi.org/10.1371/journal.pone.0247353.

Stöggl, T., Bishop, P., Höök, M., Willis, S., & Holmberg, H. C. (2015). Effect of carrying a rifle on physiology and biomechanical responses in biathletes. Medicine and science in sports and exercise, 47(3), 617–624. https://doi.org/10.1249/ MSS.0000000000000438.

Tanskanen, M. (2013). Pienoiskiväärin polviammuntaan vaikuttavat tekijät ja niiden muutokset kilpailunomaisen ammuntasarjan aikana. Pro gradu - tutkielma. Liikuntabiologian laitos. Jyväskylän yliopisto.

Vickers, J. N. & Williams, A. M. (2007). Performing under pressure: the effects of physiological arousal, cognitive anxiety, and gaze control in biathlon. Journal of Motor Behavior 39 (5), 381-394.

Viitasalo, J. T., Era, P., Konttinen, N., Mononen, H., Mononen, K. & Norvapalo, K. (2001). Effects of 12-week shooting training and mode of feedback on shooting scores among novice shooters: Effects of training and feedback on shooting. Scandinavian journal of medicine & science in sports, 11(6), 362-368. https://doi.org/10.1034/j.1600-0838.2001.110608.

Wright, D. B. (2006). Comparing groups in a before-after design: When t test and ANCOVA produce different results. British journal of educational psychology, 76(3), 663-675. https://doi.org/10.1348/000709905X52210.

Yamamoto T, Smith CE, Suzuki Y, Kiyono K, Tanahashi T, Sakoda S, Morasso P, Nomura T. (2015). Universal and individual characteristics of postural sway during quiet standing in healthy young adults. Physiol Rep. 2015 Mar;3(3):e12329. doi: 10.14814/phy2.12329. PMID: 25780094; PMCID: PMC4393163.

Žák, Michal & Ondráček, Jan & Hrebickova, Sylva & Struhár, Ivan. (2017). How one-year of systematic training changes the shooting performance in a group of young biathletes? Conference at Masaryk University, Brno.

Žák, M., Struhár, I., Janoušek, D., & Ondráček, J. (2020). Dynamic rifle stability is not influenced by exercise intensity in young biathletes. Journal of Human Sport and Exercise, 15(4), 762-771. doi: https://doi.org/10.14198/jhse.2020.154.

APPENDIX 1. Dry fire drills and instructions (Isoaho, J. 2022).

Always start with some holding exercise. One session is 15 min or 50 good shots. You may mark 2 sessions, if you have completed 30 min or 100 shots. Focus on shooting every shot perfectly and especially focus on those technical parts you want to improve.

1. Basic biathlon position exercise 10x5 (15 min / 50 shots):
-Rifle on back
-Get to position, rifle from the back, change magazine, build posture
-Shoot five shots with normal rhythm
-Rifle on back, out of position
-Small walk before next series

2. Triggering and breathing exercise 10x5 shots:
-Rifle on back, in a dark room or eyes closed
-Get to position, rifle from the back, change magazine, build posture
-Shoot five shots with normal rhythm, focus on triggering and breathing
-Rifle on back, out of position
-Small break before next series

3. Balance exercise 10x5 shots:
-Roll up a fitness mat, or use a balance pillow (possible to stand on one leg) Rifle on back.
-Rifle from the back, change magazine, get to position on rolled up mat and build posture
-Shoot five shots with normal rhythm, focusing on holding and perfect shots
-Get out of position, rifle on back
-Small walk before next series

4. Slow shooting exercise 10x1 shots:
-Rifle on back
-Get to position, rifle from the back, change magazine, build posture
-Hold 10s on target with trigger on threshold, take a shot and continue hold for 10-15s without moving and breathing
-Get out of position, rifle on back
-Small break before next series

5. Fast shooting exercise 10-20x5 shots:

-Rifle on back

-Get to position fast, rifle from the back fast, change magazine fast, build posture fast

-Shoot five shots with fast rhythm and fast breathing, into the first sight picture

-Rifle on back fast, out of position

-Small walk or run before next series

6. Interval shooting exercise 10-20x5 shots:

-Rifle on back

-Get to position, rifle from the back, change magazine, build posture

-Shoot 1 to 5 shots with varying rhythm between shots:

*Slow, normal, fast, normal, slow

-Rifle on back, out of position

-Small walk before next series

Example for holding exercises 15 min = 10x 1-2 min:

-Take a good and relaxed, but firm standing shooting posture

-When holding exercise starts, shoot at first clear sight picture and reload

-No accurate aiming during holding

-Monitor breathing

-Keep the trigger force close to threshold during holding

APPENDIX 2. MANTIS (n = 8) and CONTROL (n = 8) group percentage changes in mean ± *SD* and median(*IQR*) values of pre-post shooting test variables.

	MANTIS			CONTROL		
Variable [unit]	Pre	Post	%	Pre	Post	%
RangePTS	182.8 ± 19.1	193.0 ± 15.5	**6**	184.9 ± 20.8	185.6 ± 22.5	0
	184.5(22.3)	192.5(12.8)	**4**	184.0(14.3)	181.0(31.0)	-2
LabPTS	175.3 ± 23.9	184.1 ± 19.5	**5**	186.9 ± 20.3	184.1 ± 32.6	-1
	171.5(35.5)	185.5(31.3)	**8**	190.0(27.5)	178.0(45.5)	-6
COG [mm]	32.9 ± 10.0	30.1 ± 11.7	-8	35.2 ± 19.1	33.5 ± 13.5	-5
	34.4(15.7)	27.2(12.2)	**-21**	27.0(20.5)	31.0(8.6)	**14**
COG2Hit[mm]	37.0 ± 9.1	33.5 ± 5.5	**-9**	39.2 ± 15.6	37.1 ± 14.5	-5
	36.6(9.1)	32.2(7.1)	**-12**	34(11.9)	33.8(5.5)	-1
$TIRE_6$ [index]	4.30 ± 0.5	4.34 ± 0.5	1	4.45 ± 0.7	4.47 ± 0.3	0
	4.3(0.4)	4.2(0.6)	-2	4.3(0.7)	4.5(0.4)	5
DevX [mm]	20.2 ± 4.5	17.1 ± 1.9	**-15**	19.4 ± 5.6	18.7 ± 4.2	-3
	18.5(4.5)	17.7(3.2)	**-4**	19.2(3.7)	18.8(3.2)	-2
DevY [mm]	18.6 ± 5.0	16.3 ± 2.7	**-12**	18.5 ± 6.3	18.4 ± 7.3	-1
	17.5(5.1)	15.5(4.2)	**-12**	17.5(4)	17.2(2.9)	-2
MV_{200} [mm/s]	277.7 ± 50.7	246.9 ± 39.8	**-11**	303 ± 98.5	282.5 ± 75.8	-7
	273.6(28.1)	237.1(49.5)	**-13**	268.6(76.7)	265.6(48.1)	-1
MV_{600} [mm/s]	284.6 ± 53.1	248.3 ± 24.8	**-13**	280 ± 60.3	280.8 ± 59.0	0
	282.8(41.7)	246.9(31.9)	**-13**	265.5(32.9)	274.1(42.1)	3
$Target_{2/3}$ [%]	52.8 ± 18.2	54.7 ± 20.8	**4**	54.5 ± 22.6	55.2 ± 19.1	1
	49.1(32.6)	57.6(27.1)	**17**	57.7(29.7)	58.5(13.5)	1
TF_{-1000} [%]	76 ± 16	78 ± 14	**2**	80 ± 10	74 ± 10	-7
	83(23)	81(15)	**-2**	83(12)	74(9)	-11
TF_{-600} [%]	82 ± 15	84 ± 11	**3**	86 ± 9	83 ± 10	-3
	87(21)	87(9)	**0**	89(5)	86(7)	-3
TF_{-200} [%]	87 ± 11	89 ± 10	**3**	91 ± 8	90 ± 11	-2
	89(14)	93(4)	**4**	94(6)	93(6)	-2
TF_{+200} [%]	63 ± 37	70 ± 39	10	68 ± 18	75 ± 25	9
	59(50)	77(54)	31	68(19)	83(15)	23
WD_F [%]	55.9 ± 5.8	55.7 ± 4.9	0	61.3 ± 5.7	61.3 ± 5.8	0
	57.8(7.6)	57.7(3.2)	0	60.6(3.8)	60.2(3.6)	-1
WD_R [%]	44.1 ± 5.8	44.3 ± 4.9	0	38.8 ± 5.7	38.7 ± 5.8	0
	42.2(7.6)	42.3(3.2)	0	39.4(3.8)	39.8(3.6)	1
SDX [mm]	0.80 ± 0.17	0.65 ± 0.14	**-18**	0.73 ± 0.18	0.73 ± 0.20	0
	0.80(0.22)	0.63(0.12)	**-21**	0.77(0.26)	0.77(0.25)	0
SDY [mm]	0.50 ± 0.10	0.47 ± 0.05	-7	0.55 ± 0.11	0.52 ± 0.14	-7
	0.47(0.08)	0.47(0.03)	0	0.56(0.17)	0.45(0.19)	-19

APPENDIX 2 (continued).

Variable [unit]	MANTIS Pre	MANTIS Post	%	CONTROL Pre	CONTROL Post	%
SDX_F [mm]	0.80 ± 0.12	0.67 ± 0.09	**-17**	0.68 ± 0.21	0.66 ± 0.22	-3
	0.81(0.18)	0.66(0.12)	**-19**	0.63(0.27)	0.69(0.39)	9
SDY_F [mm]	0.32 ± 0.16	0.22 ± 0.12	**-31**	0.23 ± 0.14	0.22 ± 0.12	-4
	0.28(0.23)	0.22(0.23)	**-21**	0.23(0.18)	0.20(0.13)	-13
SDX_R [mm]	0.85 ± 0.30	0.71 ± 0.30	**-17**	0.87 ± 0.25	0.89 ± 0.34	3
	0.78(0.21)	0.63(0.25)	**-20**	0.84(0.25)	0.79(0.32)	-6
SDY_R [mm]	0.17 ± 0.08	0.17 ± 0.09	-1	0.17 ± 0.11	0.17 ± 0.07	-1
	0.15(0.06)	0.15(0.10)	-1	0.15(0.11)	0.17(0.09)	14

RangePTS, range shooting score; LabPTS, lab shooting score; COG, mean aiming accuracy distance from center; $Target_{2/3}$, relative aiming accuracy distance from hit; $TIRE_6$, timing of triggering index; DevX, horizontal stability of hold; DevY, vertical stability of hold; MV_{200}, mean velocity 200 to 0 ms before triggering; MV_{600}, mean velocity 600 to 0 ms before triggering; COG2Hit, distance of hit point to aiming mean; TF_{-200} to TF_{-1000}, Trigger force 200 to 1000 ms before triggering; TF_{+200}, Trigger force 200 ms after triggering; WD_F, percentage weight on the front leg. Postural balance (standard deviation of the center of pressure location 600 to 0 ms before triggering) of the whole body in shooting (SDY) and cross-shooting (SDX) direction, and postural balance of each leg separately (F, front; R, rear).

APPENDIX 3. HighDT (n = 8) and LowDT (n = 8) group percentage changes in mean ± *SD* and median(*IQR*) values of pre-post shooting test variables.

	HighDT			**LowDT**		
Variable [unit]	Pre	Post	%	Pre	Post	%
RangePTS	187.8 ± 23.9	195.6 ± 22.5	4	179.9 ± 13.9	183.0 ± 13.4	2
	184.5(29.3)	195.5(29.3)	**6**	184.5(13.3)	185.5(23.8)	1
LabPTS	189.9 ± 16.4	195.4 ± 28.8	**3**	172.3 ± 24.7	172.9 ± 18.1	0
	192.0(20.5)	200.0(29.0)	**4**	162(34.5)	169.5(23.5)	5
COG [mm]	34.6 ± 18.3	32.3 ± 17	-6	33.6 ± 11.5	31.3 ± 6.3	-7
	27.0(18.9)	26.8(16.2)	-1	34.4(15.7)	31.2(9.2)	-9
COG2Hit [mm]	37.1 ± 16	35.4 ± 15	-5	39.0 ± 8.4	35.3 ± 4.9	**-10**
	31.4(11.0)	31.1(6.2)	-1	36.7(8.5)	34.7(4)	**-5**
$TIRE_6$ [index]	4.55 ± 0.7	4.53 ± 0.5	0	4.20 ± 0.5	4.28 ± 0.3	2
	4.1(1.1)	4.4(0.7)	7	4.3(0.4)	4.3(0.5)	-1
DevX [mm]	17.6 ± 3.3	16.7 ± 3	-5	21.9 ± 5.5	19.1 ± 3.3	**-13**
	17.7(2.9)	17.0(3.2)	-4	20.4(5.6)	18.6(1.8)	**-9**
DevY [mm]	17.6 ± 6.4	17.0 ± 7.5	-3	19.5 ± 4.6	17.7 ± 2.4	**-9**
	15.8(3.7)	15.0(4.0)	-5	19.7(4.4)	17.8(3.0)	**-10**
MV_{200} [mm/s]	267.8 ± 61.6	266.7 ± 77.4	0	312.8 ± 87.7	262.7 ± 45.2	**-16**
	259.8(38.7)	252.1(65.7)	-3	276.2(63.3)	254.2(40.9)	**-8**
MV_{600} [mm/s]	261.2 ± 40.3	257.9 ± 56.2	-1	303.4 ± 61.9	271.3 ± 38	**-11**
	265.5(33.3)	255.3(39.6)	-4	287.2(64.3)	265.0(36.7)	**-8**
$Target_{2/3}$ [%]	54.6 ± 23.2	56.6 ± 25.5	**4**	52.7 ± 17.5	53.2 ± 11.9	1
	57.7(31.8)	62.1(29.7)	**8**	49.1(32.0)	55.5(16.5)	13
TF_{-1000} [%]	78 ± 16	73 ± 15	-6	78 ± 9	78 ± 8	**0**
	84(18)	76(17)	-10	81(15)	79(13)	**-3**
TF_{-600} [%]	84 ± 15	80 ± 14	-5	83 ± 9	87 ± 5	**4**
	90(11)	85(15)	-5	86(14)	87(5)	**2**
TF_{-200} [%]	89 ± 12	86 ± 13	-3	89 ± 8	93 ± 4	**4**
	95(9)	92(11)	-3	89(11)	93(3)	**4**
TF_{+200} [%]	66 ± 20	65 ± 33	**-2**	66 ± 36	80 ± 31	**22**
	69(24)	78(46)	**14**	62(44)	87(32)	**40**
WD_F [%]	60.4 ± 7.70	59.7 ± 7.8	-1	56.7 ± 3.9	57.3 ± 3.5	1
	60.5(2.2)	59.4(4.6)	-2	56.1(5.4)	58.0(1.7)	3
WD_R [%]	39.6 ± 7.70	40.3 ± 7.8	1	43.3 ± 3.9	42.7 ± 3.5	-1
	39.5(2.2)	40.6(4.6)	3	43.9(5.4)	42.1(1.7)	-4
SDX [mm]	0.78 ± 0.14	0.67 ± 0.15	**-14**	0.76 ± 0.21	0.72 ± 0.19	-5
	0.78(0.23)	0.67(0.22)	**-14**	0.76(0.25)	0.64(0.22)	-16
SDY [mm]	0.54 ± 0.10	0.48 ± 0.12	**-10**	0.52 ± 0.11	0.50 ± 0.08	-4
	0.49(0.16)	0.45(0.09)	**-8**	0.48(0.13)	0.47(0.07)	-3

APPENDIX 3 (continued).

Variable [unit]	HighDT Pre	HighDT Post	%	LowDT Pre	LowDT Post	%
SDX_F [mm]	0.78 ± 0.17	0.64 ± 0.18	**-18**	0.70 ± 0.18	0.69 ± 0.16	-2
	0.77(0.16)	0.59(0.25)	**-23**	0.67(0.32)	0.69(0.20)	2
SDY_F [mm]	0.33 ± 0.14	0.29 ± 0.09	-13	0.22 ± 0.16	0.16 ± 0.10	**-30**
	0.30(0.12)	0.29(0.15)	-1	0.16(0.18)	0.11(0.12)	**-31**
SDX_R [mm]	0.85 ± 0.21	0.79 ± 0.29	-7	0.87 ± 0.33	0.82 ± 0.37	-6
	0.84(0.18)	0.76(0.25)	-10	0.78(0.26)	0.67(0.33)	-14
SDY_R [mm]	0.20 ± 0.12	0.19 ± 0.08	**-5**	0.15 ± 0.04	0.15 ± 0.08	4
	0.15(0.21)	0.17(0.09)	**18**	0.15(0.05)	0.14(0.09)	-5

RangePTS, range shooting score; LabPTS, lab shooting score; COG, mean aiming accuracy distance from center; $Target_{2/3}$, relative aiming accuracy distance from hit; $TIRE_6$, timing of triggering index; DevX, horizontal stability of hold; DevY, vertical stability of hold; MV_{200}, mean velocity 200 to 0 ms before triggering; MV_{600}, mean velocity 600 to 0 ms before triggering; COG2Hit, distance of hit point to aiming mean; TF_{-200} to TF_{-1000}, Trigger force 200 to 1000 ms before triggering; TF_{+200}, Trigger force 200 ms after triggering; WD_F, percentage weight on the front leg. Postural balance (standard deviation of the center of pressure location 600 to 0 ms before triggering) of the whole body in shooting (SDY) and cross-shooting (SDX) direction, and postural balance of each leg separately (F, front; R, rear).