RELATIONSHIPS BETWEEN TECHNICAL AND PHYSICAL CHARACTERISTICS IN AIR RIFLE SHOOTING AND CHANGES IN SHOOTING PERFORMANCE OVER A PROLONGED SHOOTING SESSION

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Coaching and Testing Master`s Thesis
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Autumn 2023

TIIVISTELMÄ

Wedman, Pasi 2023. Teknisten ja fyysisten ominaisuuksien yhteydet ilmakivääriammunnassa ja muutokset ampumasuorituksessa ylipitkän ampumasuorituksen aikana. Valmennus- ja testausopin Pro gradu -tutkielma. Jyväskylän yliopisto. Liikuntabiologian laitos. 39 s.

Tämän tutkimuksen tarkoituksena oli selvittää, onko ampujan maksimaalisella hapenottokyvyllä ja maksimaalisella isometrisellä voimalla merkitsevää korrelaatiota heidän ampumatekniseen suoritukseensa: osumaan, tähtäyspisteen liikkeeseen ja tasapainoon. Tutkimuksella pyrittiin myös selvittämään, onko eri ryhmien väleillä eroja edellä mainittujen muuttujien suhteen. Lopuksi pyrittiin myös selvittämään, aiheuttaako ylipitkä ampumasuoritus havaittavia muutoksia mitatuissa muuttujissa.

Tämän tutkimuksen osallistujat rekrytoitiin Suomen ampumaurheiluliiton kiväärimaajoukkue ampujista: Miehet ($n = 5$, ikä $36{,}5 \pm 8{,}0$), naiset ($n = 5$, ikä $27{,}2 \pm 2{,}4$), juniori miehet ($n = 8$, ikä $18{,}6 \pm 1{,}1$) ja juniori naiset ($n = 6$, ikä $17{,}7 \pm 1{,}0$). Mittauksiin kuului ampumatekninen suoritus analyysi, maksimaaliset isometriset voimamittaukset ja polkupyöräegometri testi (VO2max). Pituus ja paino mitattiin kaikilta osallistujilta. Ampumateknisessä suoritusanalyysissä jokainen ampuja ampui ampumalaboratoriossa ylipitkän ampumasarjan (120 laukausta). Ampujat ampuivat laukaukset minuutin välein. Ampumamittauksiin kuului ampumatekninen analyysi, ampujan tasapainomittaus, VAS-jana kysely subjektiivisesta väsymyksen ja puutumisen tunteesta joka 20 laukaus. Ampumatekniikkaa analysoitiin käyttämällä kolmea muuttujaa: Osuma (laukauksen tulos), aseen pito horisontaalisessa (DevX) ja vertikaalisessa (DevY) suunnassa. Tasapaino mitattiin keskimääräisenä liikkeen nopeutena painon keskipisteestä anteroposterorisessa ((VelX) ja mediolateraalisessa (VelY) suunnassa, sekä vauhtimomenttina (VM) 3-0 sekuntia ennen laukausta. Maksimaaliset isometriset mittaukset tehtiin määrittämään osallistujien maksimaalinen isometrinen voima: vartalon ojennus ja koukistus, jalkojen ojennus, hauiskääntö, penkkipunnerrus ja puristusvoimat. Lopuksi jokainen osallistuja suoritti maksimaalisen polkupyöräergometri testin maksimaalisen hapenoton määrittämiseksi. Kaikki testit tehtiin samana päivänä/osallistuja.

Tulosten mukaan tähtäyspisteen liikkeellä ja osumalla oli merkitsevä korrelaatio: DevX, ($\rho = -.738$, $p<0.001$) ja devY, ($\rho = -.686$, $p<0.001$). Merkitsevä korrelaatio oli myös osumalla ja kaikilla kolmella tasapainomuuttujalla: VelX ($\rho=-.689$, $p<0.001$), VelY ($\rho=-.700$, $p<0.001$) ja VM ($\rho= -.623$, $p<0.001$. DevX korreloi merkitsevästi kaikkien tasapainomuuttujien kanssa: VelX ($\rho=.674$, $p<0.05$), VelY ($\rho=.465$, $p<0.05$) ja VM ($\rho=.703$, $p<0.001$). Tähtäyspisteen liikkeen muuttuja DevY korreloi myös merkitsevästi kaikkien tasapainomuuttujien kanssa: VelX ($\rho=.561$, $p<0.05$), VelY ($\rho=.439$, $p<0.05$) ja VM ($\rho=.503$, $p<0.05$). Tasapainomuuttuja VelX korreloi merkitsevästi kolmen maksimaalisen isometrisen voimamuuttujan kanssa (oikean- ja vasemman käden puristusvoima ja penkkipunnerrus), sekä VO2 max:in kanssa. Subjektiivinen arvio puutumisesta korreloi tasapainomuuttujien VelY ja VM kanssa. Osuman ja maksimaalisten isometristen voimamuuttujien ja VO2max:in välillä ei ollut korrelaatiota.Ylipitkä ampumasuoritus ei aiheuttanut merkitseviä muutoksia mitatuissa muuttujissa. Regressioanalyysin tulosten mukaan DevX selitti ampumatuloksen vaihtelusta 59 prosenttia.

Tämän tutkimuksen tulokset osoittavat ampumatekniikka-analyysin tärkeyden ampujan suorituksen ymmärtämisessä ja analysoinnissa. On ratkaisevan tärkeää mitata ampujan teknikkaa siihen tarkoitukseen suunnitelluilla luotettavilla laitteilla, laitteistoilla ja mittausmetodeilla. Tämän tutkimuksen tulokset tulisi rohkaista valmentajia ja urheilijoita ottamaan huomioon fyysisten ominaisuuksien, fyysisen harjoittelun ja lämmittelymetodien merkitykset ampumasuoritukseen.

Avainsanat: ampumatekniikka, aseen pito, tasapaino, fyysiset ominaisuudet

ABSTRACT

Wedman, Pasi. 2023. Relationships between technical and physical characteristics in air rifle shooting and changes in shooting performance over a prolonged shooting session. Coaching and Testing Master`s Thesis. University of Jyväskylä. Faculty of Sport and Health Sciences. 39 p.

The aim of this study was to research if there is a significant correlation between shooters' maximal oxygen uptake and maximal isometric power with their shooting performance level: hit, aim point fluctuation, and balance. The study also investigated group differences in shooting technique performance. And finally, are there observable chances with measured variables in shooting performance caused by prolonged series?

Participants of this study were rifle shooters, recruited from a Finnish national rifle team: male (n = 5, age 36,5 ± 8,0), female (n = 5, age 27,2 ± 2,4), junior male (n = 8, age 18,6 ± 1,1) and junior female (n = 6, age 17,7 ± 1,0). Measurements included shooting technique analysis, maximal isometric measurements, and cycle ergometry (VO2max). Weight and height were measured from all the subjects. In shooting technique analysis each shooter shot in a shooting laboratory a prolonged series of shots (120 Shots). Shooters fired the shots at one-minute intervals. The shooting session measurements included shooting technique analysis, shooters' postural balance measurements, and filling VAS-line questionnaire of subjective feelings of fatigue and numbness of muscles with every 20 shots. Three variables were used to analyse the shooting technique to identify the chances of the barrel hold and the shot score during the test: Hit (score of the shot), horizontal stability of hold (DevX) and vertical stability of hold (DeVY). Postural balance was measured as the mean speed of movement in the center of the pressure in anteroposterior (VelX) and mediolateral (VelY) direction and as velocity moment (VM) during the time period 3-0 s before the shot. Maximal isometric measurements were carried out to determine the subject's maximal isometric power: Body flexion and extension, leg extension, biceps curl, bench press, and grip strength. Finally, each subject carried out a maximal cycle ergometer test to determine VO2 max. All the tests were carried out in one day/subject.

The results pointed out there a was significant correlation between aim point fluctuation and score: DevX, (ρ= -.738, $p<0.001$) and devY, (ρ= -.686, $p<0.001$). There was also a significant correlation between Hit and all three balance variables VelX (ρ=-.689, $p<0.001$), VelY (ρ=-.700, $p<0.001$), and VM (ρ= -.623, $p<0.001$. Aim point fluctuation value DevX correlated significantly with all balance values VelX (ρ=.674, $p<0.05$), VelY (ρ=.465, $p<0.05$), and VM (ρ=.703, $p<0.001$). Aim point fluctuation value DevY correlated significantly with all balance values VelX (ρ=.561, $p<0.05$), VelY (ρ=.439, $p<0.05$), and VM (ρ=.503, $p<0.05$). Balance variable VelY correlated with three maximal isometric power variables (grip strength right and left and bench press) and VO2 max. Experienced physiological numbness correlated with balance values VelY and VM. There was no correlation between Hit and any measured maximal isometric power value or VO2 max. There were no significant changes with measured variables in shooting performance caused by prolonged series. The stepwise multiple regression analysis revealed that DevX as an independent variable accounted for 59% of the variance in the shooting score.

The results of this study point out the practical meaning of shooting technique analysis relevance for understanding and analyzing the shooters' performance. Measuring shooters' techniques with reliable devices designed for shooting technique analysis is crucial. This study should also encourage coaches and athletes to consider the meaning of physical characteristics, physical training, and warm-up methods for shooting performance.

Keywords: shooting technique, stability of hold, postural balance, physical characteristics.

ABBREVIATIONS

Hit	Score of the shot
DevX	Aim point fluctuation in the horizontal direction (ring)
DevY	Aim point fluctuation in the vertical direction (ring)
VelX	Mean speed of movement of the center of the pressure in the anteroposterior direction (mm/s)
VelY	Mean speed of movement of the center of the pressure in the mediolateral direction (mm/s)
VM	Average horizontal area covered by the movement of the center (VelX) and VelY) the direction of force per second (mm^2/s)
VAS	Visual analogue scale
VASFatigue Sum	Sum of subjective feelings of fatigue during shooting serie
VASFatigue Avg	Average of subjective feeling of fatigue during shooting serie
VASNumb Sum	Sum of subjective feeling of numbness during shooting serie
VASNumb Avg	Average of subjective feeling of numbness during shooting serie
VO2max	Maximal oxygen uptake

CONTENTS

1 INTRODUCTION

Air rifle shooting is an Olympic event, in which 60 shots are fired in the free-standing position. The target is 10 meters away from the shooter and has a ten ring of 0,5 mm diameter. Lower rings are 2,5 mm. The competition (qualification) must be completed in 75 minutes. Since 2018 both men and women have fired the same number of shots (women had previously 40 shots). Every hit is announced by one decimal accuracy, where the best possible shot is 10,9. The world record is 635,4 for men and 635,3 for women. (ISSF Rules and Regulations, 2023). The best shooters can hit the ten-ring with every shot in the competition.

It is necessary to achieve very high precision of technical elements of the shooting performance. There have been many studies concerning the technical elements of the shooting technique. Minimal movement of the gun barrel during the aiming phase is one of the important things for successful performance (Zatsiorsky & Aktov 1990; Konttinen et al., 1998; Ball et al., 2003; Mononen et al. 2003). Ten-ring shot is possible when the angular movement of the weapon is less than 0.016° (Zatsiorsky & Aktov 1990). Experienced shooters have been shown to be able to keep their rifles more stable during the aiming phase compared to inexperienced shooters (Viitasalo et al. 1999). The rifle hold stability has also been shown to discriminate high-score and low-score shots both among inexperienced and experienced rifle shooters (Konttinen et al.1998; Mononen et al. 2003). The holding ability in the horizontal direction has been seen to explain 54% of the variance in shooting score, (Ihalainen et al. 2016), and horizontal holding ability has the strongest relation to the changes in shooting score (Ihalainen et al. 2018).

Among the gun barrel stability, the body balance and ability to control body sway during the shooting performance have been found important things in shooting performance. This has been noticed in studies and, also among athletes and coaches. Experienced shooters have been found to produce smaller body sway amplitudes, than the general population and inexperienced shooters (Aalto et al. 1990; Era et al. 1996; Niinimaa & McAvoy 1983). The body sway amplitudes have been shown to be smaller for highly skilled rifle shooters during normal standing positions and shooting positions compared with inexperienced shooters (Aalto et al. 1990; Era et al. 1996)). Postural balance has a direct influence on shooting score and an indirect influence because of better stability of rifle hold (Ihalainen et al. 2016).

The advantages of a good physical condition for shooting performance are well recognized among athletes and coaches: shorter recovery time, longer intervals between heartbeats, transport of oxygen to and the waste products from the muscle is more efficient, the replenishment of gases and nutrients in the cells is much faster. Improvement in oxygen supply to the brain results in greater coolness and mental strength. The trained body has better chances because it functions with considerably more efficiency. (Reinkemeier et al. 2006) Despite the knowledge of the advantages of good physical fitness, studies of the relationship between physical fitness and shooting performance are not made in the author's knowledge. The aim of this study was to research if there is a significant correlation between shooters' VO2 max and maximal isometric power with their shooting performance level: hit, aim point fluctuation, and balance. The study also investigated that if there are significant group differences (male, female, junior male, junior female) with shooting technique performance, hit, aim point fluctuation, and balance. And finally, are there observable chances with measured variables in shooting performance caused by prolonged series, and if there is, is it explainable by some of the physical character?

2 PHYSICAL REQUIREMENTS OF SHOOTING PERFORMANCE

2.1 Physical fitness profile of shooters

In shooting sports, there are people of different physical builds and conditions: tall, short, slim, bulky, strong, and weak; with well- and poorly-developed lung function. Perfect physical condition is not a great advantage on its own. Technical skills such as holding, aiming, and trigger release play the most important part in the result. The athlete’s all-round condition begins to play a bigger role when he or she attempts to enter the high-performance arena. Between two shooters on the same technical level, the fitter has a significant advantage: the heart beats more slowly, recovers faster, the athlete has greater reserves to draw on, and is slower to enter the fatigue zone. (Reinkemeier et al. 2006)

2.2 Strength

Air rifle shooter does not have to be especially strong. A more proper term for a rifle shooter's strength would be local muscle endurance. The air rifle weight is no more than 5,5 kg. It is supported by the left forearm (right-handed) and usually is only lifted a few inches from the support tripod. There still are a few areas where the shooter really needs strength. When a well-trained athlete shoots a 40-shot competition the very first time, he could have expected to experience muscle stiffness afterward in the lumbar region. This is because the displacement of the torso away from the target and over the heels is unnatural. Muscle stiffness can also be experienced in the left hand because it takes time to adapt to the right way of using the fingers as a support. And in the right hand, because the need for a precise grip and release calls for special coordination. (Reinkemeier et al. 2006)

2.3 Endurance

Shooting in the standing position is a light physical performance. It is comparable to a brisk walk. If the workload increases, because the shooting range is warm or the nerves are in turmoil, the trained body has many advantages, while the weaker is already reaching its limits. There are extreme short-term stress situations that can occur on critical shots. For example, the last shot or bad shot or one that the athlete only just managed to “rescue”. In the final shooting, the athlete has many situations when a shooter must shoot the shots in a limited time. In those kinds of situations, the trained body has a better chance because it functions with considerably more efficiency. In a weaker body, the short interval between heartbeats makes trigger release successfully between heartbeats very difficult. This significantly increases the risk of a bad shot. (Reinkemeier et al. 2006)

One advantage of fitness is the shorter recovery time. The transport of oxygen to and the waste products from the muscle is more efficient, and the replenishment of gases and nutrients in the cells is much faster. Stress hormones and waste products are expelled faster. When a shooter recovers faster it helps the athlete during competition. If the athlete is not in good physical condition, steadiness reduces as the muscles tire, perception, and concentration vanish and the brain loses its sharpness. Endurance training can improve an athlete’s “nerves”, although the mental skills have in no way been improved. Simply the improvement in oxygen supply to the brain results in greater coolness and mental strength. Every shooter uses much more energy in a match because of longer aims, they interrupt the shot more often and sweat more. Also, the mental turmoil increases steadily the more successful the shooter becomes. (Reinkemeier et al. 2006)

2.4 Special condition

The trained state reached through repetition of such specific loadings is known as a *special condition* because this work in this combination and intensity can only be trained by shooting in the standing position. A special condition is acquired by actual shooting. The repeated demands on specific muscle groups cause the necessary adaptations to this performance task. Even top-level shooters who have not been shooting for a couple of months will notice how quickly certain muscle groups lose their condition because they are not loaded in the same way during everyday life. (Reinkemeier et al. 2006)

When a shooter takes a shooting position, the shooter's reserve of strength has a big role. For example, weak stomach muscles can lead the shooter to lean further back, using the tendons to do the stabilizing work. This can lead to a bendy “banana” position, and this can cause major body sway. In this kind of position, the lumbar spine is heavily loaded and increases the danger of back pain and future spinal injuries. (Reinkmeier et al. 2006)

3 SKILL REQUIREMENTS OF SHOOTING PERFORMANCE

Elite shooters have a high degree of movement precision. In air rifle shooting from a standing position at a distance of 10 m, the center of the target ("ten"), is 1 mm in diameter and the bullet's diameter is 4,5 mm. If aiming accuracy is counted with angular errors, a hit of ten demands a rifle hold which is inside 0.016 degrees. (Zatsiorsky & Aktov 1990)

3.1 Postural balance

A good postural balance is a very important component of a successful shooting performance according to shooting coaches and athletes. Elite shooters have been found to produce smaller body sway amplitudes than the general population, as indicated by the center of the pressure movement. Experienced shooters' body sway has also been found smaller than their less experienced counterparts. This can be seen in shooting and normal standing positions. (Aalto et al., 1990; Niinimaa & McAvoy 1983; Era et al. 1996)

Elite shooters produce the center of the pressure ranges of less than 1 mm in the last 2-4 s before the shot event (Viitasalo et al. 1999). Inexperienced rifle shooters produce significantly worse postural balance during less successful than successful shots (Era et al. 1996). This kind of association has not been found among top-level shooters (Era et al. 1996; Ball et al. 2003a). The elite-level athletes can decrease the amount of postural sway in the anteroposterior direction during the last second before the shot. This can be in relation to the more stable holding ability of elite-level shooters. Postural balance has a direct influence on shooting score and an indirect influence on score through better stability of hold. (Ihalainen et al. 2016)

3.2 Stability of hold

One of the important things for a shooter's successful performance is minimal movement of the gun barrel during the aiming phase (Zatsiorsky & Aktov 1990; Konttinen et al. 1998; Ball et al. 2003b; Mononen et al. 2003). Experienced shooters have been shown to be able to keep their rifles more stable during the aiming period compared to inexperienced shooters (Viitasalo et al. 1999). The aiming point stability also discriminates between high-score and low-score shots among inexperienced and experienced rifle shooters (Konttinen et al. 1998; Mononen et al. 2003). The holding ability in the horizontal direction explains 54% of the variance in shooting scores (Ihalainen et al. 2016).

The difference in the shooting score from training to competition situation is related to the changes in horizontal stability of hold, accuracy of aiming, and cleanness of triggering. Horizontal stability of hold is the technical component that has the strongest relation to the changes in shooting score. (Ihalainen et al. 2018)

4 SPECIAL CONSIDERATIONS OF AIR RIFLE SHOOTING

4.1 Triggering and cardiac cycle

It is assumed that experienced shooters can control their triggering timing in a specific phase of the cardiac cycle to avoid the body movement caused by heart contraction (Konttinen et al.2003). Helin et al. (1987) examined elite rifle and pistol shooters and inexperienced rifle shooters in terms of the timing of the triggering pull in relation to the cardiac cycle. The results pointed out that elite shooters were triggered late in cardiac cycles, during the diastole phase. Inexperienced shooters are triggered either during the systolic or diastolic phase. Inexperienced shooters achieved better shooting scores when they triggered during diastole relative to systole. Those results suggest that the best time to pull the trigger is the resting (diastolic) phase of the cardiac cycle. The critical factor is the mechanical movement associated with heart contraction. That movement may interfere with the shooter’s attempt to hold a rifle position during the aiming phase. A study by Konttinen et al. (2003) also suggested that in air rifle shooting the optimum firing time within the cardiac cycle may located in the systolic phase. Mets et al. (2006) found that junior-level shooters fired more often during the phase of 10-15 % of the R wave-to-R wave (R-R) interval. There was not any optimal location for triggering the cardiac cycle, with regards to the accuracy of performance.

4.2 Preparatory heart rate patterns

Konttinen et al. (1998) examined the relationship between competitive shooting performance and preparatory heart rate patterns. Cardiac activity was recorded from six elite and six non-elite male rifle shooters during the 6 seconds before the trigger pull. The shooting performance analysis was based on three variables: shooting score, rifle stability, and electromyographic activity in the upper body. In the pre-trigger heart rate, each shooter’s heart rate decreased. The amount of this change was smaller for the elite shooters compared to non-elite shooters. This suggests that the heart rate patterns reflected skill-related aspects of preparatory performance. The analyses of rifle-hold performance suggested that the shooter's attempts to achieve a stable rifle position were associated with observed heart rate changes. This was seen to be dependent on the shooter's skill level. Interpretation of preparatory heart rate patterns in competitive rifle shooting should not be based only on the attentional focusing aspect. It should also consider the effects of a shooter's psychomotor regulation. (Konttinen et al. 1998)

4.3 Breathing

Breathing plays an important part in the shooting position. This is because the upper body is a major building block and is constantly deformed by the lifting and stretching of the ribcage as the lungs are filled. During exhalation, the volume reduces by several liters. This is causing the rifle to sink. It is necessary, that the shooter pause his breathing after exhalation to create a quiet phase where he can aim and fire the shot. At this point, the muscles of the chest are in a relaxed state. The body’s center of gravity is lower when the lungs are empty. The heart beats more slowly the longer the breathing pause becomes because it has more space and automatically beats with reduced frequency after every exhalation. Especially in competition an experienced shooter will use breathing to slow down the beating of the heart during the holding phase. This is the most direct method of calming the inner position and causing the rifle to stop moving. (Reinkemeier et al. 2006)

4.4 Heart rate and blood pressure

Shooting implies both physical and psychological stress. Cardiovascular adaptation during shooting competition was studied with six healthy male athletes, during the Italian National Dynamic Pistol Shooting Championship. ECG and blood pressure (BP) were measured along the competition. The mean heart rate (HR) was close to 100 bpm in all except one shooter. In four shooters was recorded marked tachycardia, above 180 beats per minute. For two athletes the heart rate reached about 200 bpm, for the occurrence of paroxysmal atrial arrhythmias. BP varied among the six shooters with mean systolic values ranging between 140 and 170 mmHg. Maximal systolic values varied between 160 and 240 mmHg. Action Pistol Shooting induces acute elevation of HR and BP, which may reach abnormal values. This can be associated with impaired performance and scores. (Fenici et al. 1999)

The optimal heart rate for each individual shooter varies. The average heart rate (HR) in a study for the shooters before the shot was approximately 73 bpm. During shooting it increased 13 bpm. HR increases in cardiac requirements because of the arousal level of the shooter. Those shooters scored the worst whose HR dropped below the resting zone or increased more than 50 beats above the resting zone during the shooting period. Shooters whose HR increased between 8 and 50 beats scored the best. The research showed that there was a relationship between HR and performance optimized at an HR of approximately 93, which was the best indicator of shooting performance. Shooters perform better when heart rate elevates to an optimal level. (Edwards 1999)

5 EFFECTS OF FATIGUE TO THE SKILL PERFORMANCE

Yaggie et al. (2004) showed that after subjective fatigue of specified ankle muscles gastrocnemius and soleus affected to balance control. The center of balance shifted anteriorly and mediolateral sway during unilateral stance increased. Fatigue significantly influenced sway parameters and ranges of postural control. These changes were transient, and recovery occurred within 20 minutes.

Noda et al. (2007) examined the influence of fatigue in the lower leg muscles on the center of the pressure sway during a static upright posture. Significant differences were observed in unit time sway, front-back sway, and high-frequency band power spectrum immediately after exercise. These values returned to baseline levels 5 min after fatiguing exercise.

The study in water polo was to assess the effects of fatigue on decision-making and goal-shooting skills. Fourteen junior elite male players completed four sets of eight repetitions of an approximately 18 s maximal water polo-specific drill. Progressively declining rest ratios for each successive set of the drill were employed to induce increasing fatigue. After each set was performed a video-based temporally occluded decision-making task or goal-shooting skill test. A decision-making accuracy was 18.0 ± 21.8% better at very high fatigue than at low fatigue. Fatigue did not affect shooting accuracy and velocity. Skill technique was decreased by 43 ± 24% between the pre-test and high-fatigue conditions. Increases in fatigue can be seen to improve decision-making but technical performance declines. (Royal et al. 2006)

6 AIM, THESIS QUESTIONS AND HYPOTHESIS

The aim of this study was to research if there is a significant correlation between a shooter's VO2 max and maximal isometric power with their shooting performance level: hit, aim point fluctuation, and balance. The study was also investigated that is there significant group differences (male, female, junior male, junior female) with shooting technique performance, hit, aim point fluctuation, and balance. And finally, are there observable chances with measured variables in shooting performance caused by prolonged series?

Thesis questions:

1. Is there a significant correlation between shooters' VO2 max and maximal isometric power with their shooting performance level: hit, aim point fluctuation, and balance?

2. Are there significant group differences with shooting technique performance, hit, aim point fluctuation, and balance?

3. Are there observable chances with measured variables in shooting performance caused by prolonged series?

Hypothesis:

1. Athletes with better physiological characteristics have better results in terms of hit, aim point fluctuation, and balance, because the fitter athletes have significant advantages with greater physiological reserves to perform the shooting performance. (Reinkmeier et al. 2004)
2. There are significant group differences in shooting technique performance, hit, aim point fluctuation, and balance, because elite shooters have been found to perform better in terms of aim point fluctuation (Viitasalo et al. 1999) and balance (Niinimaa & McAvoy 1983; Era et. al.1996), compared to novice counterparts.
3. Prolonged series will cause observable chances with measured variables to shooting performance, because of muscular fatigue (Yaggie et al. 2004; Noda et al. 2007) in certain muscle groups used in shooting performance.

7 METHODS

7.1 Participants

Participants of this study were recruited from Finnish National Team rifle shooters (table 1). Male (n=5) and female (n=6) group shooters had been training for more than ten years goal-directed and they all had years of national and international competition experience. Junior males (n=8) and junior females (n=6) had been training few years goal-directed and they were national-level shooters and just starting their international careers.

TABLE 1. Participants of the study. Mean and standard deviation (in parentheses) values of subjects' height, weight, and age.

	Height (cm)	Weight (kg)	Age (yrs.)
Male	179,80 (7,05)	81,32 (8,45)	36,40 (8,02)
Female	169,20 (4,76)	71,64 (17,38)	27,20 (2,39)
Junior male	177,63 (4,50)	70,43 (10,59)	18,63 (1,06)
Junior female	166,17 (5,60)	64,33 (14,29)	17,83 (0,98)

7.2 Measurements

Before the measurements, subjects were asked to fill out the questionnaire concerning health and training status and sign an agreement to the test. The measurements are presented here in the order they were carried out for all the subjects on the measurement day. Measurements were carried out in one day per subject, a maximum of two subjects per day. All measurements were carried out in autumn 2007.

Measurements were carried out in the following order:
1. Shooting technique analysis
2. Maximal isometric measurements
3. Cycle ergometry (VO2 max)

After the first and second measurements subjects had a 30-minute break, and they ingested light snacks with juice or water.

7.3 Shooting Technique Analysis

In shooting technique analysis each shooter shot in a shooting laboratory a prolonged series of shots (120 Shots). Normally in competitions men, junior men, women, and junior women shoot 60 shots (before the year 2018, and female and junior female shot 40 shots). Shooters shot the shots with one-minute intervals. A minute interval between the shots was chosen because of its clarity and it can be seen as quite an average interval among shooters in competitions.
Shooting laboratory (figure 1) measurements lasted 2,5-3 hours including preparations. The measurements included shooting technique analysis, shooters' postural balance measurements, filling VAS-line questionnaire of subjective feelings of fatigue and numbness of muscles with every 20 shots and heart rate monitoring. The shooting analysis was conducted with a Noptel ST 2000 (Noptel Oy, Oulu, Finland) optoelectronic device. The Noptel measuring device consisted of an optical transmitter-receiver unit attached under the barrel of the rifle and a reflector attached around the center of the air rifle shooting target. The optical unit connected to a computer for data storage, analysis and visualization. Hit point and aiming point trajectory recorded at 100 Hz sampling rate and 0.1 mm accuracy. Shot score Hit and aiming point trajectory variables analyzed from the aiming point trajectory data of each shot with Noptel software (NOS4 version 4.208).

Three variables were used to analyze shooting technique to identify the chances of the barrel hold and the shot score during the test: hit (score of the shot), horizontal stability of hold (DevX) and vertical stability of hold (DeVY). Hit described the score of the shot. The shot score was shown in one decimal accuracy. Horizontal stability of hold described the barrel movement on the horizontal direction of the barrel on the target. Vertical stability of hold described the barrel movement of the vertical direction on the target. The shot’s score was shown for shooter by the monitor on the table in front of the shooter.

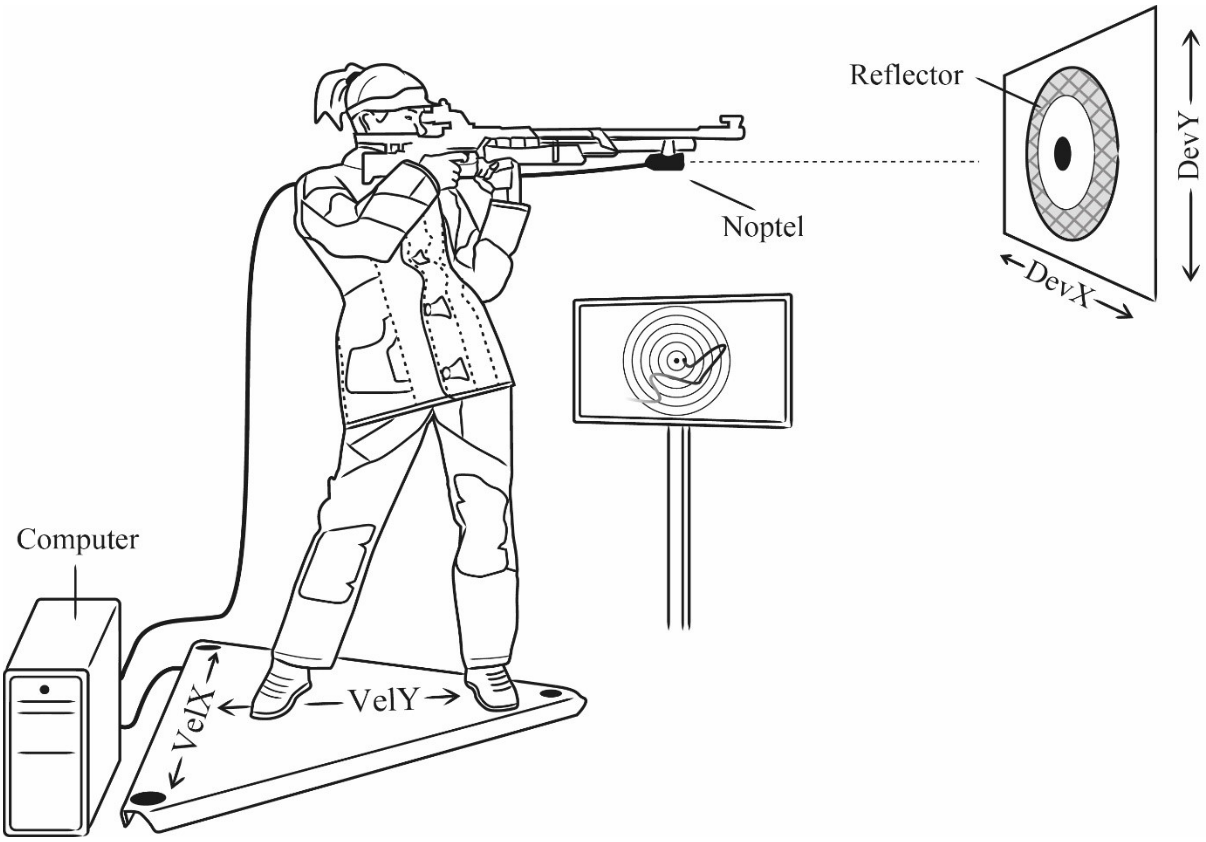

FIGURE 1 Measurement set-up in air rifle shooting test. (Modified Ihalainen 2018)

Postural balance was measured as the mean speed of movement in the center of the pressure in anteroposterior (VelX) and mediolateral (VelY) direction during a time period 3-0 s before the shot. Participants fired the shots standing on a triangular-shaped (1175 mm × 1175 mm × 1175 mm) force platform (Good Balance, Metitur Ltd., Jyväskylä, Finland). The force platform was equipped with strain-gauge transducers in each corner of the force platform. The signals were amplified and collected at 200 Hz with a 16-bit A/D-converter (National Instruments Co., Austin, Texas, USA) and stored on a personal computer hard drive for further analysis. Shot moment identified from the balance data based on microphone data collected synchronously with the same A/D converter. Center of Pressure (COP) coordinate data filtered with fourth-order zero-phase lag digital low pass filter with 10 Hz cutoff frequency. (Ihalainen, 2018)

Shooters were also asked to fill Visual Analogue Scale (VAS) to examine subjects' subjective feelings of fatigue and numbness of muscles with every 20 shots. The same questionnaire was also asked in which muscles they felt fatigue and numbness. This study used VAS (line) which was a straight horizontal line of fixed length and 100 mm wide. The subject marked on the line the point that they feel represents their perception of their current state. The VAS line was orientated from left (no fatigue, no numbness) to right (extreme fatigue, extreme numbness). Variables describing shooting performance and postural balance are in table 2.

Before the test started the test protocol was explained to the shooter. Noptel was fixed under the rifle barrel. After this shooter dressed up in shooting shoes, jacket, and trousers, stepped on the balance plate, and took the rifle ready for shooting. All shooters used their own air rifles and shooting equipment during the shooting test. Subjects were asked to make dry firing (exercise shots) and practice the timing of the shots (one-minute intervals). Subjects were guided to make timing for shots with the clock that was placed upper side of the target for the shooter easily to see. Preparation for each shot had to start in time so the shot could be released at the right time, with one-minute intervals. At the dry firing phase, the measures made sure of the appropriate functioning of Noptel and the force plate. When the shooter, set up, and measures were ready, the test began and stopped when 120 shots were performed.

TABLE 2. Variables describing shooting performance and postural balance.

Component	Variable	Description	Unit
Overall performance	Hit	Score of the shot.	points
Stability of hold	DevX DevY	Horizontal and vertical standard deviations of the location of the aiming point during the last 3 s. Smaller values indicate better holding ability.	ring
Postural balance	VelX VelY	Mean speed of movement of the center of the pressure in the antero posterior (VelX) and mediolateral (VelY) direction.	mm/s
	VM	Average horizontal area covered by movement of the center (VelX) and VelY direction) of force per second. Smaller values indicate more stable postural balance.	mm²/s

7.4 Maximal isometric measurements

Maximal isometric measurements were submitted in the Coaching and Testing laboratory at Jyväskylä University. Subjects' height and weight were measured before the maximal isometric measurements. Each test was conducted three times to determine the subject's maximal isometric power. The fourth trial was committed if the power was rising between the second and third trials. The highest power was considered for each test for each subject. Subjects warmed up on a bicycle ergometer for 5 minutes. Before every test subject rehearsed the isometric contraction with set-up in question. Rehearsing was made with submaximal levels of force. Subjects were instructed to perform the contractions of every test with maximal effort as hard as possible for 3 seconds. The rest between the contractions was 1 minute. Joint angles were adjusted with an angle meter before the trials. Measurements lasted approximately 45 minutes/subject including preparations.

Bilateral leg extension isometric force was measured on a knee extension bench (David 200, David Sports Itd, Finland). The knee extension bench was adjusted in a sitting position with a knee joint angle of 107 degrees. Forearm bilateral maximal isometric flexion (m. biceps brachii) was made in a sitting position with a 90-degree elbow ankle in a biceps curl bench. Bench press, forearm bilateral maximal extension, was made in a sitting position with a 90-degree elbow ankle with a modified David 200 dynamometer. Maximal isometric grip strength tests from both hands were made with a special grip strength dynamometer. Subjects were advised to adjust the grip to the optimal position to produce the best strength result. Body flexion and extension were made with a body dynamometer. The subject was connected to the dynamometer in a standing position from the hip and upper body. The subject produced maximal strength against the upper body connection in both tests. Test results were monitored and stored on the computer.

Measurements were carried out in the following order:

1. leg extension in leg dynamometer (107 knee ankle).
2. biceps flexion (90-degree elbow ankle).
3. bench press (90-degree elbow ankle, sitting position).
4. grip strength (both hands).
5. Body flexion and extension (body dynamometer).

7.5 Cycle ergometry (VO2max)

Maximal oxygen consumption VO2 max (ml/kg/min) was measured with a graded maximal bicycle ergometer test with gas exchange analysis. The test was performed with Monark 839 E bicycle ergometer (Monark Oy, Sweden). Gas exchange analysis was made with Vmax 229 – analyze system (Sensor Medics). Subjects were advised to keep a pedaling rate above 50 repetitions/minute and they were advised to give maximum effort for the test. Subjects warmed up on the bicycle 5-10 minutes before the test at low intensity. The initial workload was 50 watts for every subject and each grade of the test lasted 2 minutes. The workload increased by 20 watts in each grade. The test ended with a decrease in heart rate, VO2 max, the subject´s request to stop, or inability to maintain the pedaling rate. Rating of perceived exertion (RPE) was asked from the subject 30 seconds before the end of every grade.

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7.6 STATISTICAL ANALYSES

All the measured variables were not normally distributed. Therefore, to the average value of each participant (n = 21–24), a nonparametric Spearman's Correlation Coefficient was used to detect the relationships between measured variables. Likewise, Related-Samples Friedman's Test was used to analyze the effect of prolonged shooting sessions on hit and shooters' behavioral performance. To predict the relationship between hit and shooters' behavioral performance Linear Regression Analysis was used. For single trials (n = 2825–2833), the Independent-Samples Kruskal-Wallis Test was applied to detect the differences between the groups. The data were analyzed by IBM SPSS Statistics 29.0 (SPSS Inc., Chicago, Illinois, USA) statistical package.

8 RESULTS

The mean and standard deviation values of all the measured variables of all groups are presented in table 3.

TABLE 3. Mean and standard deviation (in parentheses) values of all the measured variables of all groups.

	Male	Female	Junior male	Junior female
Hit[a]	10,26 (0,42)	10,25 (0,41)	10,06 (0,53)	10,13 (0,52)
DevX[b]	0,59 (0,44)	0,62 (0,40)	0,78 (0,32)	0,78 (0,30)
DevY[c]	0,41 (0,44)	0,44 (0,37)	0,53 (0,25)	0,53 (0,34)
VelX[d]	2,25 (0,71)	1,75 (0,60)	2,68 (2,12)	1,94 (0,53)
VelY[e]	2,15 (0,50)	1,74 (0,55)	2,55 (0,91)	1,98 (0,56)
VM[f]	0,95 (0,54)	0,64 (0,43)	0,98 (0,59)	0,77 (0,46)
VASFatigue Sum[g]	175,00 (108,33)	144,40 (83,92)	140,38 (86,78)	85,33 (39,97)
VASFatigue Avg[h]	25,00 (15,48)	20,63 (11,99)	20,05 (12,40)	13,49 (8,07)
VASNumb Sum[i]	191,60 (119,92)	163,60 (86,60)	190,50 (68,61)	136,83 (38,91)
VASNumb Avg[j]	27,37 (17,13)	23,37 (12,80)	27,21 (9,80)	21,03 (7,34)
VO2max[k]	38,10 (6,28)	29,10 (6,71)	42,90 (8,30)	29,70 (4,91)
Grip right[l]	51,88 (6,15)	39,36 (3,47)	51,84 (7,70)	32,47 (7,76)
Grip left[m]	49,90 (5,32)	35,26 (3,32)	51,64 (9,48)	30,70 (6,88)
Foot dynamometer[n]	472,40 (82,13)	302,40 (49,20)	349,38 (111,62)	255,17 (69,15)
Bench press[o]	82,56 (17,80)	50,56 (10,79)	92,93 (20,49)	40,58 (5,44)
Body flexion[p]	66,86 (8,02)	53,08 (12,68)	62,68 (11,32)	40,62 (9,78)
Body extension[q]	107,06 (17,66)	69,78 (12,63)	90,85 (14,24)	54,03 (9,63)
Biceps[r]	29,90 (5,43)	21,16 (3,29)	32,31 (3,37)	17,17 (1,38)

[a] Score of the shot
[b] Aim point fluctuation in the horizontal direction
[c] Aim point fluctuation in the vertical direction
[d] Mean speed of movement of the center of the pressure in the anteroposterior direction (mm/s)
[e] Mean speed of movement of the center of the pressure in the mediolateral direction (mm/s)
[f] Average horizontal area covered by the movement of the center (VelX) and VelY) the direction of force per second (mm^2/s)
[g] Sum of subjective feelings of fatigue during shooting serie
[h] Average of subjective feeling of fatigue during shooting serie
[i] Sum of subjective feeling of numbness during shooting serie
[j] Average of subjective feeling of numbness during shooting serie
[k] Maximal oxygen uptake
[l] Maximal isometric grip squeeze power of right hand
[m] Maximal isometric grip squeeze power of left hand
[n] Maximal isometric power of leg extension
[o] Maximal isometric power of bench press
[p] Maximal isometric power of body flexion
[q] Maximal isometric power of body extension
[r] Maximal isometric power of biceps curl

8.1 Correlation of hit with all measured variables.

The score of the shot (Hit) correlated significantly with the mean aim point fluctuation variables DevX, (ρ= -.738, p<0.001) and devY, (ρ= -.686, p<0.001) when all the groups were counted for analysis (figure 2).

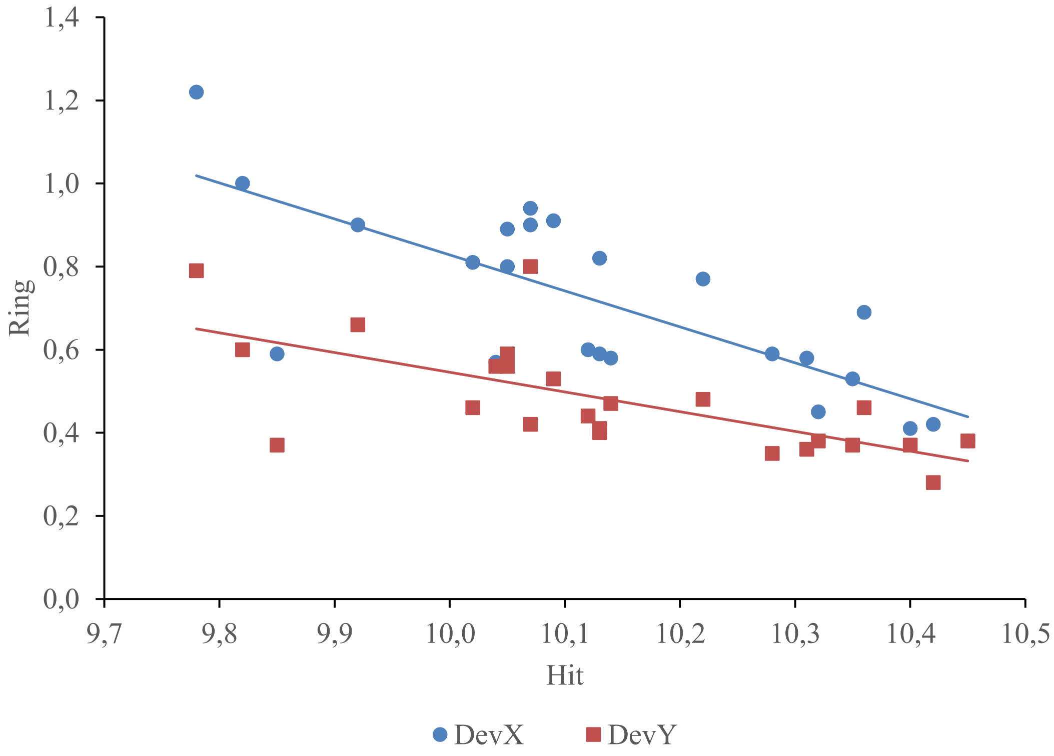

FIGURE 2. Correlation between hit and mean aim point fluctuation variables DevX and DevY.

There was also a significant correlation between the mean values of Hit and all three balance variables VelX (ρ=-.689, p<0.001), VelY (ρ=-.700, p<0.001), and VM (ρ= -.623, p<0.001) when all the groups were counted for analysis (figures 3 and 4). There were found no other significant correlations between Hit and other measured variables.

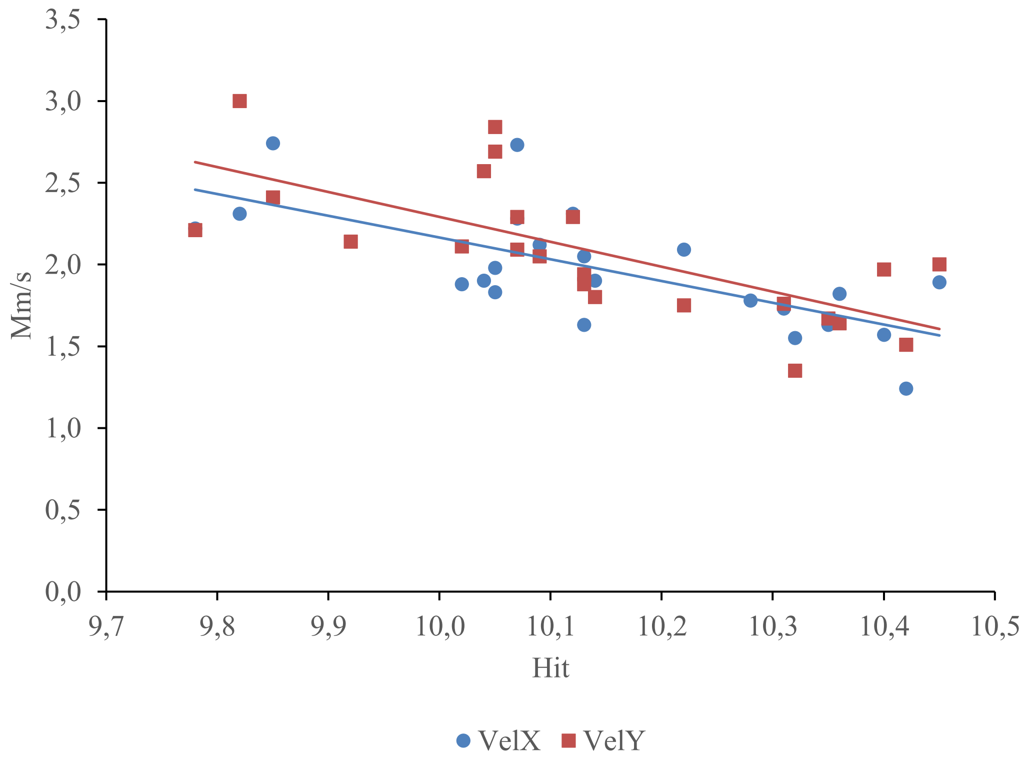

FIGURE 3. Correlation between Hit and mean balance variables VelX and VelY.

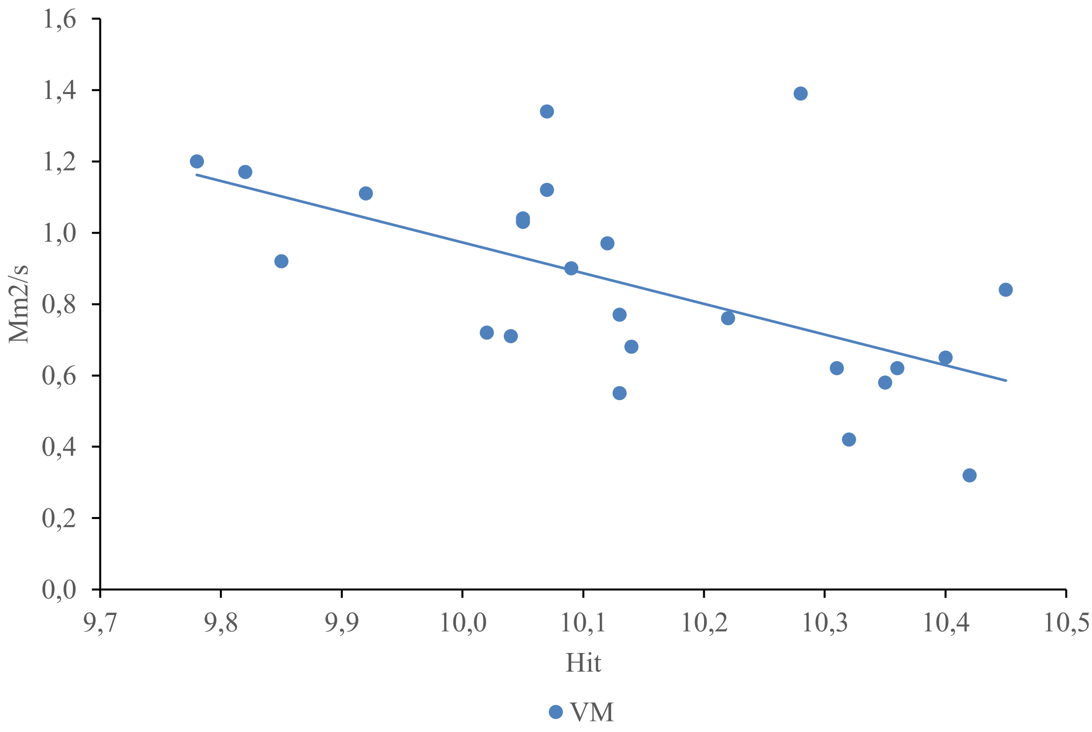

FIGURE 4. Correlation between Hit and mean balance variable VM.

As a noticeable result, the stepwise multiple regression analysis revealed that DEVX as an independent variable accounted for 59% of the variance in the shooting score ($R = 0.77$, $F(1, 22) = 31.745$, $P=0.001$).

8.2 Correlation of aim point fluctuation with all measured variables

Aim point fluctuation correlated strongly with Hit values (previous chapter). In addition for hit values, aim point fluctuation correlated significantly with balance. Aim point fluctuation value DevX correlated significantly with all balance values VelX ($\rho=.674$, $p<0.05$), VelY ($\rho=.465$, $p<0.05$), and VM ($\rho=.703$, $p<0.001$). Aim point fluctuation value DevY correlated significantly with all balance values VelX ($\rho=.561$, $p<0.05$), VelY ($\rho=.439$, $p<0.05$), and VM ($\rho=.503$, $p<0.05$). There were not found no other significant correlations with aim point fluctuation and other variables.

8.3 Correlation of balance with all measured variables

All three balance variables (VelX, VelY, and VM) correlated significantly with the Hit variables. All three balance variables correlated significantly with both aiming point fluctuation variables (previous chapters).

There was also found significant relation with balance variable VelY and VO2max ($\rho=.517$, $p < 0,05$), grip strength right ($\rho=.447$, $p < 0,05$), grip strength left ($\rho =.462$, $p < 0,05$) bench press ($\rho= .438$, $p< 0,05$) and VAS Numb Avg ($\rho =.418$, $p<0,05$). Balance value VM correlated significantly with grip strength left ($\rho =.405$, $p < 0,05$), body flexion ($\rho =.508$, $p < 0,05$), height ($\rho= .458$, $p < 0,05$) and VAS Numb Sum ($\rho =431$, $p<0,05$) and VAS Numb Avg ($\rho=.416$, $p<0,05$).

8.4 Correlation of maximal isometric power and VO2max with shooting technique variables

There was found significant correlation between mediolateral body movement (VelY) and grip strength right ($\rho = .447$, $p < 0.05$) and left ($\rho = .462$, $p < 0.05$) and bench press ($\rho = .438$, $p < 0.05$). Velocity moment (VM) correlated significantly with grip strength left ($\rho = .405$, $p < 0.05$) and body flexion ($\rho = .508$, $p < 0.05$). There was also found significant correlation ($\rho = .517$, $p < 0.05$) with VO2max and VelY. There was no significant correlation between maximal isometric power or VO2 max with aiming point fluctuation or hit.

Notice: all the maximal power values had a significant correlation with each other. VO2max values also correlated significantly with all maximal power values.

8.5 Correlation of experienced fatigue and numbness with shooting technique variables

Experienced physiological numbness sum (VAS Numb Sum) correlated with balance value VM ($\rho = .431$, $p < 0,05$). Numbness average (VAS Numb Avg) correlated with VM ($\rho = .416$, $p<0,05$,) and with VelY ($\rho = .418$, $p<0,05$). There were chances with the shooters' subjective feelings during the test. The subjective feeling of stress and numbness raised with every shooter from the start to the end of the test. Subjects reported feelings of exhaustion and numbness especially in the lower limb section.

8.6 Pairwise comparisons and group differences

In pairwise comparisons of Hit, all groups, except male and female groups, differed significantly from each other (figure 5). Male and female groups demonstrated better shooting performance compared to junior male and junior female groups. Additionally, the junior female group performed better than the junior male group.

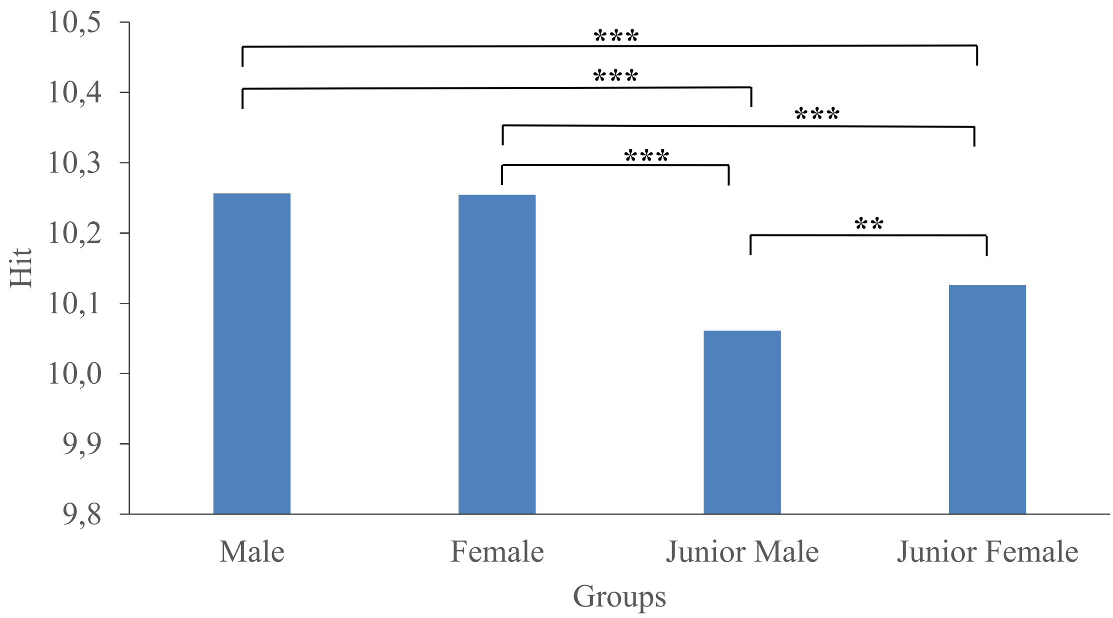

FIGURE 5. Pairwise comparisons and group differences of Hit (**p <0,01; ***p <0,001).

In rifle stability, all groups except male and female groups and junior male and junior female groups, differed significantly from each other in DevX (figure 6). The male group had the smallest horizontal aimpoint fluctuation before the shot. The female group had the second smallest fluctuation followed by junior male and junior female groups.

In DevY (figure 6) all the other groups, except male and female, differed from each other. The male group had the smallest aimpoint fluctuation before the shot. The female group had the second smallest fluctuation followed by junior male and junior female groups.

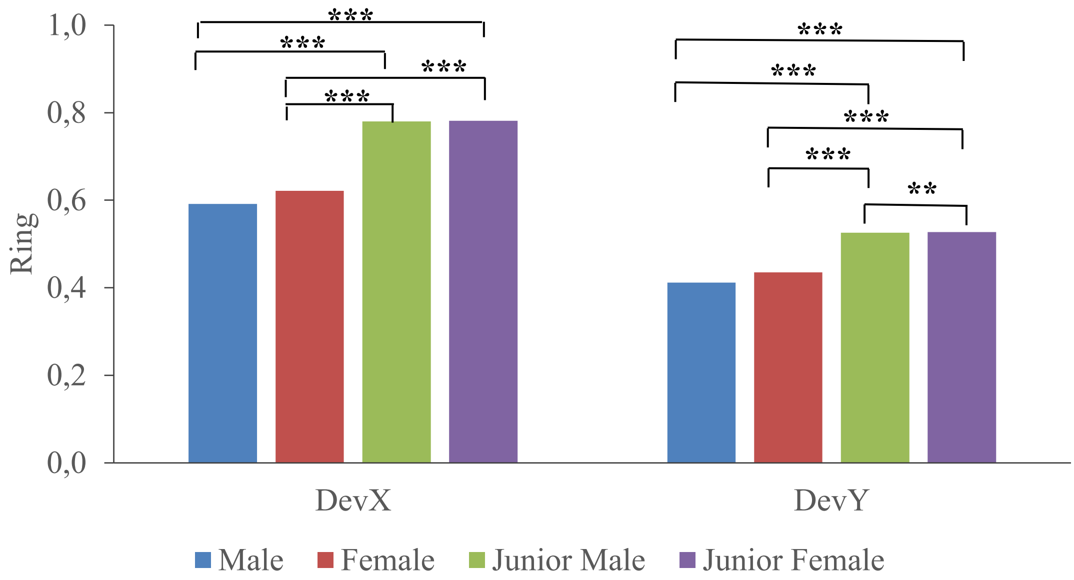

FIGURE 6. Pairwise comparisons and group differences of DevX and DevY (**p <0,01; ***p <0,001).

In postural sway velocity, all the groups differed significantly from each other both in VelX and VelY (figure 7). The female group had the lowest/smallest body movement before the shot both in horizontal and vertical directions. After the female group came/were junior female, male, and junior male groups, respectively.

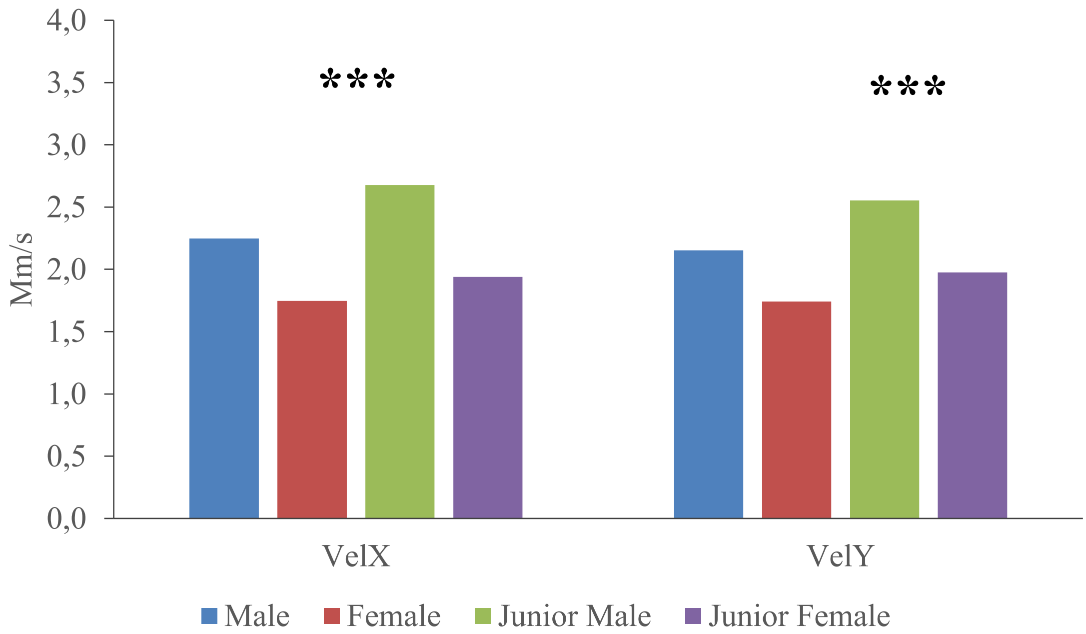

FIGURE 7 Pairwise comparisons and group differences of VelX and VelY (***p <0,001).

In VM all groups, except male and junior males, differed significantly from each other (figure 8). The female group had the smallest average horizontal area covered by the movement of the center (VelX) and VelY) the direction of force per second (mm²/s) before the shot. After the female group came junior female, male, and junior male groups, respectively.

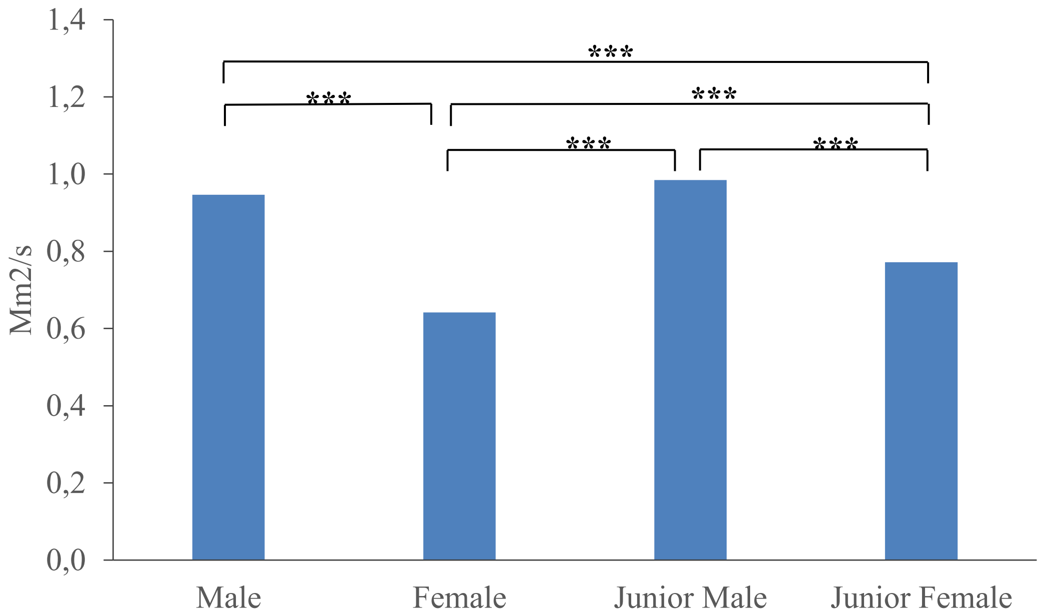

FIGURE 8. Pairwise comparisons and group differences of VM (***p <0,001).

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8.7 Changes in shooting performance during a prolonged shooting session

8.7.1 Hit

Changes in Hit values in 12 series of 10-shots with every group. There was found no significance between the series (figure 9).

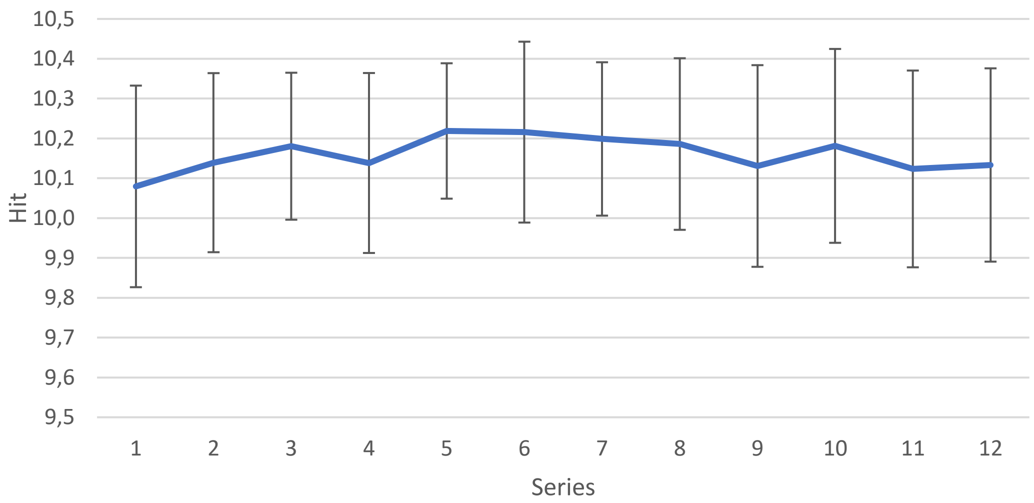

FIGURE 9. Hit (mean ± SD) of the ten-shot series of all participants (n = 23)

8.7.2. AIM POINT FLUCTUATION

Changes in DevX values in 12 series of 10-shots with every group. There was found no significance between the series (Figure 10).

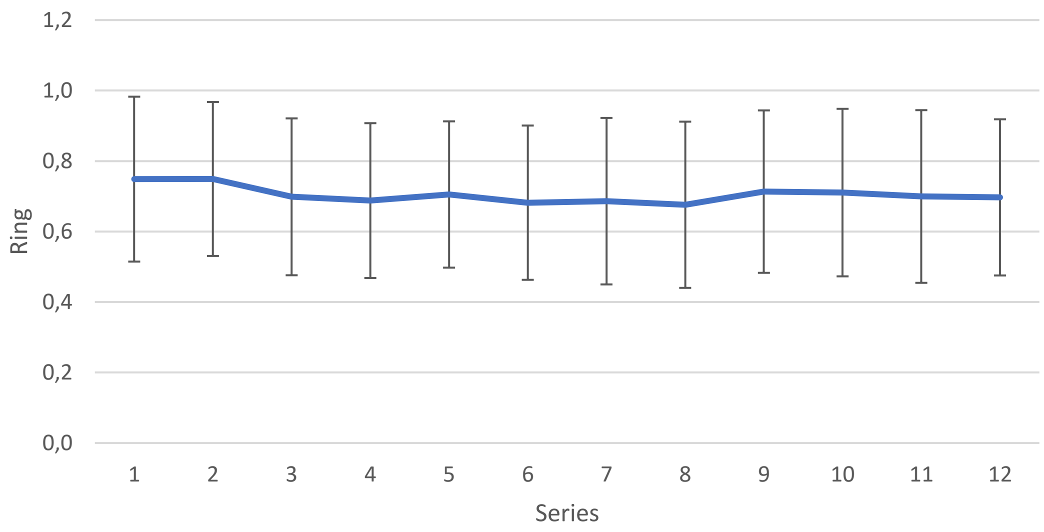

FIGURE 10. DevX (mean ± SD) of the ten-shot series of all participants (n = 23).

Changes in DevY values in 12 series of 10-shots with every group. There was found (p > 0.005) significance between the series (figure 11). DevY values decreased during the measurement.

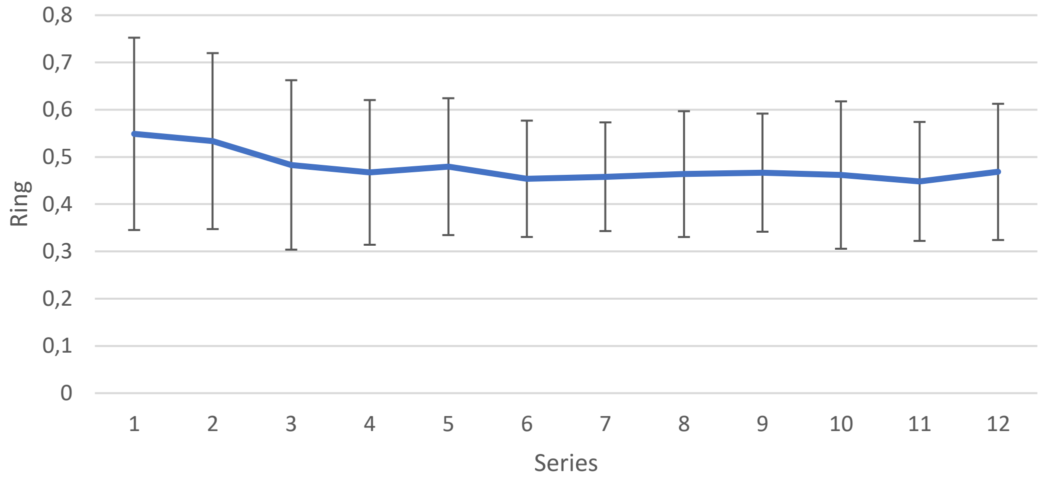

FIGURE 11. DevY (mean ± SD) of the ten-shot series of all participants (n = 23).

8.7.3. BALANCE

Changes in DevX values in 12 series of 10-shots with every group. There was found no significance between the series (figure 12).

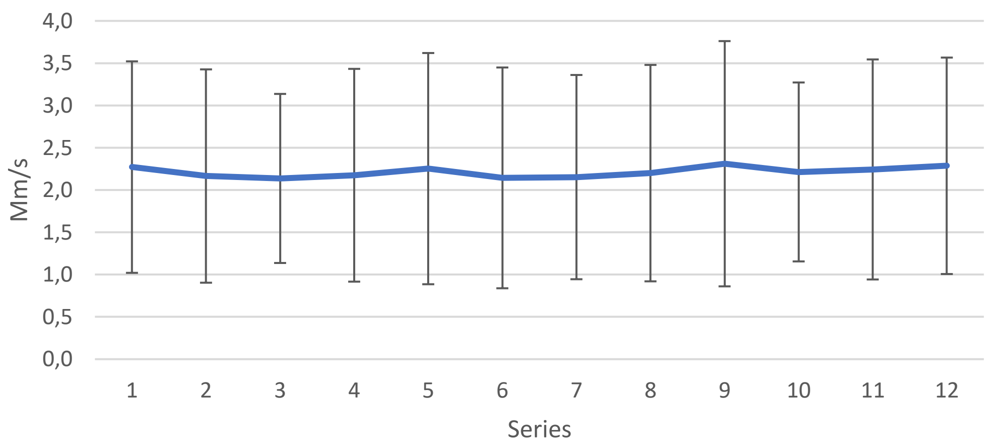

FIGURE 12. VelX (mean ± SD) of the ten-shot series of all participants (n = 23).

Changes in VelY values in 12 series of 10-shots with every group. There was found significance ($p < 0,05$) between the series. VelY values decreased during the measurement (figure 13).

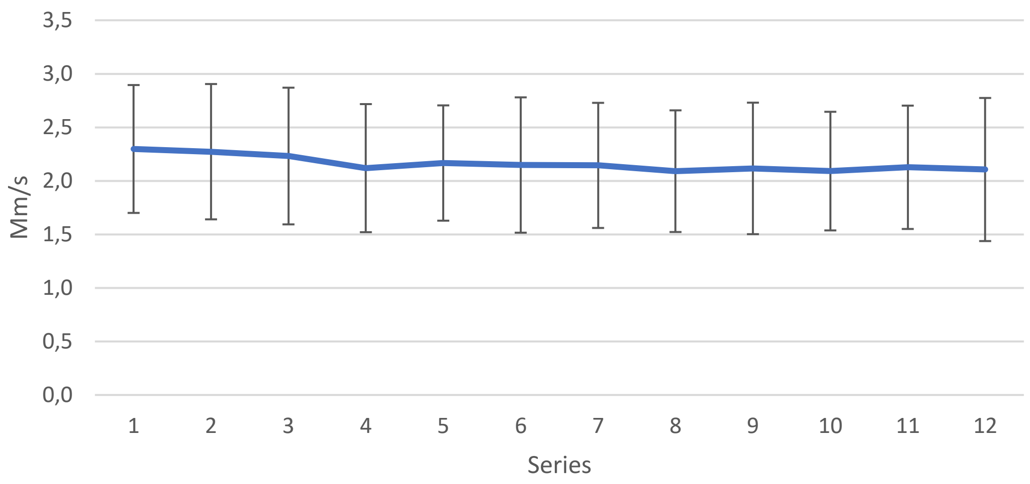

FIGURE 13. VelY (mean ± SD) of every ten-shot series of all participants (n = 23).

Changes in VM values in 12 series of 10-shots with every group. There was found no significance between the series (figure 14).

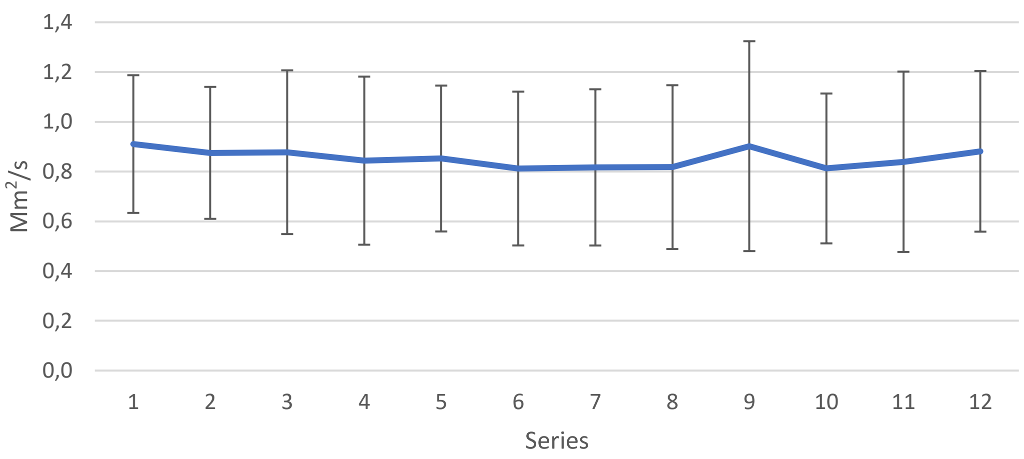

Figure 14. VM (mean ± SD) of every ten-shot series of all participants (n = 23)

8.7.4. Visual Analogue Scales

Chances in subjective feelings of fatigue (figure 15) and numbness (figure 16) during the test in 20-shot intervals starting from zero before the start.

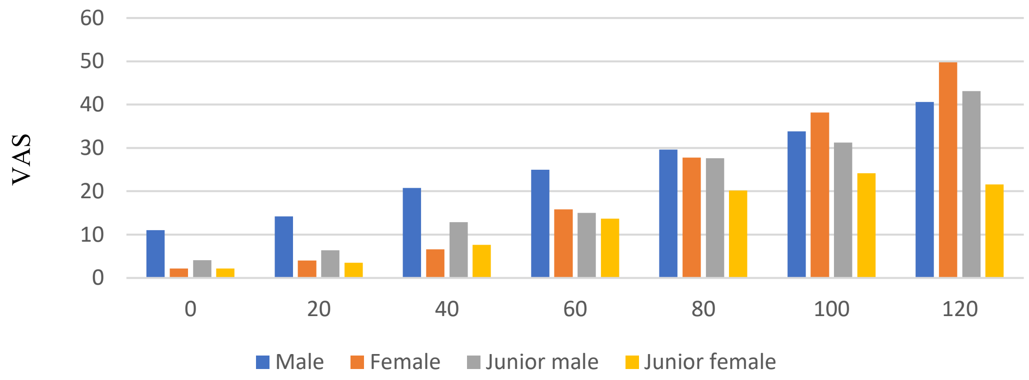

FIGURE 15. Changes in subjective feeling of fatigue during the test in 20-shot intervals starting from zero.

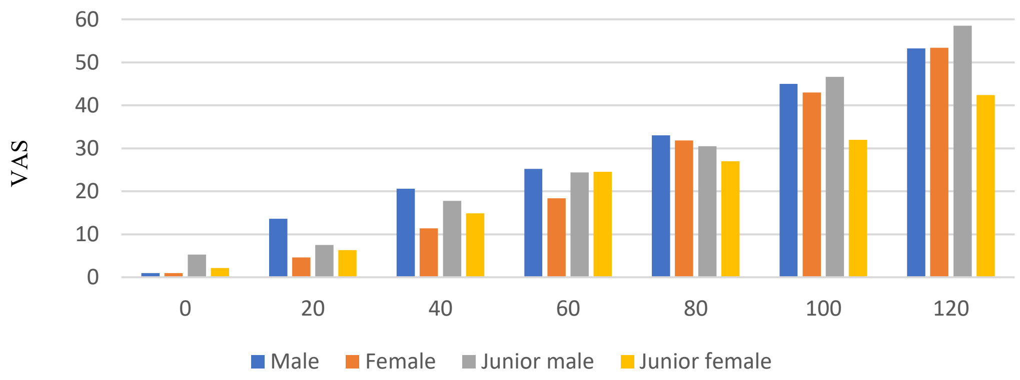

FIGURE 16. Changes in subjective feeling of numbness during the test in 20-shot intervals starting from zero.

9 DISCUSSION

The results pointed out there was no correlation between shooting technique and maximal isometric power values or VO2 max except for the balance variables VelY and VM. Experienced shooters (males and females) had better Hit scores than their less experienced counterparts (junior males and junior females). However, they were not the best in all shooting performance variables. The prolonged shooting session did not cause any significant degeneration for shooting performance variables.

The balance variable VelY correlated with three maximal isometric power variables (grip strength right and left and bench press) and VO2 max. Balance value VM correlated significantly with grip strength left, body flexion, height, and subjective feelings of numbness. Balance has a straight relation to Hit and aiming point values, so it is worth considering the meaning of those variables to shooters' balance and in addition at least indirect meaning for shooters' ability to perform.

Groups differed from each other with Hit, aim point fluctuation, and balance variables in many ways. The best results in Hit were in male and female groups. This was the expected result because of the bigger experience and training history of those groups. Male and female groups achieved the best result also in the aim point fluctuation variable DevX, which has a significant correlation to Hit values. Interestingly, the male group was third best in balance values VelX, VelY, and VM, but still, their Hit, DevX, and DevY results were the best.

A significant correlation was found between aim point fluctuation and Hit. There was also a significant correlation between balance and Hit. Balance values also correlated significantly with aim point fluctuation values which directly relate to Hit values.

These results confirm and strengthen earlier studies' results about the meaning and relevance of those three variables to air rifle shooters' ability to perform their sport. The score of the shot is the most critical variable which indicates the goodness of the shooter. Aim point fluctuation and balance are the parameters that make the good Hit (score) possible to execute by making triggering easier at the optimal moment. A good balance has its important significance to aim point fluctuation: the less the shooter’s body sways, the less the rifle moves. This is a logical conclusion about the connection of those two parameters. In practice, it is not that simple. In practice, the shooter can adjust the rifle movements to keep the aim in the center of the target even if his/her body sways to some extent. This is the expertise of a skilled shooter, and a more experienced shooter can take advantage of this skill. But it does not eliminate the fact that if body sway is as minor as possible, this method is also easier to put into practice.

This study also examined if physiologically better-conditioned athletes are more tolerant to fatigue during prolonged air rifle shooting. The results pointed out there was no statistically significant degeneration with the score of the shot during the 120-shot series among the shooters. There were four groups of shooters, and they had a different individual shooting score level and they kept their individual level through the 120-shot series. The score of the shot is the most critical variable to indicate the shooter's skill level. The score of the shot could also be seen as an indicator to examine endurance to keep that level. In conclusion could be said that despite the difference in physiological condition among the shooters there was not any degeneration in shooters' scores caused by fatigue or numbness.

Experienced physiological numbness SUM correlated with balance value VM and numbness KA correlated with VelY and VM. There were chances with the shooters' subjective feelings during the test. Fatigue and numbness raised throughout the series with every shooter from the start to the end of the test. Subjects reported feelings of exhaustion and numbness especially in the lower limb section. The amount of subjective feelings varied from subject to subject, but both feelings were raised through the test with every subject. It can be speculated that this can have a meaning for shooters' ability to perform, especially in competition situations where, in addition to physiological fatigue, psychological stress can rise very high.

The competition result is counted with decimals and the marginals between good and bad results are minor. In competition, if a shooter can shoot a ten-shot series with every series of an average of 105 points, the shooter is high in ranking and very likely in the final match. When the average result of the 10-shot series comes down one point or more under this, the whole result is totally different. Even if significance was not found between fatigue, numbness, and result, it can still exist. The results of this study showed that the best average results of the ten-shot series were between series 4 and 8. This kind of rise in 10-shot series results has a practical meaning for the result. There can be seen a minor rise in average results from the start to the fourth series. After eight series results are slightly coming downwards. Also, there was a significant decrease (improvement) in the aim point fluctuation DevY and balance movement in the mediolateral direction (VelY) during the series. According to this could be asked where is the optimal level for the shooter to perform? Many times, in competition can be seen the same phenomenon, when the hits are getting better during the competition. Naturally, there can be many reasons for it, but one can be the shooter is reaching the optimal physiological and/or mental level to perform. In practice, it is important to warm up one way or another for competition situations. Every shooter has their own routine to do it. Shooters can make dry firing in the warmup area, different kinds of muscle warm-up, or balance warm-up. Everyone is also making some kind of mental preparation, consciously or not. To avoid losing important points, the warmup should support the competition's performance from the first shot of the competition. It is unnecessary to use some of the competition series for warming up.

The shooters' height correlated with the balance value VM. Taller shooters produced bigger velocity moment values than shorter subjects. The question if shooter height has an influence on balance and aim point fluctuation was one of the interests of this study. Logic conclusion without measuring this relation could be that the taller subject produces more movement in balance values. Height correlated with VM in this study. This is one question that coaches and athletes have been speculated about in practice. It is assumed that experienced shooters can control their body sway seconds before the shot. This could be one explanation for why differences between tall and shorter shooters are so minor from a balance perspective. At the elite level, there is a lot of variation in athletes’ height. Research should be made with a larger sample of shooters from different skill levels to increase the understanding of the height’s significance to shooting technique performance in a free-standing position. It would be interesting to study with a bigger sample of athletes if height favors shorter athletes. There has not been any of this kind of research earlier in the author's knowledge.

Noticeable results were that maximal isometric power values correlated significantly with each other. VO2max values correlated with all maximal isometric power values and VO2max value correlated also with the subject's height. These were to some extent expectable results.

The stepwise multiple regression analysis revealed that DevX as an independent variable accounted for 59% of the variance in the shooting score. This result is also in line with a study by Ihalainen et al. (2016) where stability of hold was considered the most important aspect of air rifle shooting technique, accounting for 54% of the variance in shooting score. Considering the shooter's shooting posture, especially the placement of the feet, postural balance makes it possible to sway more in cross cross-shooting direction (VelX) than in the shooting direction (VelY). This is causing movement, not only to the whole body but also to the rifle´s horizontal stability of hold (DevX). Also because of the shooter's posture, and more specifically shooter´s upper body position and the hand supporting the rifle, the aim point fluctuation movement is more possible in the horizontal direction (DevX) than in the vertical direction (DevY). Consequently, both body balance and balance of rifle hold are causing aim point (stability of hold) movement in the horizontal direction more than in the vertical direction. This causation has practical significance in terms of coaching and training. It could be easy to advise coaches and shooters to train athletes' horizontal stability of hold as minor as possible. A rifle shooter's performance where shooting position, rifle layout, balance, and stability of hold play a significant role in performance is very sensitive to minimal chances. Other significant role plays also aiming accuracy and cleanness of triggering, which are not addressed in this study. The rifle shooting performance is a whole where even at the elite level of shooting every part of the technique has its own role to keep marginals of any kind of movement before and during the shot as minor as possible. At the elite level, the techniques are perfected to be similar from repetition to repetition. However, there are individual differences in minor details of shooters' performances. For example, aiming point fluctuation is a kind of signature that is identifiable for a certain shooter. This individual variation of technical components encompasses the whole performance. There are no two kinds of techniques when they are analyzed carefully. Sometimes the differences in certain parts of the technique are clearly visible to the "coach's eye" and sometimes is needed technical equipment to find out the minor details of technical components. Even if individual variation`s existence is clear, high-level shooting performance requires certain levels of excellence in many parts of the performance. Excellence in these parts of technique is common for elite shooters.

The weakness of this study was number of the subjects. For this study, the subjects were recruited from the top-level rifle teams, which was the strength of the study. In Finland the number of national-level shooters is modest. With larger sample size would achieve more statistical power for the study.

It demands many years and hundreds of thousands of repetitions of sport-specific training to achieve elite-level shooting technique. Along the sport-specific training athletes can train in different variations of physical training. The effects of different variations of physical training on shooting performance have not been studied widely. Analyzing the shooting technique with reliable equipment in a "shooting laboratory" environment is a crucial part of modern coaching and training. Along with the sport-specific training could be fruitful to consider analyzing the effects of supplementary training on the shooting performance. Is it possible to determine the most effective supplementary training methods that could develop the shooters' physical structure to the optimal level? Supplementary training should support the shooting technique characteristics, stability of hold, and postural balance. It should also support necessary physical characteristics, endurance, strength, and special condition, which are crucial from a shooting performance aspect.

The results of this study should encourage coaches and athletes to consider the meaning of physical characteristics, physical training, and warm-up methods for shooting performance. Optimal physical performance characteristics can be a significant advantage for a shooter in his/her sport and it should support the shooter's shooting performance in an optimal way during training and competition seasons. More studies are needed to clarify the relationship between different physical characteristics and shooting performance variables.

The results of this study, with its measurement set-up, underline the practical significance of shooting technique analysis relevance of understanding and analyzing the shooters' performance. Measuring shooters' techniques with reliable devices designed for shooting technique analysis is crucial. Aim point fluctuation analyzing devices are small, portable, and easy to use. Force plates are more difficult to transport and use every day or week in training. However, force plates should be used at least a few times a year together with an aim point fluctuation device to analyze shooters' techniques. The results should be stored on the computer for data collection from each athlete individually. Long-term data collection gives coaches and athletes the possibility to view the results over a long period. From the data can be seen the shooters' development year after year in different parts of the technique. Coaches and athletes should consciously increase and develop their expertise in analyzing that data. Every shooter's technique is individual and structured from many components which are crucial for the wholeness of the technique. Shooting technique is at least the sum of its parts and understanding causal relations of those parts demands years of experience and interest.

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