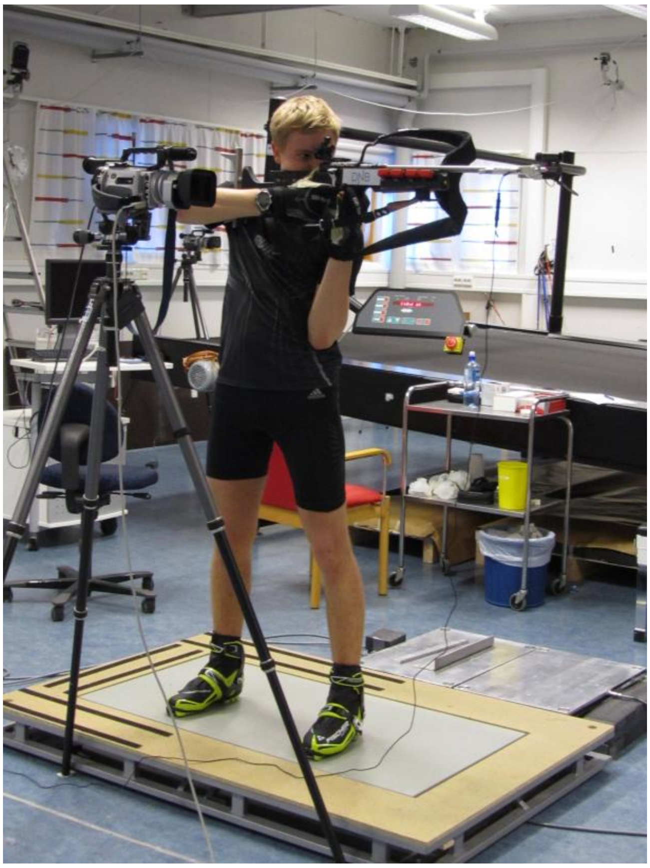
Anders Vonheim

The effect of skiing intensity on shooting performance in biathlon



BEV3901 Master Thesis
Human Movement Science Programme
Norwegian University of Science and Technology (NTNU)
Trondheim, Spring 2012

Acknowledgements

First, I would like to thank my supervisor Karin Roeleveld for guidance true the entire process, and for in collaboration with Xianchun writing the MATLAB scripts for extracting data from the lab tests, thank you! I want to thank Xianchun Tan for needed help with the equipment in the lab, and with analysis in MATLAB. Thanks also to my fellow student Trond Michael for the many ours with assistance in the lab during data collection. Finally, thanks to the rest of my fellow students and the staff at the Human Movement Science Program at NTNU for helpful discussions and advices.

Abstract

An earlier study of shooting performance in biathletes found a decrease in performance as the intensity increased. No studies have focused on the technique used by biathletes in standing shooting, which differs from the technique used by rifle shooters. Therefore, the present study investigated both shooting performance at different exercise intensities in biathletes, and the difference between isometric and dynamic precision at different intensities.

To investigate shooting performance at different intensities, 15 biathletes performed three roller ski interval exercises (4x6 min) on a treadmill at 75-80%, 85-87% and 90-95% of their maximum heart rate (HR_{max}). The biathletes performed 3 precision tasks at rest before warm up, directly after warm up and after each repetition on the interval exercises. The following precision tasks were performed (in standing position): 5 shot series, holding still at a target (isometric), and following a line (dynamic). During the precision tasks, the subjects were standing on a force plate that measured center of pressure (COP) movements in the anterior-posterior direction and medial-lateral direction. Subjects used their own weapon in the precision tasks. A laser pen and an accelerometer were attached at the front of the barrel. The "front sight" was removed from the weapon, and subjects used only their rear sight and the laser dot for aiming.

The results showed no significant effect of intensity on shooting performance during the 5 shot series (p= 0.179). The holding still task and following line task were both significant affected by intensity (holding still p= 0.017, following line p= 0.030), but the difference between the two tasks did not reach statistical significance (p= 0.070). Results from the force plate showed greater movement of COP in the anterior-posterior direction than in the medial-lateral direction. A significant effect of intensity was only found in the medial-lateral direction.

In conclusion, the present study shows no significant effect of intensity on the shooting performance in the 5 shot series. The subjects were not used to having a laser pen for aiming, and this may have affected the results. There is a difference between isometric and dynamic precision, but the difference did not reach statistical significance. Thus, the results cannot for certain justify the technique used by biathletes in standing position.

Introduction

Biathlon is a sport that combines cross-country skiing with shooting. The competitions last from 25 minutes and up to almost one hour in the longest competition form. The athletes are skiing either 3 loops with 2 series of shooting, or 5 loops with 4 series of shooting. In a competition, the biathletes always shoot in both prone and standing position. They have 5 shots to hit 5 targets at each shooting. Distance from the firing range to the target is 50 meters. The target is 4.5 cm in diameter in prone shooting and 11.5 cm in standing. For each miss, biathletes get either one penalty loop or 1 minute added to their skiing time, depending on the competition form.

Moreover, biathlon has the same demands as cross country skiing regarding the physical part, except from the classic technique. In addition, biathletes have physiological and psychological demands regarding the shooting. During competitions biathletes have an average heart rate of 90 % of their maximum while skiing in the tracks. When approaching the firing range their heart rate decreases to 85 – 87 % of maximum during a period of 50-60 seconds (Hoffman & Street, 1992). In standing shooting the heart rate falls to a minimum of about 70 % of maximum during shooting (Hoffman & Street, 1992). The shooting part in biathlon is a complex task which requires good stability and accuracy, and should also be performed as quickly as possible to save time.

Fatigue is described as an impairment of performance, as a result of a decrease in power production capacity, power output, or that we are not longer able to maintain a force (Enoka & Stuart, 1992). Fatigue can occur during repeated maximal contractions and during prolonged submaximal contractions. In biathlon the athletes perform prolonged submaximal contractions, and fatigue starts gradually after the competition has begun (Enoka, 2008). Fatigue can also occur with development of hypercapnia and dyspnoea. Factors such as the accumulation of CO_2 and a decrease in arterial oxygen saturation can also lead to fatigue (Enoka, 2008). In soldiers the shooting precision and accuracy has been shown to go back to pre-exercise levels 5 minutes after a heavy exercise that involve upper extremity muscle fatigue. Number of hits first went back to pre-exercise levels after 10 minutes (Evans et al, 2003). After a cycling exercise, shooting performance has been shown to decrease when the intensity of the exercise increases (Hoffman et al, 1991).

Biathlon combines heavy exercise with a precision task. Fatigue has been shown to occur in cross-country competitions (Vesterinen et al, 2009), and we therefore assume it also occurs in biathlon competitions. Therefore, biathletes use a different shooting technique than normal rifle shooters. In standing position rifle shooters are aiming at the center of the target, and try to hold still to get a hit as close as possible to the center of the target. Biathletes don't need to hit the center, as long as they hit the target it is good enough. They shoot with a high heart rate that makes it difficult to hold still on the target. Because of the high heart rate and fatigue, biathletes use a technique were they start aiming just outside the target, then move towards it, and when the target appears in the aiming picture they pull the trigger. A high heart rate has been shown to influence shooting precision, accuracy and stability in standing shooting (Hoffman et al, 1991).

Balance is important for shooting precision; shooters must avoid too much body movement during shooting (Era et al, 1996). Experienced rifle shooters have less body sway than not so experienced rifle shooters (Niinimaa & McAvoy, 1983), and inexperienced rifle shooters have been shown to have significantly more body sway in postural balance during less successful shots than during successful shots (Era et al, 1996), whereas no such association has been found among top-level shooters (Era et al, 1996). In pistol shooting, body sway during shooting was found to account for 53 % of the variability in shooting accuracy of elite pistol shooters (Mason et al, 1990). Mononen et al (2006) showed that high postural balance and minimal movement of the rifle barrel are essential determinants of successful shooting performance among novice shooters. Specifically the role of postural balance has been shown to be important for shooting performance; therefore may use of additional balance training programs in the shooting training help novices to improve their performance (Mononen et al, 2006).

Stability has also been shown to be important for shooting performance; a well controlled motion of the barrel just before firing a shot is essential for shooting performance (Mason et al, 1990) (Mononen et al, 2006). Elite shooters have been shown to keep their rifle much more stable during the aiming period of a shot compared with novices (Viitasalo et al, 1999). This has also been shown in biathlon, and the biathletes with the best shooting performance have a stable aiming pattern (Baca A & Kornfeind, 2010). Stability is affected by fatigue and decreases when the intensity increases (Mononen et al, 2006) (Grebot et al, 2002). For measuring stability of the barrel, a laser-based system has been used (Baca A & Kornfeind, 2010). With this system it is possible to see the movement of the barrel in the last seconds before a shot is fired in addition to the result of the shot (Baca A & Kornfeind, 2010).

The effect of intensity on shooting performance in biathletes has been given little attention in previous research. No studies have focused on the special technique biathletes use in standing shooting compared with the technique rifle shooters use, and investigated if there is a good reason for biathletes to use this technique.

The purpose of the present study was to evaluate the effect of prior exercise intensity on shooting performance, and on isometric and dynamic precision. Furthermore, we investigated how balance and stability of hold are affected by intensity, and how balance and stability relates with shooting performance.

Methods

Subjects

15 biathletes volunteered to participate in the study, 13 males and 2 females. All subjects were students from a ski gymnasium in Norway. Age of the subjects varied from 16 – 19 years, and all subjects were active biathletes that compete in national competitions in Norway. Two of the subjects had to withdraw due to illness, and we therefore ended up with 13 subjects in the analyses.

All participants were familiarized with the nature of the study before signing a written consent to participate. The study was approved by "Personvernombudet for forskning". The study was conducted in middle of December 2011, which means that the biathletes had just started their competition season and should be well trained for skiing and shooting. The biathletes characteristics are shown in table 1.

Table 1. Anthropometric and physiological characteristics of the subjects (mean ± SD)

Subjects	
Age (years)	18.1 ± 1.9
Body height (cm)	175.9 ± 8.1
Body mass (kg)	70.3 ± 10.0
VO_{2peak} (ml/kg/min)	63.35 ± 5.7
HF_{max} (bpm)	202 ± 5.1

Overall design

To measure the biathletes shooting performance on different intensities, all participants performed four treadmill roller ski tests on separate days: the first day subjects performed a submaximal test (lactate profile) and a maximum aerobic capacity test (VO_{2peak}). The other 3 days the subjects performed interval exercises consisting of 4x6 min roller skiing at different intensities; 75-80% of maximum heart rate (HR_{max}) (T2), 85-87% of HR_{max} (T3) and 90-95% of HR_{max} (T4), in randomized order. During all these tests, the subjects performed precision tasks (shooting), 3 the first test day and 6 the last three test days; at rest, after warm up and after each interval. All tests were performed at the movement lab at "Dragvoll Idrettssenter", Trondheim.

Instrument and materials

The roller skiing tests were performed on a 6x3 m motor driven treadmill (Bonte Technology, Zwolle, the Netherlands). The treadmill belt consisted of a non-slip rubber surface that allowed the subjects to use their own poles with special carbide tips. All subjects used the same roller skis (Swenor Roller skis, Troesken, Norway) with standard wheels. A safety harness was used during VO_{2peak} test to secure the skier.

Fig 1. One of the subjects during an interval repetition.

VO_2 was measured by open-circuit indirect calorimetry using an oxygen pro apparatus (Jeager GmbH, Hoechberg, Germany). The gas analyzers were calibrated using high precision gases and the inspiratory flow meter was calibrated with a 3L volume syringe (Hans Rudolph Inc., Kansas city, Missouri, USA). VO_2 was measured with a time interval at 30 seconds.

Blood lactate concentration was measured taken from the fingertip using a Lactate Pro LT-1710t (ArkRay Inc., Kyoto, Japan). Heart rate was measured using a Polar S800 with a 5s interval for storage.

For the shooting tasks, the subjects used their own weapon. A laser pen was attached at the front of the barrel (figure 2), and adjusted to be in the center of the aiming picture. The "front sight" was removed from the weapon, and biathletes used only their rear sight and the laser for aiming (figure 3).

Fig 2. The laser pen and accelerometer attached at the front of the barrel

Fig 3. The picture shows the "front sight" on a biathlon rifle. The small circle in the middle is called "aperture" and was removed from the front sight. The laser dot was adjusted to be in the middle of the aiming picture instead of the "aperture".

The target was an A4 sheet consisting of a normal 5 shot's target, a 21cm line and a circle with the same size as the 5 shot's target (figure 3). This was placed 7 meters away from the shooter, and scaled to be the same size that biathletes normally use on a 50 m shooting range. Radius of the target on the 5 shot series and the circle was 6.5 mm.

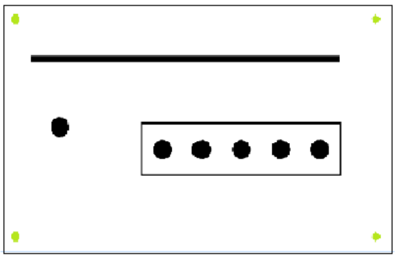


Fig 4. The target that was used during precision tasks

A video camera (Sony DCR-VX 2000E PAL) was used to record the laser dot; with a samplingsrate of 50 Hz. When subjects fired a shot, a "click" sound occurred and this was captured by a microphone in the camera and used in the analysis to calculate when the subjects fired a shot.

An accelerometer (Noraxon DTS 3D accelerometer) was attached at the front of the barrel (figure 2). Subjects were standing on a force plate (AMTI, model OR/6-5-1000) during the shooting tasks (figure 5). The accelerometer and force plate had a samplingsrate of 1500 Hz.

The video camera, AMTI force plate and accelerometer were all synchronized into Noraxon data system (Noraxon U.S.A. Inc.).

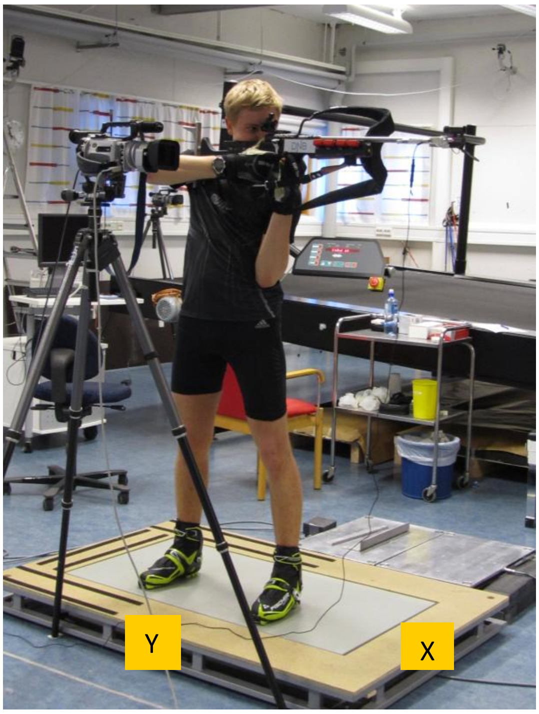


Fig 5. A subject performing a precision task. X and Y show the axis on the force plate. X = movement in the anterior-posterior direction, Y = movement in the medial-lateral direction.

Test protocols and measurements

Precision tasks (shooting)

During each shooting session the subjects performed 3 different precision tasks. All tasks were performed in standing position. The three tasks were: (1) a shooting series of 5 shots, (2) holding still at a target for 10 seconds, and (3) trace a horizontal line of 21cm. When performing the 5 shot shooting series, the subjects were instructed to shoot when the laser was visible on target. When holding still, the subjects were instructed to hold the laser as close as possible to the center of the target for 10 seconds. When following the line, the subjects were instructed to follow the line with the laser, with a constant velocity (about 10 sec), and without any movement in the vertical direction. The three tasks were performed directly after each other and the order of the tasks were randomized; it differed what task the subjects performed first, second and last in a shooting session. The subjects performed the tasks without roller skis, but with ski boots on. When performing the tests, the subjects were standing on the force plate. The accelerometer and laser pen recorded the movement of the barrel and the position of the laser on the target sheet was recorded by a video camera. The subjects used about 50 sec to perform all three precision tasks.

Table 2 shows when the precision tasks were performed, 3 times on test day 1, and 6 times on test day 2, 3 and 4. On test day 1 the precision tasks was performed at rest before the warm up, after submaximal test and 2 min after the end of $VO2_{peak}$ test. On day 2, 3 and 4 the precision tasks was performed at rest before warm up, after warm up and after each repetition in the interval exercise.

Table 2. A view of when the subjects performed precision tasks.

Test day	Before Warm up	After Warm up	After 1 Interval	After 2 interval	After 3 Interval	After 4 Interval	After submax. test	After $VO2_{peak}$
1	X						X	X
2	X	X	X	X	X	X		
3	X	X	X	X	X	X		
4	X	X	X	X	X	X		

Test day 1, submaximal test

First, the subjects performed a warm up that consisted of 5-10 min easy roller skiing on the treadmill, where the subjects chose the velocity themselves. Subjects borrowed roller skis, but used their own poles. Start speed at the test was for men 10 km/h and for women 8 km/h, with the incline of the treadmill constant at 5%. Subjects were skiing periods of 5 minutes. During the 5 min period, the test leader wrote down the subject’s heart rate every minute on a separate form. Immediately after the 5 minutes period the subject was stopped, and lactate was measured. When that was done the subject started skiing again immediately. After the first period, the velocity was increased with 2 km/h and after this with 1 km/h. The subjects continued the 5 min periods until they reached a blood lactate concentration of 5 mmol or higher. Test procedures are shown in figure 6.

Test day 1, maximal test

Maximum aerobic capacity was tested as an incremental test on the treadmill, with the inclination constant at 5%. The start speed was 1km/h lower than the highest velocity during the submaximal test. The speed was increased by 1km/h every minute until exhaustion. VO_2 was measured continuously, and the highest 30s measurement determined VO_{2peak}. The highest heart rate value during the test (HR_{peak}) +5 bpm was defined as maximum heart rate (HR_{max}). 5 bpm were added to HR_{peak} because athletes usually don't reach their absolute maximum heart rate during a $VO2_{peak}$ test.

The submaximal and maximal tests were performed to find the velocity each subject should have on the treadmill for the interval exercises; 75-80%, 85-87% and 90-95% of HR_{max}. Heart rate was plotted against velocity, and interpolation was used to calculate the velocity for the interval exercises. Which heart rate each subject should have on the different interval exercise tests, were calculated from their $HR_{max.}$ Lactate measures and VO2 measures were carried out to give the subjects a rapport with a lactate profile curve and $VO2_{peak}$ test data.

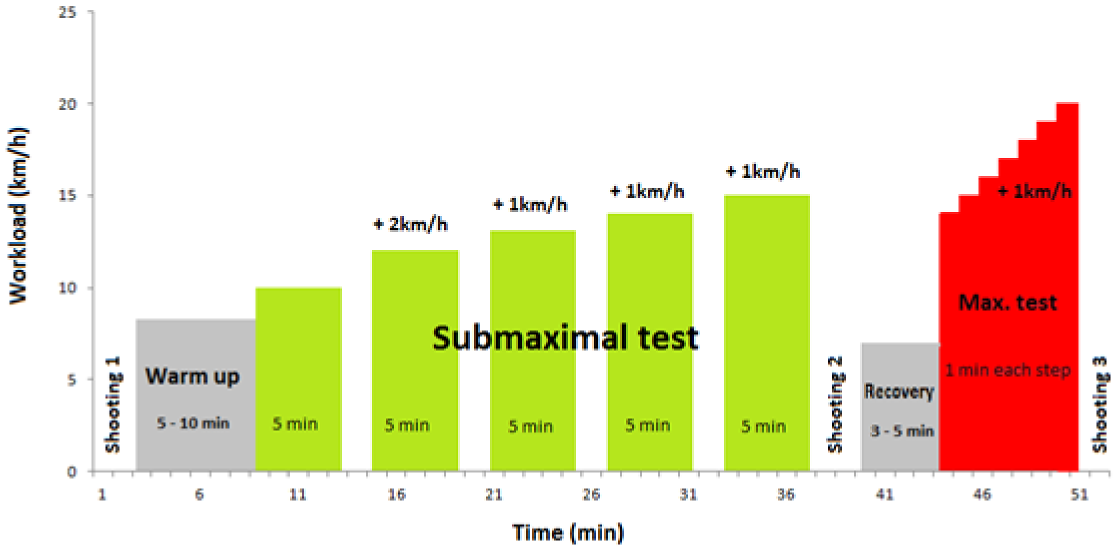


Fig 6. Test procedure on test day 1, submaximal and maximal test.

Test day 2 (75-80%), 3 (85-87%) and 4 (90-95%)

Interval exercise

The warm up consisted of 15-20 min easy roller skiing, with 2 slow sprints at the end of the warm up. During warm up the subjects decided the velocity of the treadmill themselves. The interval exercises consisted of 4 repetitions of 6 min with an intensity of 75-80%, 85-87% or 90-95% of HR_{max}. These exercise heart rates were chosen to represent a range of values that a biathlete might have at arriving the firing range. Velocity of the treadmill was determined based on the results from the submaximal and maximal test. The test leader monitored the heart rate during the intervals to make sure the subjects were at the correct intensity. If not, the speed was adjusted. After each repetition subjects had a break of 3 minutes, where they performed the precision tasks. After each interval repetition the subjects had to get as fast as possible from the treadmill and on to the force plate and then start the precision tasks, before heart rate decreased below the given intensity.

Test day 2, 3 and 4 were similar except from the intensity on the interval exercises. The order of the tests was randomized; which intensity the subjects had on their first, second and last test differed between the subjects.

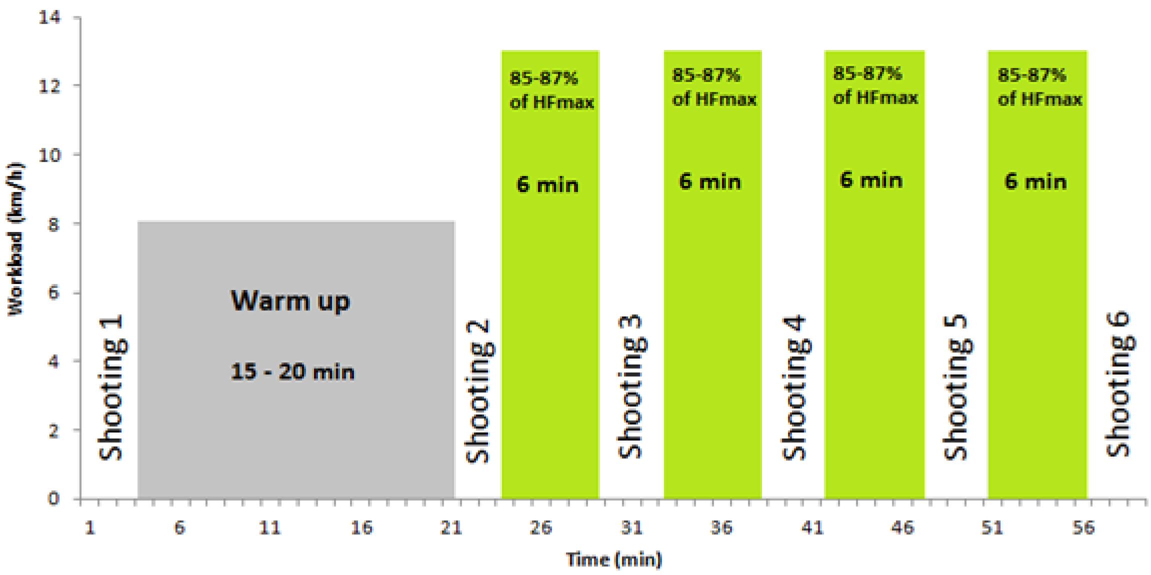


Fig 7. Test procedure on test day 2, 3 and 4. This is an example from a test at 85-87% of HR_{max}.

Data analyses

Data from the video camera, force plate and accelerometer was processed in MATLAB (R2009a). The different targets on the A4 sheet were calibrated using 4 green circles at each corner of the sheet (figure 4). The position of the laser dot was found on the sheet and calculated with distance from the target with an X- and Y-axis in millimeter (mm). In the 5 shot series the data are presented as distance from center of the target in mm, from where the shot was fired. Data from the holding still at target task is shown as average and as standard deviation (SD) of the radial distance from the center in mm and as SD of vertical movements in the Y-axis during the same time period as following line task; subjects used shorter time performing the following line task, compared with the holding still task. Therefore, we used the same time period in the holding still task that the time subject used during the following line task, even though the holding still task always took 10 sec to perform. Data from the following line task are shown as average distance from the line in mm and as SD of vertical movements (Y-axis). The trials where subjects performed the following line task in a shorter time period than 4 sec were removed from the analysis. In total 6 trials were removed. Data from the force plate are presented as center of pressure (COP) in mm, in X- and Y-axis, were the X-axis is movement in the anterior-posterior direction and the Y-axis is movement in the medial-lateral direction. Together, this axis was used to calculate the position of the center of pressure relative to the origin of the force plate. COP data from holding still task is taken from the same time period as COP data in the following line task. The accelerometer data was analyzed in three axes, X, Y and Z. The results are presented as an average of the 3-axes in G ($9.8\ m/s^2$). All data are presented as an average of several trials.

Statistics

All statistical tests were processed using SPSS version 19 (SPSS Inc., Chicago, USA). General linear model, with repeated measures were used for comparison between the different intensities (rest, warm up, 75-80%, 85-87% and 90-95% of HR_{max}) and between the different tasks (5 shot series, holding still and following the line). Bivariate correlation was used for correlation analysis of COP and accelerometer with standard deviation (mm) in the holding still and following line tasks. Statistical significance was set at $P < 0.05$.

Results

Heart rate

Figure 8 shows the average heart rate achieved by the subjects at the different tests; 75-80% (T2), 85-87% (T3) and 90-95% (T4) of HR_{max}. The heart rate was significantly different between the tests (p= 0.000). In T3 and T4 the mean heart rate of the subjects before shooting were 1% below the given heart rate interval, and in T2 within the given heart rate interval.

The decrease in heart rate from before to after shooting was about the same at each intensity level, at least for the 3 interval exercises: 15% decrease in T2 and T4, and 16% in T3. At the warm up intensity, the decrease from before to after shooting was 12%.

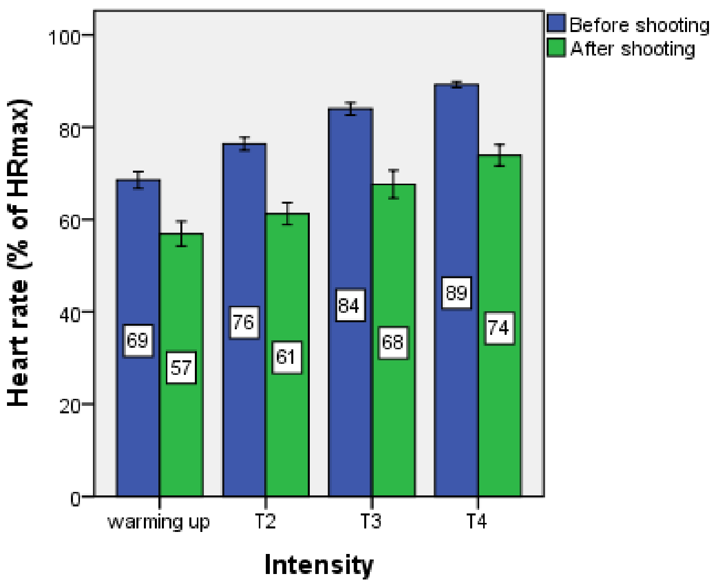


Fig 8. Heart rate achieved at the start of shooting and at the end of shooting at warm up, T2, T3 and T4. Labels show average heart rate achieved by the subjects before and after shooting at the different intensities. Error-bars represent 95 % CI.

Average distance from center

The results given as average distance from center of the target for the 5shot series are shown in figure 9. No significant differences were found in the 5 shot series between the different intensities (p= 0.179).

However, the results of the holding still task and following line task show an effect of intensity (figure 10). The holding still task is here shown with movement only in the vertical direction, and in the same time period as the following line task. The holding still task shows a significant effect of intensity (p= 0.018). The following line task did also show a significant effect of intensity (p= 0.006), but there was no significant difference between the two tasks (p= 0.244).

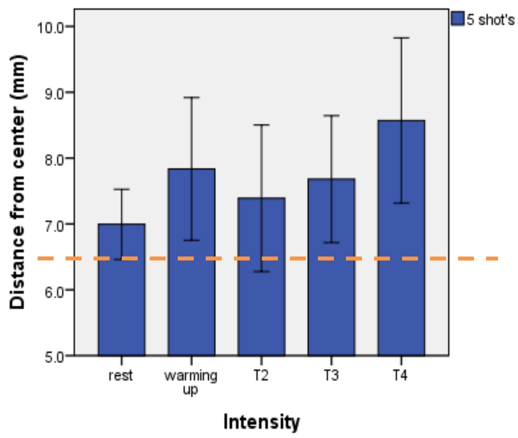


Fig 9. The 5 shot series task at the different intensities. The dotted line shows radius of the target. Error-bars represent 95 % CI.

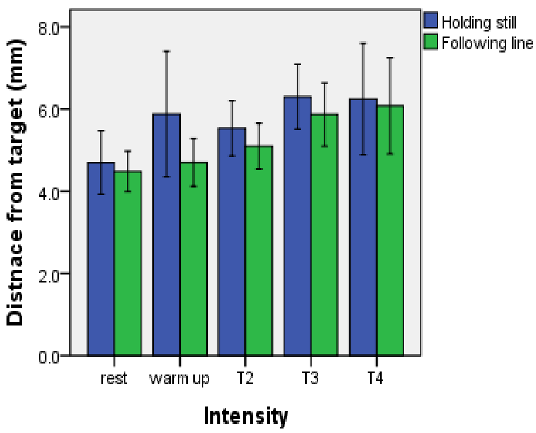


Fig 10. Average distance from the target in the holding still and following line task. In the vertical direction, and at the same time period as the following line task. Error-bars represent 95 % CI.

Figure 11 shows how much in percent the performance changed from rest as the intensity increased, in the holding still and following line tasks. There is no significant difference between the tasks (p= 0.236). The holding still task did not show any significant effect of intensity (holding still task p= 0.373), while the following line task did show a significant effect of intensity (p= 0.029).

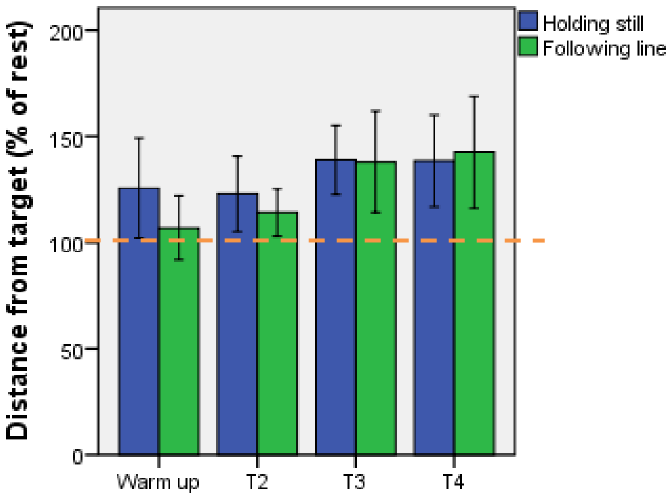


Fig 11. The figure shows how much in percent the holding still task and following line task is affected by intensity. The dotted line shows “rest” (100%). Error-bars represent 95 % CI.

Standard deviation in the holding still and the following line tasks

Figure 12 shows the results from the holding still task and following line task. The holding still task is shown as standard deviation of the radial distance (horizontal and vertical direction). The results from the holding still task are significant different from the following line task (p= 0.000), subjects performed better at the following line task. Both tasks showed a significant effect of intensity (p= 0.000).

Figure 13 shows the results from the holding still task and following line task with SD of vertical movements in both tasks. The holding still task is shown with the same time period as the following line task. The results shows a difference between the tasks, but the difference did not reach statistical significance (p= 0.070). There is still a significant effect of intensity in the holding still task (p= 0.017), and in the following line task (p= 0.030).

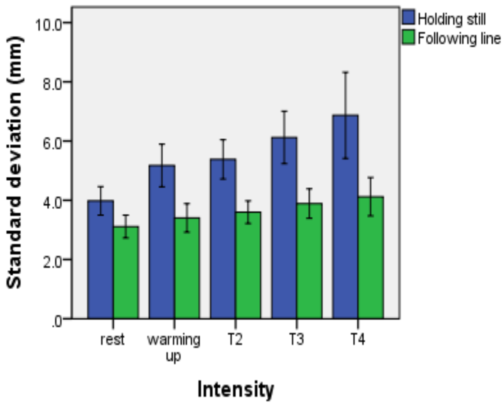


Fig 12. Standard deviation of the radial distance from the target in the holding still task, and SD of vertical movements in the following line tasks. Error-bars represent 95 % CI.

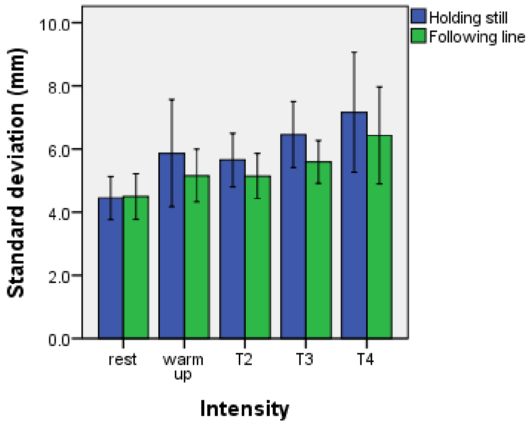


Fig 13. Standard deviation of vertical movements in the holding still and following line tasks. Holding still task is shown with the same time period as the following line task. Error-bars represent 95 % CI.

Figure 14 shows the time spent during the holding still task and during the following line task. Subjects used significantly longer time performing the holding still task than the following line task ($p= 0.000$). In time used at the following line task there is a significant effect of intensity ($p= 0.008$), time decreased as intensity increased.

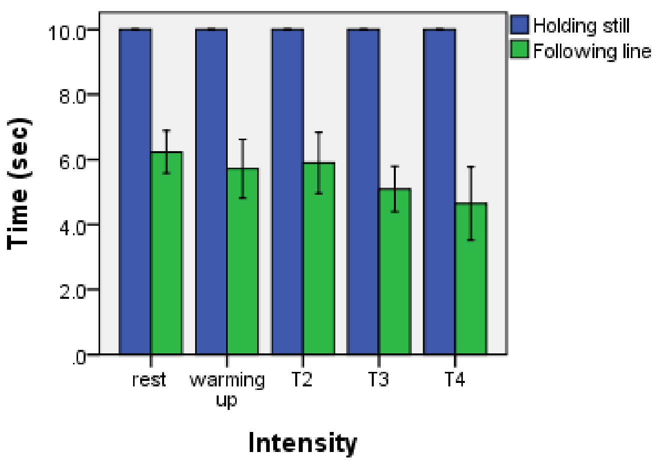


Fig 14. Time used during the holding still task and during the following line task at the different intensities. Error bars represent 95 % CI.

Center of pressure

Center of pressure movements during the holding still task and the following line task are shown in figure 15 (anterior-posterior direction) and 16 (medial-lateral direction). Movement in the X-axis (anterior-posterior) is greater than the movement in the Y-axis (medial-lateral) in both tasks. There is no significant difference between the holding still task and the following line task, in neither the X- (p= 0.753) or the Y-axis (p= 0.137).

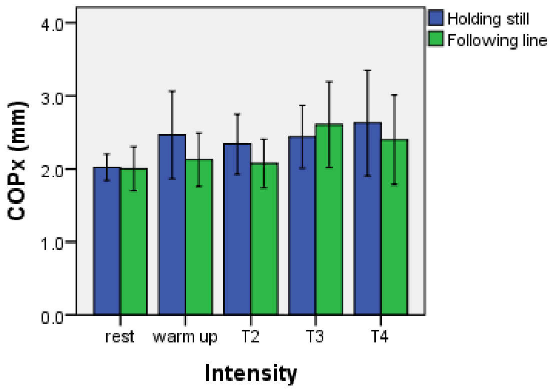


Fig 15. COP movement in the holding still and following line tasks, in the X-axis (anterior-posterior direction). Error-bars represent 95 % CI.

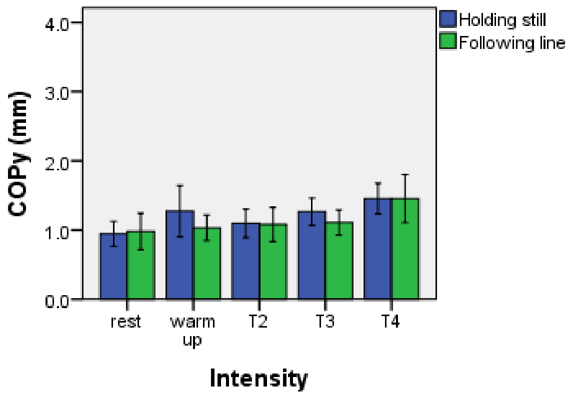


Fig 16. COP movement in the holding still and following line tasks, in the Y-axis (medial-lateral direction). Error-bars represent 95 % CI.

Figure 17 and 18 shows how much center of pressure movements is affected by intensity, given as percent of rest. In the X-axis (anterior-posterior direction) there are no significant effect of intensity (holding still p= 0.191, following line p= 0.117), and no difference between the tasks (p= 0.789). The Y-axis (medial-lateral direction) did not show a significant difference between the two tasks (p= 0.753). The holding still task shows a significant effect of intensity (p= 0.032) in the Y-axis (medial-lateral direction), while the following line task did not show a significant effect of intensity (p= 0.092).

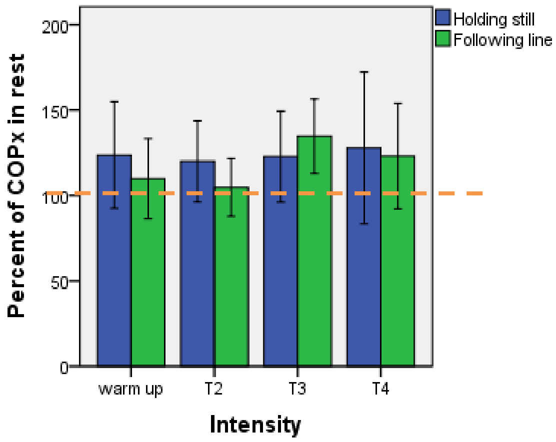


Fig 17. Percent of rest in COP movements in the X-axis (posterior-anterior direction). The dotted line shows “rest” (100%). Error-bars represent 95 % CI.

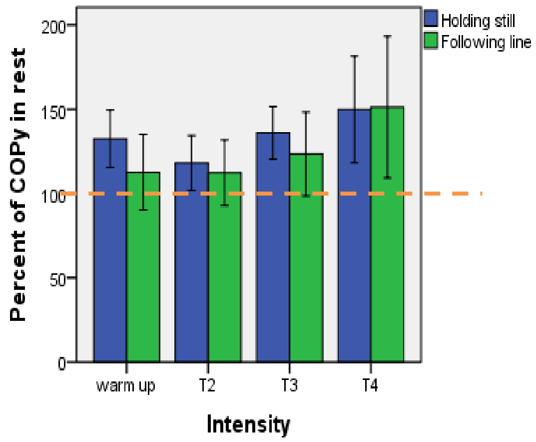


Fig 18. Percent of rest in COP movements in the Y-axis (medial-lateral direction). The dotted line shows “rest” (100%). Error-bars represent 95 % CI.

Accelerometer

Results from the accelerometer in the holding still and following line tasks are shown in figure 19. The results showed no significant effect of intensity (holding still p= 0.142, following line p= 0.760), and no significant difference between the two tasks (p= 0.417).

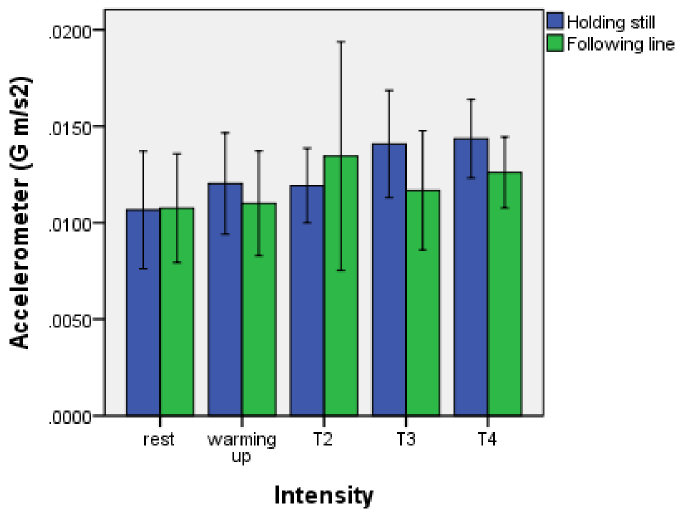


Fig 19. Accelerometer in the holding still and following line tasks at the different intensities. Error-bars represent 95 % CI.

Correlations

Holding still task

Figure 20 and 21 shows the correlation between standard deviation (mm) of vertical movements in the holding still task and COP movements in the medial-lateral direction (figure 20) and the anterior-posterior direction (figure 21). There is a stronger correlation between standard deviation of vertical movements in holding still task and COP movements in the medial-lateral direction (r= 0.759) than in the anterior-posterior direction (r= 0.420). The correlation is significant in both directions.

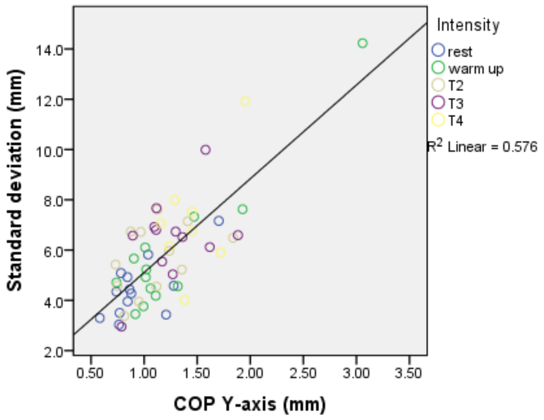


Fig 19. Correlation between SD of vertical movements in the holding still task and COP movements in the Y-axis (medial-lateral direction).

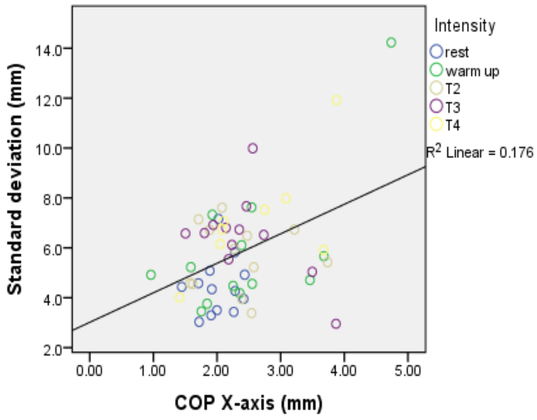


Fig 20. Correlation between SD of vertical movements in holding still task and COP movements in the X-axis (anterior-posterior direction).

Following line task

Correlation between COP movements (anterior-posterior and medial-lateral directions) and standard deviation (mm) of vertical movements in the following line task are shown in figure 22 and 23. The correlation is stronger in the medial-lateral direction (r= 0.740) than in the anterior-posterior direction (r= 0.294). COP movements in both directions show a significant correlation with standard deviation of vertical movements in the following line task.

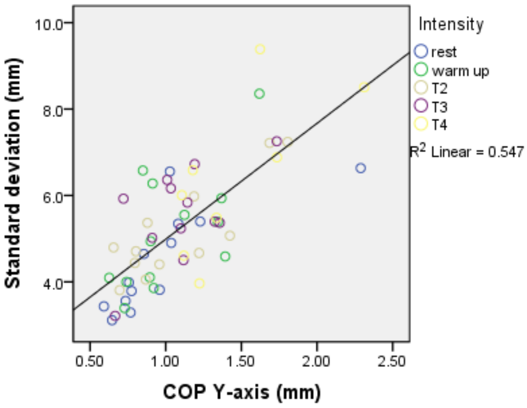


Fig 22. Correlation between SD of vertical movements in following line and COP movements in the Y-axis (medial-lateral direction).

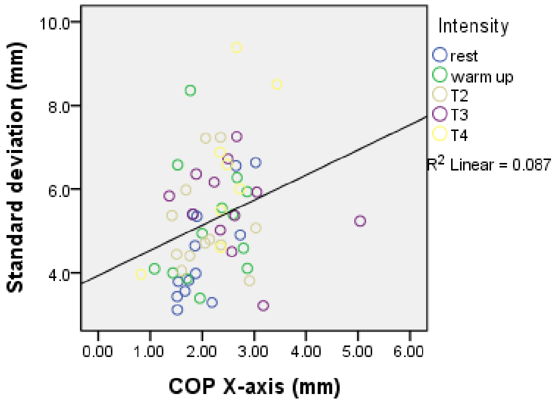


Fig 23. Correlation between SD of vertical movements in following line and COP movements in the X-axis (anterior-posterior direction).

The correlation between SD of verticals movements and COP movements is significant in both the following line task and the holding still task, and the correlation is strongest in the medial-lateral direction in both tasks.

Accelerometer

There is no significant correlation between accelerometer data and standard deviation of vertical movements, neither in the holding still task (r= 0.115) or the following line task (r= 0.018).

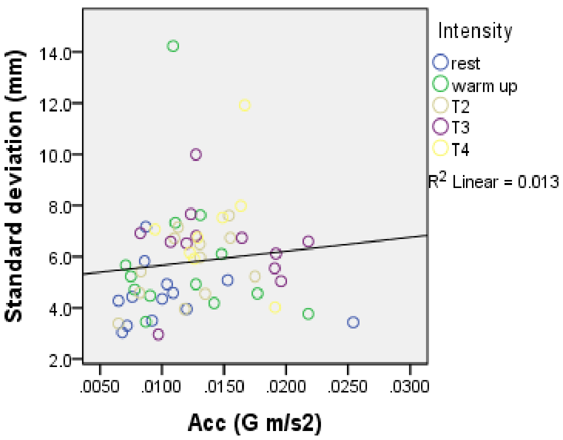


Fig 24. Correlation between accelerometer data and SD of vertical movements in the holding still task.

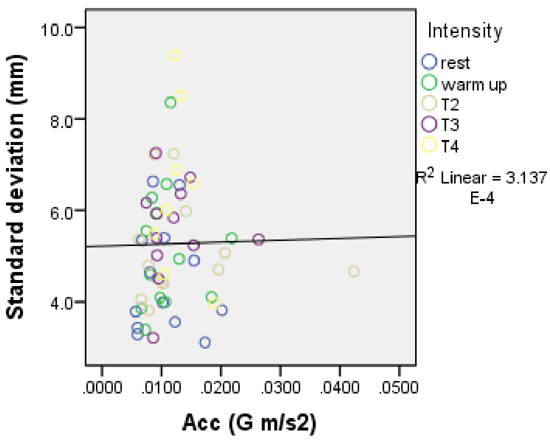


Fig 25. Correlation between accelerometer data and SD of vertical movements in the following line task.

Discussion

The main findings in this investigation showed no significant effect of prior exercise intensity on shooting performance regarding the 5 shot series. In contrast, the holding still on target and following line tasks were both significantly affected by prior exercise intensity. Movement of COP during shooting was greater in the anterior-posterior direction than in the medial-lateral direction. The accelerometer attached at the front of the barrel did not show any significant effect of intensity.

Heart rate

According to Hoffman and Street (1992), biathletes are approaching the firing range with a heart rate of 85 – 87% of HR_{max} in competitions. During shooting, the heart rate decreases to a minimum of 70% of HR_{max}. In one of the tests the subjects were supposed to shot with a heart rate of 85 – 87% of HR_{max}, and the average heart rate achieved by the subjects on the test was 84% of HR_{max}. After shooting the subjects heart rate dropped to 68% of HR_{max}. The subjects had 3 tasks to perform and spent therefore more time on the shooting than a biathlete usually would do in a competition. It is reasonable to think that this would cause a greater drop in heart rate than in a normal competition. This, however, was not the case, even though the precision task took about 50 sec to perform, while in competition the biathletes use about 20-25 sec. Since the decrease in heart rate at T3 (85-87% of HR_{max}) was about similar to what Hoffman & Street (1992) found in a normal shooting series in a competition, it seems as if the drop in heart rate is greatest during the initial 20-25 sec, and then flattens out. The differences in heart rate, both before and after shooting, was significantly different between the test days ($p= 0.000$). This confirms that the subjects experienced different intensities at the 3 test days.

5 shot series

The results showed no significant effect of intensity on the 5 shot series ($p= 0.179$). This is in contrast with Hoffman et al (1991). They found that shot score (distance from center) in standing shooting was significant greater ($p= 0.001$) for the two highest exercise conditions compared with the lowest exercise condition and at rest. In our investigation the “front sight” was removed from the subject’s weapon and only their rear sight and the laser was used for aiming. Subjects were not used to have a laser dot for aiming, and it seemed like they found it difficult to know exactly when to pull the trigger. Several subjects pulled the trigger too late. Thus, the aspect of timing became difficult. The result may have been more similar to

Hoffman et al (1991) if the subjects had used their "front sight" (aperture) for aiming instead of the laser pen. Maybe, if there had been more trials per subject or more subjects in total, the effect of intensity could have been statistical significant. Thus, the results cannot tell at which heart rate subjects perform best, or at what intensity level biathletes should approach the shooting range for best performance.

Isometric vs. dynamic precision

The holding still task was significantly more affected by intensity than the following line task ($p= 0.002$) when looking at results given as standard deviation of radial distance from the center in the holding still task (figure 12). However, there are some factors needed to be taken into consideration. This is the direction of the movement of the laser in holding still task, and the time used during the tasks. Because the results from the following line task are given as SD of vertical movements we did analysis were SD of only vertical movements also are shown in the holding still task (figure 13), instead of movements in both the horizontal and vertical direction (figure 12). In addition, we used the same time period during the holding still task, as in the following line task. When these factors (figure 13) are taken into consideration, there was no longer a significant difference between the tasks ($p= 0.070$). The effect of intensity was still significant (holding still $p= 0.017$, following line $p= 0.030$). Results given as average distance from center shows about the same as the SD results; holding still and following line tasks are both significantly affected by fatigue (holding still $p= 0.018$, following line $p= 0.006$), and there is no significant difference between the two tasks ($p= 0.244$).

When performing the holding still task at rest, the subjects were able to hold their breath for the 10 seconds used to perform the task. When the intensity increased, it seemed like this became difficult, and the subjects needed to have at least one breath during the 10 seconds. This caused a relatively large movement in the barrel. This may have caused a greater effect of intensity than there would have been if the subjects didn't have to breathe during the task. The time spent at each task may also be an important factor. Performing the holding still task took 10 seconds. The time used during following the line task varied from 2 – 11 seconds. There is a significant effect of intensity on time spent on the following line task; time decreased as intensity increased. When the heart rate increased, it seemed to become more difficult for the subjects to hold their breath and controllably move the laser across the line. Therefore, it seemed like the subjects performed the task faster to avoid hypoxia, and to avoid having to breathe during the task. When the subjects performed the task too fast (faster than 4 seconds), it is no longer a relevant task compared with the biathletes aiming technique in standing shooting. Therefore, we had a cut off on 4 sec, and removed all trials performed faster than 4 sec in the following line task. Thus, some data were lost, in total 6 trials. There are some factors that make it difficult to compare the holding still and following line tasks, and the difference between them is not strong enough to say for certain if the subjects perform better in dynamic precision (following line) than in isometric precision (holding still), or if isometric precision is more affected by intensity than dynamic precision.

The holding still task is not significantly more affected by intensity than the following line task. On average there was a difference, but this did not reach statistical significance. It is possible that with an increased number of subjects or more trials per subjects, the results could have reached statistical significance. Thus, the results cannot for certain justify the technique used by biathletes in standing shooting. If there had been a significant difference between isometric and dynamic precision and the subjects performed best at dynamic precision, the results could have justified the biathletes shooting technique in standing position. But as mentioned, there are some factors that make it difficult to compare the holding still task with the following line task. In addition, the results do not show any data on the aspect of timing, and how this is affected by intensity.

Center of pressure (balance)

It could be expected that the COP movement in the anterior-posterior direction would be greater in the following line task than in the holding still task, because the subjects moved their weapon in this direction when following the line. This was not the case, and it seemed like the subjects were able to rotate their upper body as they followed the line, without changing the center of pressure.

Center of pressure movement is clearly greater in the anterior-posterior direction than in the medial-lateral direction. One important factor in biathletes standing position is to find a leg placement that avoids as much body sway in both directions as possible. Because of the greater COP movement in the anterior-posterior direction it seems especially important to have a leg placement that avoids movement in this direction. Many biathletes move their rear leg either anterior or posterior to the front leg, to get a more stable position. It is interesting to see that there is no significant effect of intensity on COP movement in the anterior-posterior direction. In the medial-lateral direction there is a significant effect of intensity in the holding still task (p= 0.032), but not in the following line task (p= 0.092). This shows that stance width (distance between the legs in the medial-lateral direction) of the legs may be an important factor in standing position, to avoid body movement in the medial-lateral direction as intensity increases. Earlier studies have shown that stance width may be an important factor for shooting performance (Hawkins & Sefton, 2011). The same is also shown from the correlations data. The COP movement in the medial-lateral direction shows a stronger correlation with standard deviation of vertical movements in both the holding still and following line task, than the anterior-posterior direction. This indicates that balance and stance width in the medial-lateral direction is important for a good shooting performance when intensity increases.

Earlier studies on balance and shooting performance have been focusing on the differences in elite shooters and novice shooters (Niinimaa & McAvoy, 1983), and about the context between balance and successful and not so successful shots (Era et al, 1996). Previous studies show about the same COP movement (mm) among shooters, as the subjects in this study had when shooting at rest (Hawkins & Sefton, 2011) (Herpin et al, 2009). No studies have investigated the effect of prior exercise on COP movement and shooting. Our results showed a significant correlation between performance in the holding still and following line task, with the COP data. In addition to other studies, our results suggest that balance is important for shooting performance.

Accelerometer (stability of hold)

Results from the variation in accelerometer showed no significant effect of intensity, or between the holding still task and the following line task. Previous studies have shown that biathletes with a good shooting performance have a stable aiming pattern (Baca A & Kornfeind, 2010), and that stability is affected by intensity (Mononen et al, 2006) (Grebot & Groslambert, 2003). This is in contrast with our results, at least the results from the accelerometer, which showed no significant correlation with performance in neither the holding still nor the following line task. The results from the laser are also an indication of the stability of hold. These show that stability is significantly affected by intensity in the holding still and following line tasks. Results from the accelerometer show that the use of an accelerometer may not be the best way to measure stability of hold, and that a laser based or infrared system may be a better way to look at the aiming pattern, and stability.

Method discussion

Shooting performance in biathlon is a topic that has been given little attention in previous research. The best method for studying shooting performance is therefore unclear, and we did not have much to base our method on. We tried with a laser-based system, and as earlier mentioned this may have affected some of the results. With more trials per subject and more subjects in total our data may have been different. If the subjects had more time to get used to the laser before starting the tests, maybe the aspect of timing would be easier, and the shooting performance better. If we were only interested in shooting performance, the subjects could have started with the 5 shot series at each test, and that way have the correct heart rate at every shooting.

Time used in the following line task varied much, from ca 2 – 11 seconds. When subjects performed the task faster than 4 seconds, the task was no longer relevant to the aiming technique used by biathletes in standing shooting. The subjects reduced time used in the following line task as the intensity increased. That way they could still be able to move across the line without having to take a breath during the task. Maybe, if the line had been shorter, and the test leader had been stricter about how fast they should move the laser across the line, the results could have been more relevant to biathletes actually aiming pattern.

As intensity increased the subjects needed to breathe at least once during the holding still task. If the holding time had been reduced to 5 sec, subjects may have avoid the extra breath, and the comparison from rest to 75-80%, 85-87% and 90-95% of HR_{max} would be more reliable.

Test day 1 was performed as a pre-test to decide the velocity on the treadmill for each subject on 75-80%, 85-87% and 90-95% of HR_{max}. The velocity appeared to be relatively correct in relation to the given heart rate interval, although some adjustment of the speed was needed, especially at the 75-80% of HR_{max} test. Overall the procedure at test day 1 seems to be a good way to calculate the correct velocity at the different intensities.

After the data collection was done, we had a great amount of data. For this master thesis, we had to select the most important data for the purpose of this study, because of the time available. Therefore, further investigation can be done with the data that was collected. There is information about heart rate values every 5 sec during the precision tasks. Thus, we can find what heart rate each subject had when performing the 3 different tasks. This is interesting since the heart rate decreased relatively much during shooting. For example, heart rate after shooting at T4 (90-95% of HR_{max}) was lower than heart rate before shooting at T2 (75-80% of HR_{max}). It also would be interesting to look at only the 5 first sec of the holding still task. Maybe we then could have avoided the extra movement in the barrel caused by breathing during the task. However, some of the extra breathes has already been removed, due to using the same time period on the holding still task as on the following line task.

Conclusions

The current results showed no significant effect of intensity on shooting performance (5 shot series). There was a difference between the holding still task (isometric precision) and the following line task (dynamic precision), but the difference did not reach statistical significance (p= 0.07). Center of pressure movement is greater in the anterior-posterior direction than in the medial-lateral direction. Results from the accelerometer showed no significant correlation with shooting performance.

The results did not show any specific heart rate at which subjects performed best, but show that performance, at least in the holding still and following line task, decreases as the intensity increases.

Since the difference between isometric and dynamic precision didn't reach statistical significance, the results cannot for certain justify the shooting technique used by biathletes in standing shooting. A stable standing position to avoid body sway seems to be important for performance in the holding still and following line task. Therefore, additional use of balance training in standing position may be useful.

References

- Baca A, Kornfeind P. Stability analysis of motion patterns in biathlon shooting. Human Movement Science (2010), doi: 10.1016/j.humov.2010.05.008

- Enoka, RM & Duchateau, J. Muscle Fatigue: What, why and how it influences muscle function.2008. Journal Physiology 586(1): p.11-23.
- Enoka R, Stuart D.G. Neurobiology of muscle fatigue. Journal of Applied Physiology, 1992: Vol. 72 Issue 5. p. 1631-1648
- Era P, Konttinen N, Mehto P, Saarela P, Lyytinen H. Postural stability and skilled performance-a study on top-level and naive rifle shooters. Journal of Biomechanics, 1996: Vol. 29 Issue 3. p. 301-306
- Evans R, Scoville C, Ito M, Mello R. Upper body Fatiguing exercise and shooting performance. Military Medicine: 2003; 168, 6
- Grebot C, Groslambert A, Rouillon JD. Relationship between velocity and accuracy in standing shooting in biathlon. Science & Sports 2002 ; 17 : p. 35-7
- Groslambert A, Grappe F, Candau R, Rouillon JD. Cardio-ventilatory responses in biathlon standing shooting. Science & sports 1998; 13: p. 135-7.
- Hawkins R, Sefton J. Effects of stance width on performance and postural stability in national-standard pistol shooters. Journal of sports sciences, 2011; 29(13): p. 1381 – 1387.
- Herpin G, Gauchard G.C, Lion A, Collet P, Keller D, Perrin P. Sensorimotor specificities in balance control of expert fencers and pistol shooters. Journal of Electromyography & Kinesiology 2010, Vol. 20 Issue 1, p. 162 8p.
- Hoffman M.D, Gilson P.M, Westenburg T.M, Spencer W.A. Biathlon shooting performance after exercise of different intensities. International Journal of Sports Medicine 1992: Vol. 13 Issue 3. p. 270-273
- Hoffman M.D, Street G.M. Characterization of heart rate response during biathlon. International Journal of Sports Medicine 1992: Vol. 13 Issue 5. p. 390-394
- Mason B, Cowan L.F, Gonczol T. Biomechanical factors affecting accuracy in pistol shooting. Excel 1990: Vol. 6 Issue 4. p. 2-6
- Niinimaa V, McAvoy T. Influence of exercise on body sway in the standing rifle shooting position. Canadian Journal of Applied Sport Sciences 1983: Vol. 8 Issue 1. p. 30-33

- Vesterinen V, Mikkola J, Nummela A, Hynynen E, Hakkinen K. Fatigue in a simulated cross-country skiing sprint competition. Journal of Sports Sciences 2009, Vol. 27 Issue 10, p. 1069
- Viitasalo J.T, Era P, Konttinen N, Mononen H, Mononen K, Norvapalo K, Rintakoski E. The posture steadiness of running target shooters of different skill levels. Kinesiology 1999: Vol. 31 Issue 1. p. 18-28