

Effect of exercise intensity on shooting performance in the sport of Summer Biathlon
by Brian Keith Higginson

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Health and Human Development
Montana State University
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Abstract:
The purpose of this study was to determine the effect of running intensity on shooting performance in summer biathletes by comparing shooting scores immediately following bouts of exercise at four different intensities in an effort to determine if running intensity can be maintained, or increased, without a subsequent decrement in shooting performance.

Each subject (seven elite and three novice) was required to shoot five shots at paper targets immediately following bouts of exercise at four different intensities. Exercise intensities included shooting with a resting heart rate (INTI), slowing to 75% of race pace (INT2), maintaining race pace (INT3), and sprinting (INT4). All subjects began testing by shooting five shots prone and five shots standing at INTI. All subsequent conditions were counterbalanced for intensity and position. A one kilometer loop was run between shooting bouts with changes in exercise intensity (INT2-INT4) occurring 50 meters prior to entering the range. Measures of shooting performance included the number of shots hit (SH), shooting accuracy (SA), and shooting precision (SP).

As intensity increased from INT2 to INT4, there was a, significant decrease (pO.OOl) in 50 meter run time prior to entering the range (12.52 s vs. 8.96 s, respectively), with no difference in one kilometer run times (p=0.50). Although an , increase in exercise intensity was associated with a decrease in SH for both the prone and standing position, there was no significant difference in SH for the elite subjects (N7), or all subjects as a group (N10), as a result of position (N7: p=0.64, N10: p=0.86) or intensity (N7: p=0.10, N10: p=0.12). A significant interaction effect was found in N7 for the SA measure of shooting performance (p=0.005), as well as a significant difference in both position (p<0.00l) and intensity (p=0.008) for the SP measure. SA for NlO was significantly different for both position (p<0.001) and intensity (p=0.009). There was no difference between N7 and NlO for the SP measure of shooting performance.

These preliminary findings indicate that race times may be decreased in the sport of summer biathlon by as much as 7.12 seconds in a 5 km race without a subsequent compromise in shooting performance.

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Brian Keith Higginson

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

Daniel P. Heil, PhD — (Signature) — 4/17/02 Date

Approved for the Department of Health and Human Development

Ellen Kreighbaum, PhD — (Signature) — 4/17/02 Date

Approved for the College of Graduate Studies

Bruce McLeod, PhD — (Signature) — 4-22-02 Date

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ABSTRACT

The purpose of this study was to determine the effect of running intensity on shooting performance in summer biathletes by comparing shooting scores immediately following bouts of exercise at four different intensities in an effort to determine if running intensity can be maintained, or increased, without a subsequent decrement in shooting performance.

Each subject (seven elite and three novice) was required to shoot five shots at paper targets immediately following bouts of exercise at four different intensities. Exercise intensities included shooting with a resting heart rate (INT1), slowing to 75% of race pace (INT2), maintaining race pace (INT3), and sprinting (INT4). All subjects began testing by shooting five shots prone and five shots standing at INT1. All subsequent conditions were counterbalanced for intensity and position. A one kilometer loop was run between shooting bouts with changes in exercise intensity (INT2-INT4) occurring 50 meters prior to entering the range. Measures of shooting performance included the number of shots hit (SH), shooting accuracy (SA), and shooting precision (SP).

As intensity increased from INT2 to INT4, there was a significant decrease ($p<0.001$) in 50 meter run time prior to entering the range (12.52 s vs. 8.96 s, respectively), with no difference in one kilometer run times ($p=0.50$). Although an increase in exercise intensity was associated with a decrease in SH for both the prone and standing position, there was no significant difference in SH for the elite subjects (N7), or all subjects as a group (N10), as a result of position (N7: $p=0.64$, N10: $p=0.86$) or intensity (N7: $p=0.10$, N10: $p=0.12$). A significant interaction effect was found in N7 for the SA measure of shooting performance ($p=0.005$), as well as a significant difference in both position ($p<0.001$) and intensity ($p=0.008$) for the SP measure. SA for N10 was significantly different for both position ($p<0.001$) and intensity ($p=0.009$). There was no difference between N7 and N10 for the SP measure of shooting performance.

These preliminary findings indicate that race times may be decreased in the sport of summer biathlon by as much as 7.12 seconds in a 5 km race without a subsequent compromise in shooting performance.

CHAPTER ONE

INTRODUCTION

In the sport of biathlon, it is not uncommon for top-ten finishes of elite competitors to be decided by a matter seconds. The 2000 US National Biathlon Championships is a prime example of this. The difference between 2nd and 3rd place was a mere three tenths of a second. A one-minute difference could have potentially moved the 24th place finisher up to 14th place. With competition this tight it is apparent that a need exists for elite biathletes to find a way to decrease their race times by even the smallest of margins. Being able to take two seconds off a 25 minute race could potentially mean the difference between a first and second place finish.

Historical Background

The name "biathlon" is a Greek word meaning two tests, and combines two skills with entirely different requirements (Niinimaa 1988). Biathlon is an Olympic winter sport combining the endurance of cross country skiing and the precision of rifle marksmanship. The origins of Biathlon have been traced as far back as 3000 BC where rock paintings depicted hunters with bow and arrows moving on "sliding timbers". However, the first written descriptions of hunting on skis came from Roman, Greek, and Chinese historical writings in 400 BC. Traditional military patrol races, the most commonly recognized origins of Biathlon, came into being in the Middle Ages. Skiing

regiments were becoming active in Scandinavia and Russia in the 1500's, and by the end of the 19th century, Germany, Austria, and Switzerland were also beginning to see soldiers on skis.

Although the first recorded "Biathlon" competition took place between Swedish and Norwegian border patrol units in 1767, it was not until the first Winter Olympic Games in Chamonix, France in 1924 that the military ski patrol race was introduced as a demonstration sport. Individual events did not occur until the 1960 Winter Olympic Games in Squaw Valley, CA, when the first Mens Individual 20 km Biathlon made its debut. Up until 1977 only large bore (30.06, .308, and .243 cal) rifles were used for competition, since then only small bore (.22 cal) rifles have been allowed. The change to small bore rifles was made primarily to make the sport more accessible to a wider range of competitors, in addition to saving money on ammunition and targets and decreasing the space required to hold competitions. Although it is still a relatively obscure sport in the United States, with around 1,000 competitors nationwide, it is the most popular televised winter sporting event in Europe.

Traditionally, Winter Biathlon has been the most widely recognized form of biathlon. However, in the early 1980's the sport of Summer Biathlon was introduced as a way for winter biathletes to stay in shape and, as a result, has rapidly increased in popularity over the last decade. The main reason for this is that it incorporates running instead of skiing. Therefore more people are able and willing to participate since it requires less of a financial obligation by the athlete than winter biathlon, and more race venues are available since most climates facilitate running during the summer months.

Summer Biathlon race distances are typically five to eight kilometers (km) in length and consist of either two or four shooting bouts, with one to two and a half kilometer loops run between bouts. Shooting bouts alternate between the prone and standing (off-hand) shooting positions, starting with the prone. Targets are located 50 m from the firing line with target diameters of 40 millimeters (mm) and 110 mm for prone and standing, respectively. Five shots are allowed to hit five targets, with either a 100 m penalty lap assessed for missed targets, or a time penalty in the case of some of the longer events. Winners are determined by the shortest elapsed race time, regardless of shooting score.

Unlike most shooting sports in which success is based on accuracy (proximity of shot to center of target), shooting performance in the sport of summer biathlon is based on a hit or miss system. As long as each shot falls within the 40 mm and 110 mm diameter target for the prone and standing shooting positions, respectively, it is considered a hit. This method of scoring tends to favor the biathlete best able to minimize their shot group (proximity of shots in relation to each other), and maximize their accuracy, thereby facilitating a greater margin of error while shooting.

Since the sport of Summer Biathlon incorporates running and shooting, overall race times can be reduced by either improving running performance, increasing shooting accuracy, or a combination of both. Although there are numerous studies on improving running performance, as well as the effects of heart rate, breathing, and muscle fatigue on competitive position shooters, very little research has been done on the effects of these variables in combination as they relate to the sport of biathlon. The limited research in

this area may be a function not only of the relative obscurity of the sport, but also the difficulty in measuring the various physiological parameters associated with the sport in a field setting. Researchers such as Hoffman, Gilson, Wetenburg, and Spencer (1992), and Groslambert, Candau, Belli, Gilliot, and Roillion (1997) have addressed the limitations of biathlon research conducted in the lab. Even though it may be easier to collect physiological data in the lab, the applicability of these results to actual race conditions are questionable.

Currently, it is common for elite biathletes to decrease their running speed prior to entering the shooting range in an effort to decrease both respiratory and heart rate. This decrease in respiratory and heart rate is believed to result in better overall shooting performance by limiting the amount of rifle movement while shooting. It has recently been suggested, however, that an increased intensity of exercise immediately prior to shooting has minimal effect on shooting performance in elite-level winter biathletes (Niinima 1988; Hoffman et al., 1992; Soldatov 1983). Soldatov reported that if an athlete is able to enter the shooting range at a greater intensity, yet maintain satisfactory shooting performance, the potential exists to decrease race times by as much as 25-30 seconds in a 20 km race (winter biathlon). If this holds true, then it is likely that the greatest potential for improvement in performance (decreased race times) for the elite biathlete is to reduce the amount of time lost during the approach to the firing line. Since most previous research in this area has dealt with Winter Biathlon (Hoffman et al., 1992; Hoffman 1992; Groslambert et al., 1997; Soldatov 1983), it would be of interest to see if this strategy can be successfully applied to the sport of Summer Biathlon. Therefore, it was

the purpose of this study to evaluate the relationship between exercise intensity and its subsequent effects on shooting performance in summer biathletes in a field (simulated race) setting. Shooting performance was measured using three variables: number of shots hit (SH); shooting accuracy (SA); and shooting precision (SP). Shooting performance was compared between four conditions: 1) Resting heart rate (INT1), in which shooting occurred prior to any exercise; 2) After running a one km loop at race pace (RP), then decreasing to 75% of RP 50 m prior to entering the shooting range (INT2); 3) Maintaining RP all the way into the shooting range (INT3); and 4) Sprinting the last 50m into the shooting range after running a one km loop (INT4).

Statement of Purpose

The purpose of this study was to determine the effects of running intensity immediately prior to shooting (last 50 m) on shooting performance in summer biathletes. This was achieved by comparing shooting scores immediately following bouts of exercise at the four different intensities (INT1, INT2, INT3, and INT4) in an effort to determine if running intensity (speed) immediately prior to shooting can be maintained, or increased, without a subsequent decrement in shooting performance.

Hypothesis

The mean shooting variables (SH, SA, SP) are not significantly different among the four levels of the independent variables (INT1, INT2, INT3, INT4) for the prone and standing positions.

$$\mathbf{H_o: \mu_{Pi} \neq \mu_{Pj}, and\ \mu_{Si} \neq \mu_{Sj}}$$

$$\mathbf{H_a: \mu_{Pi} = \mu_{Pj}, and\ \mu_{Si} = \mu_{Sj}}$$

Where: μ_P and μ_S are population means for shooting performance (SH, SA, SP) in the prone and standing position, respectively, with i and j representing any two levels of each dependent variable across the four intensity levels.

Limitations

1. The subjects' unfamiliarity with shooting under conditions required by the protocol could potentially affect shooting scores. Biathletes typically shoot at either a resting heart rate (during practice), or at a heart rate similar to that elicited in actual competition.
2. Due to the subjectivity of INT2 it was assumed that all subjects could accurately determine 75% of their race pace and reduce their speed accordingly and consistently for both INT2 conditions (prone and standing shooting positions).

Delimitations

1. The scope of this study was delimited to competitive biathletes from the Bozeman, Montana, community.
2. Since all shooting data was collected outdoors, attempts were made to minimize the affects of weather on shooting performance by not collecting data on days that were excessively cold or windy.
3. No sight adjustments were allowed once testing began.

Definitions

Accuracy:	The distance of a shot from the center of the target.
Elite level:	This category includes all individuals on the U.S. National, World, Olympic, or development teams. It may also include less experienced competitors who chose to race in this category, and is differentiated from Open level competitors through the use of smaller targets in the prone position.
Hit:	A shot that results in the knocking down of a target. Shot must hit within a 40 mm and 110 mm diameter circle for prone and standing, respectively.
Misfire:	Trigger is pulled, but the round fails to fire.
Miss:	A shot that does not result in the knockdown of a target (i.e., shot does not fall within the 40 mm and 110 mm diameter circle for prone and standing, respectively).
Off-hand:	Shooting position in which the competitor remains standing, more commonly referred to as the standing position.
Precision:	Closeness of all shots in relation to each other. Typically measured by the smallest circle that encompasses all shots.
Prone:	Shooting position in which the competitor is lying down.
Range:	Shooting range where all shooting takes place.
Recovery:	Arbitrary distance selected by each individual athlete prior to entering the range in which they slow down in an effort to decrease their breathing and heart rate.
Set-up time:	Amount of time used to take the first shot once a competitor gets into the shooting position.
Zero:	Action performed prior to competition in which all competitors make sight adjustments to their rifle.

Operational Definitions

Age Predicted Maximal Heart Rate:	220 minus current age in years.
Maximal Oxygen Consumption ($\dot{V}O_{2max}$):	The rate of oxygen utilization by working muscle tissue during heavy exercise. $\dot{V}O_{2max}$ is achieved by progressively increasing the level of exercise intensity until oxygen consumption plateaus, or changes very little, despite further increases in intensity.
Respiratory Exchange Ratio (RER):	The ratio of CO_2 produced to the volume of O_2 consumed during resting or steady state exercise conditions.

CHAPTER TWO

REVIEW OF THE LITERATURE

Introduction

Although there are numerous studies that address the individual sports of cross country skiing (Rundell 1996; Rundell and Bacharach, 1994), running (Conley 1981; Koeslag and Sloan, 1976; Rundell 1996), and shooting (Era, Konttinen, Mehto, Saarela, and Lyytinen, 1996; Helin, Sihvonen, and Hanninen, 1987; Konttinen and Lyytinen, 1992; Konttinen, Lyytinen, and Konttinen, 1995; Konttinen, Lyytinen, and Viitasalo, 1998a, 1998b; Lakie, Villagra, Bowman, and Wilby, 1995; Zatsiorsky and Aktov, 1990), there is limited research specifically addressing the integration of these components into the sport of biathlon. Of these studies, all pertain to winter biathlon, and most are strictly observational (Groslambert et al., 1997; Hoffman and Street, 1992), or experimentally controlled in a laboratory setting (Bozsik and Kaske, 1998; Groslambert, Candau, Hoffman, Bardy, and Rouillion, 1999; Groslambert, Grappe, Candau, and Rouillion, 1998; Hoffman et al., 1992). The lack of research in the sport of summer biathlon, particularly in a field setting under actual race conditions, prompted the current study.

Observational Studies

The Albertville Winter Olympic Games of 1992 gave Groslambert et al. (1997) an opportunity to look at the correlation between the installation phase (set-up time) of shooting and shooting performance. Groslambert observed 24 males competing on the 6

highest-ranked relay teams at the Olympic Games. A positive relationship was found between installation time and penalty time (shots missed) in the prone position. As the installation time increased, the more likely an individual was to miss the target. The opposite was found to be true for the standing position. As installation time increased, the number of missed shots decreased. This trend could be attributed to the fatigue associated with the high level of physical exertion immediately prior to shooting, decreasing the stability of hold. Due to this decreased stability of hold, and a smaller base of support afforded by the standing shooting position, postural control of the rifle can be increased by maximizing installation time. In conclusion, Groslambert recommended that elite level biathletes minimize installation time in the prone position, and adapt their installation time in the standing position to individual heart rate recovery to maximize shooting performance. Although he agrees with other investigators (Niinimaa 1988; Hoffman et al., 1992; Soldatov 1983) that overall race times for elite level biathletes can be decreased by maintaining skiing speed prior to shooting, he was in disagreement as to its magnitude.

Soldatov (1983) suggested that 24-30 seconds could be gained in a 20 km race by maintaining skiing speed prior to shooting, while Groslamberts' data shows a gain of only 10.2 seconds. There are two possible explanations for this discrepancy. The first being that since Groslamberts' was an observational study, individual recovery times were unable to be controlled and accounted for. Based on data from video analysis, the amount of time for the athlete to cover the last 50 m prior to entering the shooting range could be calculated. Therefore, if an athlete started recovery (slowing down) before that

point, any loss of time associated with the decrease would not have been considered. Also, Groslambert collected data during a relay race, in which the competitors have an additional three rounds (eight rounds total) to hit five targets in each shooting bout. Therefore, it is not uncommon for biathletes in a relay race to come into the range at a higher intensity (speed) than they normally would since they know there is more room for error while shooting. This could account for the disparity between the two times since Soldatov studied time decreases during individual races (five shots per shooting bout).

Hoffman (1992) conducted a similar observational study on 14 members (five men, six women) of the US National Biathlon Team during an early season biathlon race series. Heart rate data were gathered throughout the race (18.4 and 14.8 km for men and women, respectively) to get a better understanding of the physiological demands of biathlon and the strategies used in approaching the shooting range. Hoffman found that heart rates decreased 10-12 beats per minute (bpm) over a time of approximately 50-60 seconds during the approach to the firing line. Upon arrival to the firing line heart rates between the two shooting positions were similar (85-87% of maximum heart rate) with minimum heart rates during firing around 20 bpm lower for the prone position than the standing. This lower minimum heart rate in the prone position is to be expected since more time is usually spent in this position, allowing for greater recovery. Also, less work is required by the heart in this position since venous return of the blood from the legs is not required to work against gravity, thereby decreasing peripheral resistance (Bevegard, Freyschuss, and Strandell, 1966; Stenberg, Astrand, Ekblom, Royce, and Stalin, 1967).

This decrease in peripheral resistance increases stroke volume which, in turn, decreases the number of times per minute the heart has to beat to pump a given volume of blood.

Although it would seem logical to assume that a larger stroke volume would result in greater rifle movement, a slower heart beat might allow for a longer period in which to stabilize the hold before shooting and facilitate timing of the shot with the cardiac cycle. Research has yet to be done in this area to ascertain whether the additional base of support (increased stability of hold) in the prone position is sufficient to overcome the increased movement associated with a greater stroke volume.

Experimental Studies

With the exception of Hoffman et al. (1992), most experimental research involving shooting performance in the sport of biathlon has focused on shooting stability in the standing position (Bozsik 1998; Groslambert et al., 1998; Groslambert et al., 1999; Niinimaa and McAvoy, 1983).

A force plate was utilized by Niinimaa (1983) to measure the influence of physical exercise simulating biathlon race intensities on body sway while in the standing shooting position. He tested a wide range of shooters, including biathletes (n=4), position shooters (n=4), and a control group, which had no previous shooting experience (n=4). He found a significant decrease in horizontal movement (sway) in the subjects with the most shooting experience. Although this agrees with other research on rifle hold stability (Era et al., 1996; Konttinen et al., 1998; Zatsiorsky 1990), he also concluded that a decline in ventilation, and subsequent reduction in rifle movement, does not improve standing

stability. This contradicts the findings of Groslambert et al. (1998) who showed that decreased ventilation increased stability of hold.

Driven by reports from Niinimaa (1988) and Soldatov (1983) that elite biathletes should maintain race velocities (speed) into the shooting range, Hoffman et al. (1992) used 13 members (six male, seven female) of the US National Biathlon Team to study the effects of various exercise intensities on shooting performance in the prone and standing shooting positions. Each subject shot at rest, after exercising on a bicycle ergometer to 130, 150 , and 170 beats per minute, and again after maximal exercise. The number of hits for the prone condition was not significantly different among the resting and exercise conditions. In the standing position the number of shots hit were significantly lower in the three highest exercise conditions (condition 2 was not significantly different from either the resting or three highest exercise conditions). The use of a bicycle ergometer as an exercise modality was justified by Hoffman due to the convenience in performing this activity next to the firing line at an indoor shooting range. Unfortunately this modality effectively eliminates muscular fatigue in the arm muscles associated with cross-country skiing or running. Due to the importance of the upper extremities in maintaining rifle stability, especially in the standing position, the elimination of upper body fatigue using a cycle ergometer could potentially facilitate inflated shooting scores. To more accurately elucidate the effects of exercise intensity on shooting performance, tests of shooting performance need to be conducted utilizing similar modalities as those found in actual race conditions to elicit the required physiological responses.

Shooting Research

Contrary to what might be expected, Landers (1983) found an inverted-U relationship between shooting performance and heart rate (HR) in position shooters in the standing position, with shooting performance maximizing between 90 and 100 beats per minute (bpm). This is surprising in light of the fact that most shooters report that a HR over 50 bpm results in noticeable sight deviations in time with their cardiac cycle.

Hoffman et al. (1992) found similar results in biathletes in the standing shooting position. There was no significant difference between shooting scores at resting HR, compared to shooting scores at 130 bpm. Given Landers' inverted-U relationship this would be expected since a resting HR elicited approximately the same shooting score as 130 bpm in his position shooters. Unlike the standing position, Hoffman found no significant difference between prone shooting scores at 130, 150, and 170 bpm. This is probably due to the greater base of support provided by the prone shooting position. The increased base of support allows greater rifle stability so that shooting scores can be maintained even at elevated HRs. In light of these findings it is apparent that the relationship found by Landers can only be applied to the standing rifle position, even though this limitation was not specifically addressed in his work.

Numerous other studies have indicated that the most successful shooters not only have a lower HR at the time of triggering, but also time their triggering in relation to their cardiac cycle (Helin et al., 1987; Konttinen et al., 1992; Konttinen et al., 1998a). Helin et al. (1987) found that champion rifle shooters consistently fired toward the end of diastole, whereas beginner shooters fired either during systole or diastole. He concluded that the

best time of triggering is during late diastole, when the relaxation of the heart has lasted for nearly the longest possible period. Although Landers (1983) recorded a greater magnitude of individual variability than Helin, he found that elite shooters tend to fire just before the heartbeat when averaged across all shots for all 62 of his subjects.

Heart Rate and Respiratory Effects

Due to the increased physiological demand placed on the human body at high levels of physical activity, respiratory rate is substantially elevated upon entering the range during a biathlon race. The most obvious implication related to a high respiratory rate is movement of the rifle during inspiration and expiration, resulting in a lower stability of hold (HS). It is for this reason that biathletes time their shots according to breathing patterns, usually taking one breath per shot. However, respiration also plays an indirect role in HS. It has been shown that respiration is a primary determinant of HR (Blanchard, Young, and Mcleod, 1972; Bonaduce et al., 1998; Brooke, Hamley, and Thomason, 1970; Hirsch and Bishop, 1981; Hnatiow and Lang, 1965; McFarland and Campbell, 1975; Puig et al., 1993; Sroufe 1971; Suggs 1966; Wescott and Huttenlocher, 1961; Whipp and Wasserman, 1973). These studies indicate that rapid shallow breathing decreases HR and HR variability (HRV), whereas slow deep breathing increases HR and HRV. Unfortunately, most of the research looking at the effects of rate and depth of breathing utilize protocols under resting conditions. Since the demand of the body to remove accumulated CO_2 may override any attempts to control respiration, application to the sport of biathlon may be questionable. This is one area that needs to be addressed and

applied specifically to the sport. This information has the potential to greatly benefit the elite level biathlete since it may allow them to control their HR with respiratory rate (RR). Attempting to control for both simultaneously leaves the athlete either waiting for HR and RR cycles to coincide so that they can fire, or forces them to hold their breath until they choose an appropriate time in their cardiac cycle to shoot, effectively forcing the shot. This approach is potentially detrimental to the shooting performance of the athlete.

Summary

Currently there is no published research in the sport of summer biathlon. All of the experimentally controlled research done on winter biathletes have been performed in the lab and, therefore, have limited application to actual competition. The current study was undertaken to fill an obvious gap in the literature by systematically altering the physiological demands placed on summer biathletes immediately prior to shooting in order to observe the associated effects on shooting performance in simulated summer biathlon race conditions. This allows application of the findings to conditions indicative of actual competition.

CHAPTER THREE

METHODOLOGY

Subjects

Ten "low risk" subjects, as defined by the American College of Sports Medicine (ACSM 2000), volunteered to take part in the current study. The subjects participating in the study consisted of male (n=7) and female (n=3) biathletes with varying running and shooting experience. Seven of the subjects were elite-level biathletes with at least two years of competitive experience in the sport of summer biathlon, while three were novice competitors. Three of the seven elite biathletes also competed in winter biathlon. All subjects were right handed except for one elite-level biathlete. Each subject signed an Informed Consent Form reviewed by the Human Subjects Committee at Montana State University, which included a description of the testing procedures (Appendix A), and filled out a Biathlon Experience and Training Questionnaire (Appendix B). A health history questionnaire was administered to ensure subjects had no contraindications to the level of physical activity required by the protocol

Procedures

Subject testing was conducted on two separate days and consisted of a field and lab testing component. Shooting, heart rate, and running data were collected during the initial field test, while the lab component included signing the appropriate forms, collecting demographic data (age, height, weight, and gender), and administration of a

maximal oxygen consumption ($\dot{V}O_{2max}$) test. In addition to providing descriptive information as to the cardiovascular fitness of the subjects, lab testing also served as an incentive for participation in the study. All subjects were asked to wear shoes and clothing indicative of what they would normally wear during competition, and were required to wear the same shoes for all days of testing.

Field Testing

During the initial visit, shooting data were collected at the biathlon range located at Bohart Cross Country Ski Ranch in Bozeman, MT (elevation 1,935 m). This location was selected because it facilitated sustained, level terrain immediately prior to the shooting range, decreasing the effects that an uphill or downhill approach may have on heart rate response during testing. In an effort to minimize running detraining effects coming off the winter racing season, these test sessions occurred at the end of the 2000 summer racing season and coincided with the training peaks of the subjects returning from the 2000 Summer National and Summer World Championships.

Shooting performance was assessed under four different conditions in the prone and standing shooting positions (eight conditions total). The four shooting conditions consisted of: 1) Shooting with a resting heart rate prior to any exercise (INT1); 2) Decreasing to 75% of race pace (RP) 50 meters prior to entering the range (INT2); 3) Maintaining RP all the way into the range (INT3); and 4) Sprinting into the range, starting 50 meters prior to entering (INT4). All testing started with INT1 to provide a baseline shooting score. All subsequent running conditions were counterbalanced among subjects for both position and intensity to account for order effects. The same one km

loop was used for all subjects during each running condition (INT2, INT3, and INT4), with changes in conditions occurring over the last 50 meters prior to entering the range. A three-minute rest was allowed for recovery between conditions. Although this three-minute recovery is toward the low end of the two to ten minute recovery range used by Hoffman et al. (1992), a longer recovery time may have resulted a cool-down effect that could potentially hinder performance on subsequent trials.

Due to the nature of the sport, biathletes tend to have highly customized rifles to maximize comfort, fit, and stability while shooting. Therefore, subjects were allowed to use their own rifles during testing, as long as they conformed to the guidelines outlined by the International Biathlon Union (IBU), the governing body of both summer and winter biathlon. Given the high level of variability associated with ballistics of any given rifle (Niinimaa, 1998), even of the same make and model, subjects were also allowed to use their preferred ammunition as long is it conformed to IBU guidelines (standard velocity, .22 cal long rifle). The non-elite subjects were provided with Marlin summer biathlon rifles and Federal Match grade ammunition since they did not possess rifles or ammunition of their own. Trigger weights were not tested, but assumed to meet the IBU requirement of at least 500 grams. Trigger weights are checked prior to all National and World level competitions and typically are not changed by the competitor once they have passed. Trigger weights of the Marlin rifles provided to the non-elite subjects well exceed the 500 gram minimum set by the IBU for safety reasons. Cuff and slings were permitted for shooting in the prone position, however they were not provided for the non-elite subjects.

Prior to testing, all subjects were allowed as much time as needed to zero their rifles, with no sight adjustments allowed once testing began. Upon completion of zero, each subject fired five rounds under resting conditions (INT1) in first the prone and then the standing position. Subjects were instructed to shoot the "tightest group possible", taking as much time as they needed. The remaining six running conditions required the subjects to shoot as they normally would in competition.

All shooting was done on paper targets and consisted of five shots per condition. Metal "knock-down" targets are utilized during biathlon competitions, providing instant feedback to the athlete as to whether a shot was hit or missed. This feedback is typically utilized by the athlete to adjust shooting cadence (how fast shots are fired). The use of paper targets for testing precluded the subjects from receiving this feedback, therefore the subjects were informed verbally after every shot whether it was a hit or miss in order for shooting cadence to be adjusted accordingly.

Since shooting performance in the sport of Summer Biathlon is based on a hit or miss system, the number of shots hit (SH) were recorded for all four conditions for both prone and standing positions. Target diameters of 40 mm for the prone and 110 mm for the standing shooting position were used to determine number of shots hit (SH). Shooting accuracy (SA) and shooting precision (SP) were also measured to better assess shooting performance. These additional dependent variables (SA and SP) increase the sensitivity for identification of an effect for prior exercise intensity on shooting performance. SA was evaluated by measuring the distance of each shot from the center of the target, while SP was determined by finding the smallest circle that encompassed all

five shots. For the purpose of this study, SA and SP indicates a shooting score expressed as the distance of the shot from the center of the target (SA), or the diameter of the circle encompassing all five shots (SP). Therefore, a greater SA score results in decreased accuracy, and a greater SP score results in decreased precision.

Times were recorded for both the running and shooting components of testing. The amount of time required to run the one km loop was recorded for repeatability measures to determine if any order effects existed between conditions (i.e., to determine if running times increased as the number of conditions increased). The amount of time required to run the last 50 m was utilized to detect significant decreases in 50 m run times as intensity increased (INT2-INT4). The time component for shooting was broken down into three phases: set-up time, shooting time, and total range time. Set-up times were calculated from the time the subject stepped onto a 1.2 by 1.5 meter shooting mat, located at the shooting position, to the time the first shot was fired. Shooting time consisted of the amount of time required to fire all five shots. Total range time was calculated from the time the subject stepped onto the shooting mat until the last shot was fired. Both components of run times (one kilometer and 50 m times), as well as the three components of range time (set-up, shooting, and total range times), were recorded utilizing a stopwatch. In the event of a misfire or jammed rifle, time credit was given for the amount of time it took to clear or reload the rifle. All shooting was recorded using a video camera connected to a time-code generator. This time-code was used to calculate time credits in the event of a misfire or jammed rifle. Heart rate monitors, set to record heart rate at five-second averages, were used to collect heart rate data during all aspects

of field testing. Heart rate was analyzed during set-up as the subject stepped onto the shooting mat, at the first shot, and the last shot.

The best way to account for confounding variables such as wind and cold is to collect data in a controlled condition such as an indoor shooting range. Hoffman et al. (1992) used this approach in his study and addressed the limitations of applying results from these "ideal conditions" to actual race conditions. Due to these limitations, data for the current study were collected utilizing race (field) conditions while annotating weather conditions (i.e., wind speed, temp, etc.). Attempts to minimize weather extremes included not collecting data on days with sustained winds greater than 10 mph, or temperatures colder than 0° C.

Lab Testing

On the second visit subjects reported to the Movement Science Lab at Montana State University where the maximal oxygen consumption ($\dot{V}O_{2max}$) test was administered. All subjects were allowed a familiarization period (5-10 min) on the treadmill at which time they were able to warm up until they felt ready to start the graded exercise test. During the familiarization period subjects were asked to select a treadmill speed that corresponded to their normal (comfortable) 5 km race pace (RP). This self-selected speed was used to construct a $\dot{V}O_{2max}$ protocol for each individual subject. The first stage of the $\dot{V}O_{2max}$ test involved running at 50% of the subjects self-selected RP at 0% grade for a duration of three minutes. The second stage was of same duration and grade, but the speed was increased to the subjects RP. Each subsequent stage remained at RP with a 2% increase in grade every two minutes.

Upon completion of the warm-up period the subject was connected to the gas analysis system by way of a gas collection tube running from the metabolic cart to the subject. The gas collection tube mouthpiece contained a low resistance two-way valve, which allowed ambient air to be inspired, while sending expired air to the metabolic cart for analysis. Upon initiation of the graded exercise test, the work rate was gradually increased until volitional exhaustion of the subject, while $\dot{V}O_{2max}$ was verified by satisfying two of four criteria: 1) A plateau in oxygen uptake (or failure to increase oxygen uptake by 150 mL/min) with increased workload; 2) A respiratory exchange ratio >1.15; 3) Failure of heart rate to increase with further increases in exercise intensity; 4) Rating of perceived exertion of more than 17 (6-20 scale). Such criteria for establishing $\dot{V}O_{2max}$ have been utilized by numerous sources (ACSM, 2000; Bonaduce et al., 1998). Environmental conditions in the laboratory during all $\dot{V}O_{2max}$ tests followed the guidelines outlined by in *Protocols for the Physiological Assessment of Cross-Country Skiers and Biathletes* (Martin et al., 1998). Temperature remained between 22-24° C, relative humidity was kept below 50%, and consistent airflow was provided to the subject via a fan to aid in thermoregulation. All subjects were asked to refrain from any strenuous physical activity or exercise for at least 24 hours prior to testing.

Instrumentation

All $\dot{V}O_{2max}$ tests were performed on the Trackmaster Model 48 (Vacumetrics Inc., Ventura Ca.) low-profile, oversized (belt dimensions: 1.22 x 2.44 m) treadmill. Oxygen consumption was measured by standard indirect open-circuit spirometry utilizing the

SensorMedics 2900 Metabolic Cart (SensorMedics Corporation, Yorba Linda, Ca.). Respiratory gases were sampled continuously with respiratory parameters being computed every 20 seconds. Calibration of the gas analysis system was performed prior to each test using calibrated gas mixtures (26% O_2, balance N_2, and 16% O_2, 4% CO_2, balance N_2) with which to compare ambient gas concentrations. Treadmill speed was verified using the Biddle Contact Hand Tachometer (Avo International, Blue Bell, PA) by converting number of revolutions per minute to miles per hour.

The Polar Accurex Plus™ (Polar Electro Inc., Woodbury, NY) wireless heart rate monitor, set to record heart rate at five second averages, was used to collect heart rate data during the $\dot{V}O_{2max}$ test, as well as field testing phase. A Panasonic AG-450 camcorder (Panasonic, Secaucus, NJ) was utilized to film the subjects while shooting. This allowed the investigators to adjust set-up time and shooting time in the event of a misfire or rifle jam.

Statistical analysis

A Multivariate two-factor repeated measures ANOVA was utilized to compare dependent variables (SH, SA, SP) between shooting positions (prone and standing) and exercise intensities (INT1, INT2, INT3, INT4). Differences in one km run times were tested using a single-factor repeated measures ANOVA. When statistical significance was indicated by the ANOVA analyses, individual comparisons were made using Scheffes' post-hoc analysis. An alpha level of 0.05 was chosen for establishing statistical significance for all individual tests.

CHAPTER FOUR

RESULTS

Subjects

Ten subjects participated in the study, seven elite-level competitors and three novice competitors. All elite subjects participated in the US Summer National Championships the previous year, two were members of the US Summer World Team, three were members of the US Summer National Team, and one was a three-time Winter Olympian. Although experienced runners, the shooting experience of two of the three novice subjects was limited to actual biathlon competitions. The third novice subject reportedly shot up to 300 rounds per week during the summer, but maintained only a 15% shooting average for the previous season. Due to the heterogeneous nature of the subject sample, shooting data were analyzed separately for elite-level subjects (N7), as well as for all subjects (N10). Subject characteristics are shown in Table 1, with heart rate and $\dot{V}O_{2max}$ test results shown in Table 2. Due to geographic limitations, four of the subjects were unable to returned to complete $\dot{V}O_{2max}$ testing.

Table 1. Subject Characteristics (n=10).

Subject #	Category	Gender	Age (yrs)	Height (cm)	Weight (kg)
1	Elite	M	32	180	75.0
2	Elite	M	38	179	66.8
3	Elite	M	43	187	83.6
4	Non-elite	M	22	173	60.5
5	Non-elite	M	22	170	59.6
6	Elite	M	35	189	84.1
7	Elite	M	28	188	79.5
8	Elite	F	37	173	52.0
9	Non-elite	F	41	151	51.0
10	Elite	F	21	162	56.8
Mean±SD			31.9±8.23	175.2±12.16	66.9±12.79

Table 2. Maximal heart rate (HR_{max}) and maximal oxygen uptake ($\dot{V}O_{2max}$) characteristics for all subjects. Missing data expressed as N/A (n=10).

Subject #	Category	Gender	$\dot{V}O_{2max}$ (ml/kg/min)	HR_{max} (bpm)	Predicted HR_{max} (bpm)
1	Elite	M	N/A	N/A	N/A
2	Elite	M	76.93	168	182
3	Elite	M	70.62	181	177
4	Non-elite	M	76.16	184	198
5	Non-elite	M	70.31	189	198
6	Elite	M	N/A	N/A	N/A
7	Elite	M	N/A	N/A	N/A
8	Elite	F	60.83	174	183
9	Non-elite	F	61.66	180	179
10	Elite	F	N/A	N/A	N/A
Mean±SD			69.42±6.90	179±7.4	186±9.4

Run Times

As intensity increased from INT2 to INT3 and INT4, there was a significant decrease ($p<0.001$) in 50 m run time prior to entering the range (12.52 s, 11.22 s, and 8.96 s, respectively), with no difference in one km run times (3.69±0.13 minutes, $p=0.50$). These results indicate that the independent variable (intensity) elicited the desired change in 50 m run time immediately prior to shooting, without a subsequent order effect occurring during the one km run.

Shooting Variables

Shooting scores (Means±SE) for all three measures of shooting performance are shown in Table 3. Although an increase in exercise intensity was associated with a decrease in SH for both the prone and standing position, there was no significant difference in SH as a result of position (N7: p=0.64, N10: p=0.86) or intensity (N7: p=0.10, N10: p=0.12) for either group (see Table 7 and 8 in Appendix C: ANOVA Tables for Shooting Variables). There was also no significant interaction effect for either group (N7: p=0.169, N10: p=0.162). Both groups had the same absolute decrease in the number of SH in the prone position from INT1 to INT4 (0.4 shots), but N7 averaged 0.7 shots more than N10 at any given condition. Both groups showed the same general trend in the standing position with the number of shots gradually decreasing, although not significantly, from INT1 (4.0±0.3 for N7, 3.2±0.5 for N10) to INT3 (2.0±0.3 for N7, 1.7± 0.3 for N10), with a slight increase at INT4 (2.1±0.6 for N7, 1.9±0.4 for N10). Figures 1 and 2 show the number of shots hit in both shooting positions for N7 and N10, respectively.

A significant interaction effect was detected in the N7 group (see Table 9 in Appendix C: ANOVA Tables for Shooting Variables) for the SA measure of shooting performance (p=0.005). Significant differences were found in INT2, INT3, and INT4 between positions, with no difference in SA for the prone position across intensities (see Figures 3 for post-hoc comparisons). For the standing position INT3 was not significantly different from any other intensity, and INT1 and INT2 were significantly different from INT4. While a significant difference in both position ($p<0.001$) and

intensity (p=0.009) was found in the N10 group (see Table 10 in Appendix C: ANOVA Tables for Shooting Variables), post-hoc analysis (Figure 4) indicated no significant difference in position as a function of intensity, and a significant difference between positions for all intensity levels except INT1. The trends for accuracy scores were similar for both groups, with SA in the prone position being more consistent with increases in intensity from INT1 to INT4 (4.6 cm for N7, 7.3 cm for N10). Although the absolute increase in accuracy scores for the standing position was greater for N7 than N10 (49.9 cm vs. 31.6 cm, respectively), N7 averaged 10-15 cm less than N10 at any given intensity except for INT4 (86.8±10.1 cm vs. 89.6±14.4 cm for N10 and N7, respectively).

Table 3. Shooting scores (Mean±SE) expressed as number of shots hit (SH), shooting accuracy (SA), and shooting precision (SP) for Elite subjects (N7) and all subjects (N10) across all four intensity conditions (INT1-INT4).

	Elite Subjects (n=7)			All Subjects (n=10)		
	SH	SA (mm)	SP (mm)	SH	SA (mm)	SP (mm)
Prone						
INT1	3.1±0.6	16.3±2.6	32.7±2.2	2.4±0.6	26.2±6.4	46.6±10.4
INT2	3.0±0.6	18.5±3.4	48.6±10.7	2.2±0.6	28.6±6.0	63.4±10.8
INT3	2.9±0.4	20.7±3.1	53.7±3.8	2.3±0.4	32.3±6.4	86.1±17.4
INT4	2.7±0.5	20.9±2.4	54.0±7.2	2.0±1.6	33.5±6.9	72.1±11.0
Standing						
INT1	4.0±0.3	39.7±3.9	121.6±17.9	3.2±0.5	55.2±9.3	150.6±20.8
INT2	2.6±0.7	54.1±7.9	141.2±15.7	2.4±0.5	64.6±8.1	158.8±16.2
INT3	2.0±0.3	61.4±4.9	143.6±8.8	1.7±0.3	72.8±8.1	160.5±11.0
INT4	2.1±0.6	89.6±14.4	178.7±14.3	1.9±0.4	86.8±10.1	188.8±13.1

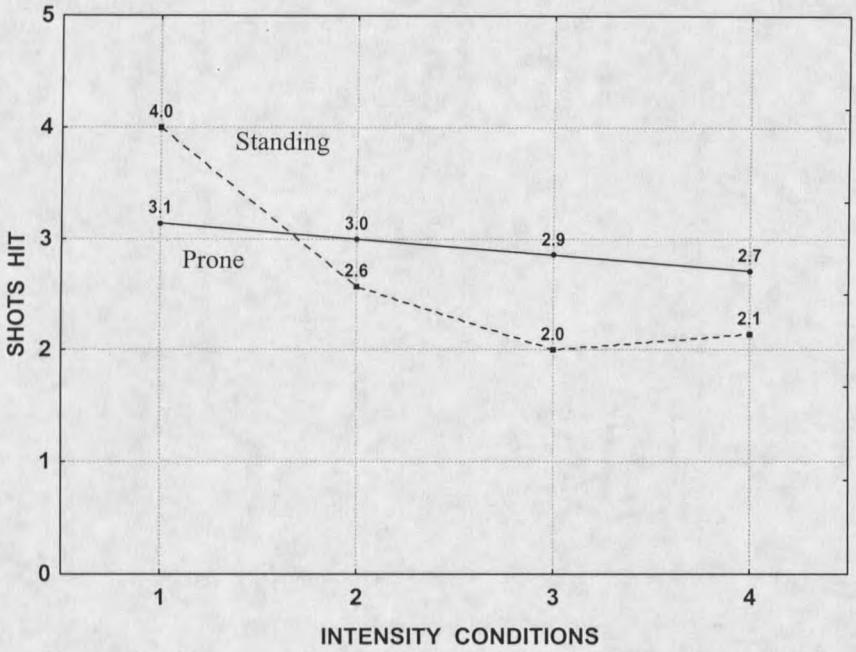


Figure 1. Mean number of shots hit for each intensity condition (INT1-INT4) in the prone and standing shooting positions for Elite subjects (n=7).

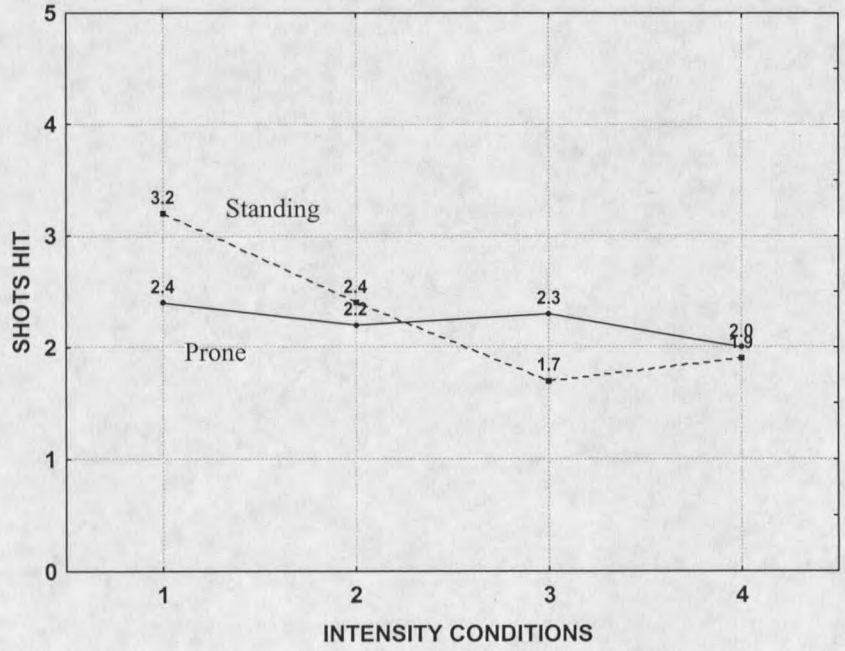


Figure 2. Mean number of shots hit for each intensity condition (INT1-INT4) in the prone and standing shooting positions for all subjects (n=10).

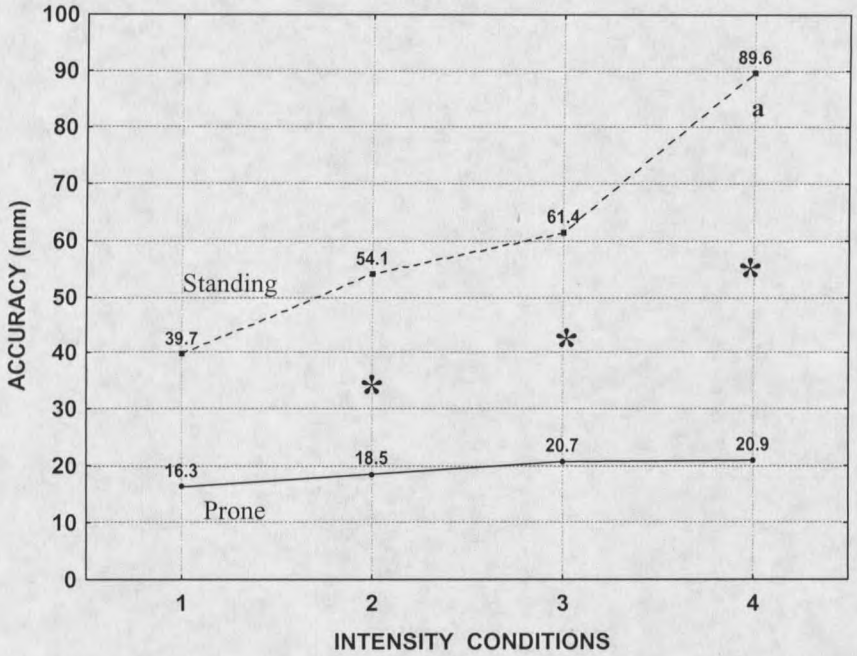


Figure 3. Mean accuracy scores (mm) for each intensity condition (INT1-INT4) in the prone and standing shooting positions for Elite subjects (n=7). Significant differences between positions are indicated by "*". [a] INT4 differs significantly from INT1 and INT2.

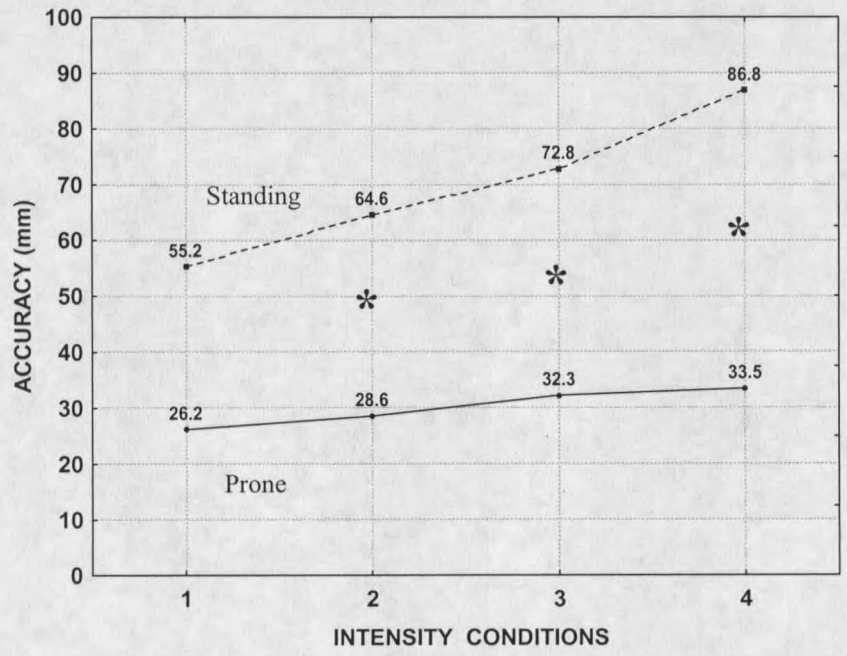


Figure 4. Mean accuracy scores (mm) for each intensity condition (INT1-INT4) in the prone and standing shooting positions for all subjects (n=10). Significant differences between positions are indicated by "*".

No interaction effect was detected in the SP measure of shooting performance for either N7 or N10 ($p=0.250$ and $p=0.356$, respectively). Differences in SP were similar in both groups with significant differences found as a result of position ($p<0.001$), as well as intensity ($p=0.008$) for both groups (see Tables 11 and 12 in Appendix C: ANOVA Tables for Shooting Variables). Post-hoc analysis revealed a significant difference between positions as a function of intensity, but no difference between intensities as a function of position (Figures 5 and 6). As with SA, SP in the prone position was more resistant to changes in intensity than the standing position for both groups. Although neither group showed significant change in SP between INT2 and INT3 in the standing position (2.2 cm and 1.8 cm for N7 and N10, respectively), the absolute increase from INT1 to INT4 was once again greater for N7 than N10 (57.1 cm vs. 38.2 cm, respectively) even though N10 tended to be greater than N7 at any given point (approximately 29 cm at INT1, 17 cm at INT2 and INT3, and 10 cm at INT4). The greatest increases among group means occurred between INT3 and INT4 in the standing position, with N7 increasing from 143.6±8.8 to 178.7±14.3, respectively, and N10 increasing from 160.5±11.0 to 188.8±13.1, respectively.

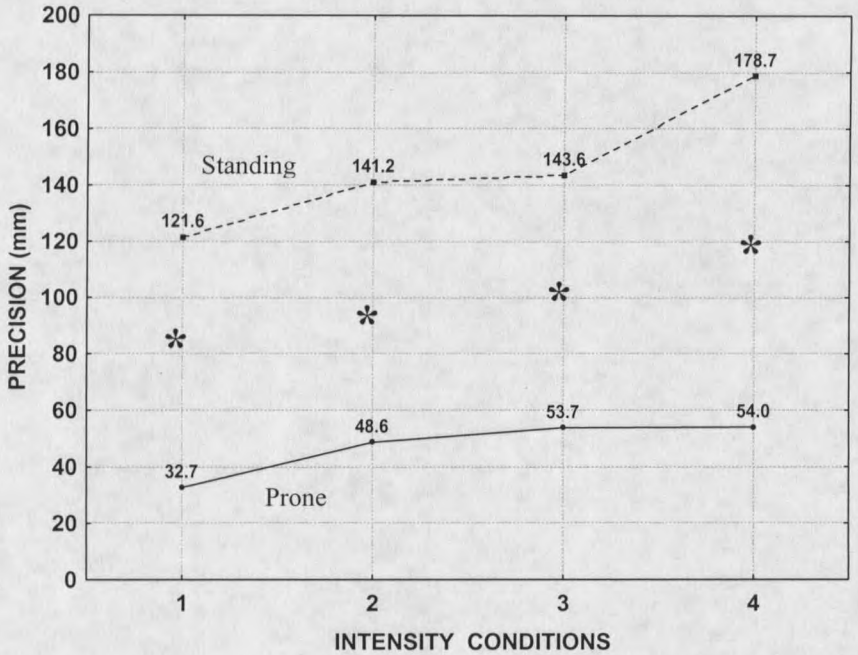


Figure 5. Mean precision scores (mm) for each intensity condition (INT1-INT4) in the prone and standing shooting positions for Elite subjects (n=7). Significant differences between positions are indicated by "*".

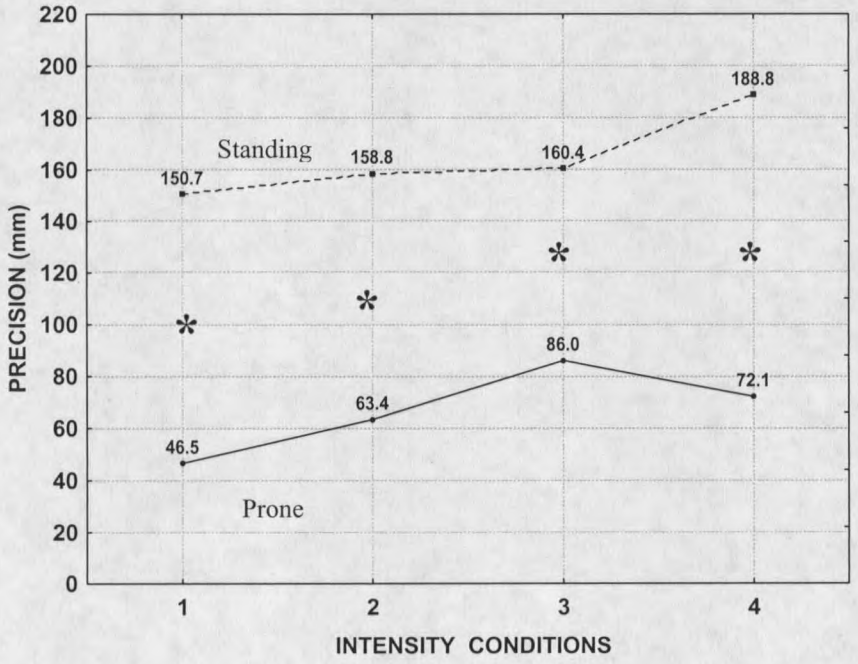


Figure 6. Mean precision scores (mm) for each intensity condition (INT1-INT4) in the prone and standing shooting positions for all subjects (n=10). Significant differences between positions are indicated by "*".

Range Times

Although there was no significant difference in total range time for either group across the three running conditions as a function of position (p=0.625 for N7, p=0.351 for N10) or intensity (p=0.466 for N7, p=0.753 for N10), there was a significant interaction effect detected for the time it took for all shots to be fired in the N7 group (p=0.038). Post-hoc analysis indicated no significant difference in time between position or intensity, but approached significance (p=0.092) between INT2 and INT4 in the standing position as time increased from 27.0±1.8 to 37.8±4.8 seconds. Although set-up times tended to increase in the prone position and decrease in the standing position, particularly for N7, there was no significant difference as a function of position (N7: p=0.223, N10: p=0.909) or intensity (N7: p=0.899, N10: p=0.667). Table 4 shows the mean set-up, shooting, and total range times for both groups. The greatest change in time for both groups occurred during the time it took to fire all five shots in the standing position. Although N7 shot all five shots in less time than N10 at INT2 and INT4 (27.0± 3.6 s vs. 31.2± 3.0 s at INT2, and 37.8± 4.8 s vs. 36.6± 3.6 s at INT4 for N7 and N10, respectively), the increase in time to shoot all five shots between INT2 and INT4 was twice as great for N7 than N10 (10.8 s vs. 5.4 s, respectively).

Table 4. Mean times (±SE) for set-up, shooting, and total range times (s) for Elite subjects (N7) and all subjects (N10) in the prone and standing shooting positions for all four conditions (INT1-INT4).

	Elite Subjects (n=7)			All subjects (n=10)		
	Set-up	Shots	Total	Set-up	Shots	Total
Prone						
INT2	27.0±2.4	32.4±3.6	60.0±0.6	28.8±3.6	34.2±3.0	63.6±4.8
INT3	28.8±2.4	32.4±2.4	61.2±3.6	28.2±1.8	31.8±2.4	60.0±2.4
INT4	30.0±3.0	30.6±4.8	60.6±6.6	28.2±2.4	32.4±4.2	60.6±4.8
Standing						
INT2	27.0±3.0	27.0±1.8	54.0±1.8	25.8±1.8	31.2±3.6	57.0±3.0
INT3	25.2±1.8	31.8±2.4	57.6±3.6	24.0±1.2	32.4±3.0	57.0±3.0
INT4	25.8±3.6	37.8±4.8	63.6±7.2	24.0±3.0	36.6±3.6	61.2±4.8

Heart Rates

There was a significant interaction effect for heart rates in the N7 group ($p=0.045$), and a significant difference as a function of intensity for N10 ($p<0.001$) at set-up (SU). Heart rates at the first shot (FS) were significantly different in both groups for position and intensity ($p<0.023$, and $p<0.001$, respectively). Last shot (LS) heart rates were significantly different in N7 for position and intensity ($p=0.005$, and $p<0.001$, respectively), with a significant interaction effect in N10 ($p=0.027$).

Table 5. Mean (±SE) shooting heart rates (bpm) for Elite subjects (N7) and all subjects (N10) in the prone and standing shooting positions for all four conditions (INT1-INT4).

	Elite Subects (n=7)			All Subjects (n=10)		
	Set-up	First Shot	Last Shot	Set-up	First Shot	Last Shot
Prone						
INT1		91±8.4	78±8.4		93±7.2	83±7.3
INT2	163±8.6	142±8.2	110±9.0	166±6.6	146±6.7	111±7.0
INT3	174±6.1	144±8.9	111±9.9	175±4.5	150±7.4	114±7.7
INT4	176±5.7	159±5.1	122±6.6	177±4.2	161±4.1	124±5.0
Standing						
INT1		100±11.6	85 ±10.6		105±9.1	93±9.5
INT2	170±6.8	151±7.5	125±12.4	170±5.0	154±6.0	127±9.2
INT3	172±6.4	165±7.8	131±10.4	174±4.8	167±5.9	138±7.8
INT4	176±5.5	167±6.3	134±7.2	177±4.1	168±4.8	140±6.6

CHAPTER FIVE

DISCUSSION

First place finishes in the sport of summer biathlon are decided by a matter of seconds, particularly at the men's elite level. Although the need exists to find a way to decrease overall race times by even the smallest of margins, either by decreasing running times, increasing shooting performance, or a combination of both, there has been surprisingly little research done in this area. It was this need to find a way to decrease overall race times, as well as fill the obvious gap in the literature, that prompted the current study. It was the purpose of this study to determine the effect of running intensity on shooting performance in summer biathletes by comparing shooting scores immediately following bouts of exercise at four different intensities in an effort to determine if running intensity prior to shooting can be maintained, or even increased, without a subsequent decrement in shooting performance. If this strategy can be successfully applied to competition without a subsequent decrease in shooting performance, the potential exists to decrease overall race times in the sport of Summer Biathlon.

Shooting Results

The current study showed no significant difference in the number of shots hit (SH) as a function of position or intensity (Figures 1 and 2). SH for both groups (N7 and N10) tended to decrease as intensity increased and showed a similar trend for both

shooting positions (prone and standing) over all intensity conditions (INT1, INT2, INT3, and INT4). The only difference being that N10 tended to have fewer shots hit at any given intensity (average of 0.7 for the prone position, and 0.3 in the standing position, except INT1 which was 0.8 shots lower). This same trend was also observed in Hoffman et al. (1992) analysis of 13 members of the US Winter Biathlon Team. The number of shots hit at rest (INT1) for N7 (3.1±0.6 for prone, and 4.0±0.3 for standing) were similar to the number of shots recorded by Hoffman (approximately 3.3 for prone, and 4.2 for standing), with shots tending to be somewhat lower in N7 for INT2-INT4, particularly in the standing position. This discrepancy between number of shots hit between the two studies is possibly due to the higher level of shooting-specific training afforded to the US Biathletes, and high level of shooting proficiency required to maintain a position on the team. This resulted in a subject sample with higher and more consistent shooting performance than the current study. Hoffman also used a bicycle ergometer to elicit the desired heart rate response, effectively removing upper body fatigue as a factor in compromised shooting scores. The use of an indoor range by Hoffman also facilitated a controlled shooting environment, which could have potentially inflated shooting scores in his subjects. The current study used an outdoor range where factors such as windspeed and temperature may have contributed to lower shooting scores. For the current study windspeed averaged 2.85 mph, and mean temperature was 7.2° C.

One noticeable difference in shooting data between the two studies is that Hoffman's group had consistently higher shooting scores (SH) in the standing position than the prone position for all intensity levels. Under normal circumstances this trend

would be expected. Even though the base of support is greater in the prone position, the target diameter is almost one-third the size of the target in the standing position, resulting in fewer shots hit than in the standing position. However, in the current study, the standing position resulted in more shots hit at only the first condition (INT1) for N7, and the first two conditions (INT1 and INT2) for N10. Comparing the data from both studies it would appear that not only is shooting performance compromised to a lesser degree in the prone shooting position as a function of intensity, but perhaps more importantly, it would seem that shooting performance is compromised less in the more proficient shooters as the level of intensity increases, regardless of position.

The difference in inter-group shooting performance of the current study (N7 vs. N10) was most likely influenced by the lack of shooting experience of the non-elite subjects. This lack of experience was potentially exacerbated by the rifles used by the subjects. While the elite subjects used their personal rifles (all N7 subjects used top-of-the-line Anschutz competition rifles specifically designed for the sport of biathlon), the non-elite subjects borrowed Marlin entry-level rifles that were unfamiliar to them. Even though they were allowed to sight in their rifles until they felt comfortable with their shot group, the entry-level Marlin rifles are inherently less accurate than their Anschutz counterparts. Prone scores for the non-elite subjects may have also been lower than the elite subjects due to the lack of a sling and cuff commonly used to increase stability of hold in that position.

Shooting scores for accuracy (SA) were also similar between Hoffman et al. (1992) and those of the current study, particularly in the prone position. SA for

Hoffman's group, as well as N7 of the current study, all had scores between 15 and 20 mm across all exercise intensities. Accuracy scores for both studies increased slightly in the prone position from rest to the second condition, leveling off at approximately 20 mm from condition two to condition four. Given a prone target diameter of 40 mm, if all shots were equidistant from the center of the target they would fall on the hit/miss boundary. SH for both studies averaged approximately 3 hits over the same three conditions indicating that three of the five shots were closer to the center of the target, with two falling outside the 20 mm target radius.

Although N10 of the current study showed the same general trend as exercise intensity increased in the prone position, SA scores tended to be greater than N7, ranging from 26.2±6.4 mm to 33.5±6.9 mm from INT1 to INT4 (Table 3). For elite-level competitors this increase in SA would typically result in fewer shots hit. However, as long as the shots were centered around the target center it would not effect SH for novice competitors since the same target size (110 mm) is used in both the standing and prone positions during novice competitions.

The major difference in SA scores between studies was seen at the highest intensity in the standing position. The current study resulted in almost twice the SA score (89.6±14.4 mm for N7, and 86.8±10.1 mm for N10) than reported by Hoffman (around 48 mm) at the highest intensity. With no subsequent decrease in SH between INT3 and INT4 in the current study, it would appear that this sudden increase in SA between conditions is a result of the missed shots being farther from the target center, as opposed to all shots being distant. This may be a result of the "anticipation strategy" used by

biathletes in this position while shooting. Position shooters attempt to control body and rifle sway, effectively forcing their sight picture to remain on the target. Considering the high level of exercise intensity immediately prior to shooting in the sport of biathlon, and the limited base of support in the standing shooting position, rifle stability is compromised to the point where this fixation strategy is ineffective. It has been reported that the mean duration of the target appearance in the sight ring prior to shooting in elite biathletes is only 200 ms during standing shooting (Groslambert et al., 1999). Biathletes adapt to this by allowing sight deviation (rifle movement) to follow a near-normal pattern and attempt to time triggering as the sight passes through the target. As intensity prior to shooting increases, so does the magnitude of this movement pattern. Therefore, a miscalculation in triggering will not only result in a miss, but a miss by a greater margin than if a shot was triggered during a smaller movement pattern.

As with SH and SA, trends in precision scores (SP) were similar for both Hoffman and the current study, although N10 showed a greater increase between INT2 and INT3 (Figure 6) for SP in the prone position than N7 or Hoffman's group. Of interest in looking at the data from both studies is that the greatest deviation (increase) in SP occurred in the standing position at approximately the same heart rates (170 bpm). This lends evidence to the suggestion of Soldatov (1983) and Niinimaa (1988) that even though exercise intensity can be maintained, or even increased prior to shooting, it has a greater adverse affect on shooting in the standing position. Although it is well documented that stability of hold is compromised in the standing position due to numerous factors, the point at which it becomes problematic has never been addressed.

The results of the data presented by Hoffman, as well as the current study, indicate that this point may be in the range of 160-180 bpm for most elite-level biathletes. It is obvious that more research is warranted in this area.

Although mean SA and SP scores were consistently higher for N10 than N7 in both shooting positions, these scores may have been underestimated for the N10 group due to limitations in collection of these data points. For shots that fell outside the margins of the paper targets it was not always possible to get accurate measurements from the center of the target, particularly in the vertical direction. For shots that landed outside the margins of the paper in the vertical direction a distance of 160 mm was assigned to that shot (the maximum distance from the center of the target to the vertical edge of the paper). Since four paper targets were set side-by-side, shots that landed off the paper in the horizontal direction typically landed on an adjoining target, and were therefore able to be measured. In the case where shots landed off the paper horizontally to the left on the first target, or horizontally to the right on the last target, a distance of 160 mm was assigned to that shot. Since the N10 group had a higher frequency of shots falling outside the margins of the paper targets, this group's SA and SP scores may have been underestimated.

Range Times

The fact that the current data suggests a small effect on shooting performance as a function of exercise intensity, specifically as it relates to SH, is promising to elite-level biathletes looking to decrease overall race times by even the smallest of margins.

However, its application becomes questionable if increases in exercise intensity prior to shooting subsequently results in an increase in range time as the athlete attempts to regain control of elevated heart rate and breathing. It is for this reason that the current study involved a component to look at the effect of exercise intensity on range times.

Although there was not a significant difference in range times among position or intensity for either group (N7 or N10), the time it took for N7 to shoot all five shots in the standing position approached significance ($p=0.092$) as time increased from 27.0±1.8 s at INT2 to 37.8±4.8 s at INT4 (Table 4). These results indicate that not only are SA and SP scores compromised to a greater degree as intensity increases in the standing position, but the time spent in the range also increases. With a potential decrease in shooting performance and concurrent increase in total range time, the benefit of increasing exercise intensity immediately prior to entering the range in an attempt to decrease run time may not be sufficient to outweigh the cost of incurring additional range time or penalty laps in the standing position. Table 6 gives hypothetical time differences (gain or loss) beginning 50 m from the firing line to the end of any incurred penalty laps. Range times (from elite group) and 50 m run times are group means from the current study for any given intensity level (INT2-INT4) for both the prone and standing shooting positions. The time to run a 100 m penalty lap is assumed to be constant (average of 23 seconds per lap). Three possible outcomes for the number of shots hit are given.

Table 6. Representative time differences (s) beginning 50 m from the firing line to the end of any incurred penalty laps. Range times (from elite group) and 50 m run times are pulled from the current study for any given intensity level (INT2-INT4) for both the prone and standing shooting positions. The time to run a 100 m penalty lap is assumed to be constant (average of 23 seconds per lap).

50 m Time (s)	Total Range Time (s)	Shots Hit	Penalty Lap (s)	Total Time (s)	Change Score
12.52	60.0	3	46.0	118.5	0.0
12.52	60.0	2	69.0	141.5	23.0
12.52	60.0	1	92.0	164.5	46.0
11.22	61.2	3	46.0	118.4	-0.1
11.22	61.2	2	69.0	141.4	22.9
11.22	61.2	1	92.0	164.4	45.9
8.96	60.6	3	46.0	115.6	-2.9
8.96	60.6	2	69.0	138.6	20.1
8.96	60.6	1	92.0	161.6	43.1
12.52	54.0	3	46.0	112.5	0.0
12.52	54.0	2	69.0	135.5	23.0
12.52	54.0	1	92.0	158.5	46.0
11.22	57.6	3	46.0	114.8	2.3
11.22	57.6	2	69.0	137.8	25.3
11.22	57.6	1	92.0	160.8	48.3
8.96	63.6	3	46.0	118.6	6.1
8.96	63.6	2	69.0	141.6	29.1
8.96	63.6	1	92.0	164.6	52.1

As intensity increases in the prone position, total times are maintained from INT2 to INT3, and decreases (approximately 3 s) from INT3 to INT4, given the same number of shots hit. Unlike the prone position where total range times are fairly constant across intensities, the increase in range time from INT2 to INT4 (54.0 to 63.6 s) in the standing position negates the time saved from decreased 50 m run times (12.52 vs. 8.96 s for INT2 and INT4, respectively), regardless of SH. This would indicate that even if the number of SH can be maintained in the standing position as intensity increases, unless range times are reduced, or held constant, this strategy is of limited benefit.

One limitation addressed in the current study was that of subject unfamiliarity with shooting at the intensities required by the protocol. Although there was no significant difference in SH as intensity increased, the general trend for SH to decrease from INT1 to INT4 may be attributed more to the lack of experience shooting at these intensity levels than the intervention itself. This is supported by Groslambert et al. (1997) who found a negative relationship between installation (set-up) time and the number of shots hit in the prone position. As installation time increased, the more likely an individual was to miss a target. This was found in the current study, particularly in the N7 group. As set-up time increased from 27.0±2.4 (INT2) to 30.0±3.0 (INT4) the number of shots hit decreased (nonsignificantly) from 3.0±0.6 to 2.7±0.5 (Table 3.). The opposite was true for the standing position, the number of shots hits decreased as installation time decreased. This decrease in the number of shots hit was also observed in the results from the N7 group. When set-up time decreased from 27.0±3.0 s (INT2) to 25.2±1.8 s (INT3) the number of shots hit decreased from 2.6±0.7 to 2.0±0.03 (Tables 2 and 3). As set-up time slightly increased again from INT3 (25.2±1.8 s) to INT4 (25.8±3.6 s), so did the number of shots hit (2.0±0.3 to 2.1±0.6). These results indicate that if the subjects were more familiar with shooting at these intensities they may be able to adapt their set-up times to maximize their shooting performance.

Range times for Olympic Biathletes vary between 20-60 seconds, with average range times of 25-30 seconds for standing, and 30-35 seconds for prone (Niinimaa 1988). Assuming that the range times reported by Niinimaa were calculated in the same manner (not just shooting times), the average range times of the current study were almost twice

as long (58 and 61 seconds for standing and prone, respectively). Even though these times are significantly greater than reported by Niinimaa for Olympic-level biathletes, they were similar to the times reported by Hoffman (1992) in an observational study characterizing the heart rate response during biathlon using 14 members of the US National Biathlon Team (47 seconds standing, and 54 seconds prone).

With no significant difference in range times across intensity levels in the current study, and the similarity in range times by US National team members reported by Hoffman (1992), it would appear that an increase in exercise intensity immediately prior to shooting has no significant effect on the amount of time spent in the range while shooting, even though there may be a shift in time between the set-up and shooting time components.

Heart Rates

Heart rates were similar for both groups during set-up (SU), first shot (FS), and last shot (LS). As expected, heart rates in the prone position tended to be lower than the standing position for any given time component (Table 5). The decrease in heart rate from SU to FS was twice as great in the prone position than the standing (21.5 bpm vs. 11.2 bpm, respectively). Decreases in heart rate from SU to LS averaged 16 bpm greater in the prone position (56.5 bpm) than the standing (40.6 bpm). Similar decreases in heart rate between arrival to the firing line and last shot were observed by Hoffman (1992). A decrease of 47 bpm was found in the prone position, and 32 bpm in the standing position. Although the absolute decrease in heart rate wasn't as great as the current study, the

difference between both positions were similar (approximately 10 s difference among positions of either study). The higher drop in heart rate of the current study was most likely a function of entering the range at a higher heart rate than Hoffman's groups (172 bpm vs. 166 bpm). Also, Hoffman used a 15 second average while collecting heart rate data, whereas the current study used a five second sample period. The 15 second average used by Hoffman may have smoothed the data, effectively lowering high heart rates and raising low heart rates, resulting in a compromised ability to detect differences between two separate data points collected within a one minute period (total range time).

CHAPTER SIX

CONCLUSIONS

With no significant difference in the number of shots hit, or time spent in the range while shooting, these preliminary findings indicate that overall race times may be decreased in the sport of Summer Biathlon without a subsequent compromise in shooting performance by maintaining, or increasing, the intensity in which the competitor enters the range. Although increasing exercise intensity while entering the range may provide valuable seconds, it is important to realize that it also results in greater shot variability (decreased accuracy and precision) resulting in a decreased margin for error, especially in the standing position. With the increased base of support and increased heart rate recovery associated with the prone position it is possible to enter the range with a greater intensity than the standing position while maintaining a high level of shooting performance. Although there were no significant decreases in SH in the standing position, the sudden decrease in SA and SP between INT3 and INT4 indicates that using this strategy prior to standing shooting could potentially compromise shooting performance to a greater degree than in the prone position. Since SH actually increased, although not significantly, between the same intensities, the corresponding decreases in SA and SP are most likely due to one or two shots being significantly further away from the others, as opposed to all shots being distant. This decrease in SA and SP could also be attributed to the subjects having to shoot with higher respiratory and heart rates than they are accustomed to. It is possible that training at these elevated levels may decrease

the shot variability over time by allowing them to adjust their set-up time to maximize shooting performance.

In the current study an average of 3.56 seconds was saved when approaching the range at INT4 vs. INT2, and 1.3 seconds saved when approaching at INT3 vs. INT2. In a typical 5 km Summer Biathlon race consisting of two shooting bouts, this could potentially decrease race times by as much as 7.12 seconds, given similar shooting performances (i.e., same number of shots hit). While this may sound insignificant, it could have meant the difference between a first and second place finish in the men's 5 km sprint at the 2001 US Summer Biathlon National Championships. In that race there were ten competitors (out of 34 total) that could have increased their standings with a 7.5 second reduction in overall race times, with 11th through 14th place being decided by a mere seven seconds. Similar results occurred during the 2000 US Summer National Championships (5th-9th place was decided by four seconds), as well as the 2000 Summer World Championships (only 8.3 seconds separated 1st and 2nd, and 15th-18th place was decided by less than six seconds).

Although there were no significant differences found in most shooting measures of performance (SH, SA, SP) across intensities for a given position, this could have potentially been a result of group means washing out the results of responders vs. non-responders. The sport of Summer Biathlon consists of competitors that are inherently better shooters, those that are inherently better runners, or those that are moderately proficient at both. Overall race times of individual competitors may be within seconds of each other, but the way in which these times are achieved may be remarkably different.

A prime example of this was found in the current study. Not only did one of the subjects decrease 50 m run time by 3.77 seconds from INT2 to IN4 (7.54 seconds total for two shooting bouts), but also hit one more shot at INT4 than INT2 for both positions, which would have resulted in one less penalty lap in actual competition. Given an average of 23 seconds to run a 100 m penalty lap, this strategy could have potentially reduced overall race time by as much as 30.54 seconds, enough to move from 4th to a 1st place finish at the 2000 Summer World Championships.

Ultimately the question that needs to be asked is who stands to benefit from incorporating these changes into their race strategy? The potential benefits for elite-level men have been established, however, chances are that gaining 7.12 seconds in a 5 km race for a novice competitor is not going to outweigh the risk of compromised shooting performance. Even though women have the potential to decrease race times by the same margin, finish times between elite-level women competitors are typically greater than the men (59 seconds separated 1st and 2nd place at the 2000 Summer World Championships), making the additional risk to shooting performance questionable. Individual results of the current study indicate that biathletes who rely on shooting performance to remain competitive could potentially adapt to this strategy more readily than those who lack shooting proficiency and rely mainly on running speed. Obviously the efficacy of such a variation in race strategy should be determined on an individual basis prior to implementation in actual competition.

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APPENDICES

APPENDIX A

SUBJECT CONSENT FORM

SUBJECT CONSENT FORM

FOR PARTICIPATION IN HUMAN RESEARCH
MONTANA STATE UNIVERSITY

Project Title: Effect of Exercise Intensity on Shooting Performance in Elite-Level Summer Biathletes.

Principle Investigator: Brian K. Higginson
Graduate Student, Exercise Physiology
Department of Health and Human Development
Movement Science Laboratory
Romney 103, Montana State University
Bozeman, MT 59717-3540
(406)587-6117 brianh@montana.edu

Lab Director: Daniel P. Heil, PhD.
Assistant Professor, Exercise Physiology
Department of Health and Human Development
Movement Science Laboratory
Romney 103, Montana State University
Bozeman, MT 59717-3540
(406)994-6324 dheil@montana.edu

Purpose of the study:

You are being asked to participate in a study that will compare shooting performance between four different levels of exercise intensity immediately prior to shooting. Data will be collected under simulated race conditions for both the prone and standing shooting positions. Results from this study will be used to determine the highest level of intensity that can be maintained immediately prior to shooting without a subsequent decrease in shooting performance. You were selected as a subject for this study based on your accomplishments in the sport of summer biathlon, primarily placement in the 1999 and 2000 Summer National Championships, or your involvement with one of the US Biathlon teams.

Prior to any testing, each subject is required to read and sign a Subject Consent Form. Medical clearance will be obtained using the Physical Activity Readiness Questionnaire (PAR-Q) and Health Status Questionnaire. Answering "Yes" to any question on the PAR-Q may automatically disqualify you from participating in this study without further clearance from your physician. The medical questionnaires will be used for identification and exclusion of subjects with medical contraindications to the level of exercise required by the protocol. All testing and screening procedures are in accordance with those outlined for testing "Apparently Healthy" adults by the American College of Sports Medicine.

Testing Procedures:

If you agree to participate in this study, you will be required to make one visit to the Movement Science Lab in the basement of Romney gymnasium on the Montana State University campus, and one visit to the biathlon range at Bohart Cross Country Ski Ranch, Bozeman, MT. You should expect to spend approximately one hour during the lab visit, and approximately an hour and a half at Bohart (excluding travel time).

During the initial visit to the Movement Science Lab, anthropometric and demographic data such as age, height, weight, and gender will be collected. After all necessary forms are completed you will then be asked to participate in a $\dot{V}O_{2max}$ test (running on a treadmill), which will be used to assess your aerobic capacity. You will be allowed five to ten minutes to warmup and become familiar with the treadmill. After the warmup you will be asked to select a comfortable race pace (a pace indicative of what you would normally run in competition). Once this pace is selected you will be fitted with a mouthpiece connected to a gas collection tube that runs to the metabolic system. The purpose of this mouthpiece and tube is to collect your expired air so that the amount of oxygen consumed by your body during exercise can be calculated. The mouthpiece is designed to fit inside your mouth much like that of a snorkel. You will also be required to wear a heart rate monitor transmitter around your chest for the duration of the test to monitor heart rate.

You will begin testing by running on the treadmill for three minutes at 50 percent of your selected race pace. At the end of the first three-minute stage, the treadmill speed will be increased to your normal race pace for an additional three minutes. All subsequent stages will remain at this speed with the incline increasing two percent every two minutes until you are unable to continue with the test.

For all testing conducted at the biathlon range at Bohart you will be allowed to use your own rifle and ammunition for all shooting aspects of the study. All shooting will be done using paper targets. Upon arrival at the testing site you will be allowed to zero your rifle, at which time there will be no sight adjustments allowed for the duration of that days testing. Once the zero is complete you will shoot five shots with a resting heart rate for both the prone and standing positions. Since the next three conditions for the prone and standing positions include running a 1 km loop prior to shooting you will be given time to warmup until you feel ready to start the running portion of the test. During the running portion of the test your rifle will be located in a rifle rack next to your shooting position. The final conditions will involve running the same 1 km loop, with the intensity at which you enter the range changing for the three conditions. You will be required to: 1) enter the range at 75% of your race pace beginning 50m from the range; 2) maintain the same intensity (race pace) all the way into the range; 3) or increase intensity to maximal effort (similar to sprinting to the finish line) beginning 50m from the range. These three conditions will be run for both the prone and standing positions (six conditions total), with the order of

conditions randomized. You will be required to wear a heart rate monitor for the duration of the test to verify intensity of all running conditions.

Strenuous physical activity or exercise should be avoided on all days of testing. In addition, you should refrain from ingesting food, alcohol, caffeine, or tobacco products within three hours of testing. Clothing indicative of what you would normally wear during competition should be worn on all days in which shooting data is to be collected.

Potential Risks:

During the treadmill portion of the test some discomfort may be experienced due to the mouthpiece and headgear used to support the gas collection tube while running. Although uncomfortable, this is required to accurately assess your aerobic capacity. The heart rate monitor worn for all days of testing may feel restrictive if you are not used to wearing one. Every effort will be made to make you as comfortable as possible during all aspects of testing.

Benefits:

By participating in this study, a $\dot{V}O_{2max}$ test to assess aerobic capacity will be administered at no charge to you. In addition, you will receive a copy of your shooting data collected from this study upon request. This information could potentially be used to modify current race strategies in an attempt to decrease overall race times.

Confidentiality:

The data and personal information obtained from this study will be regarded as privileged and confidential. They will not be released except upon your written request/consent. Your right to privacy will be maintained in any ensuing analysis and/or presentation of the data by using coded identifications of each subject's data.

Freedom of Consent:

You may withdraw consent in writing, by telephone, or in person with the investigator, Brian Higginson (406-587-6117), and discontinue participation in the study at any time and without prejudice or loss of benefits (as described above). Participation is completely voluntary.

In the UNLIKELY event that your participation in this research results in physical injury to you, the principle investigator will advise and assist the participant in receiving medical treatment (CPR and First Aid certified personnel will be on hand for all testing). In addition, Montana State University will not be held responsible for injury, accidents, or expenses that may occur as a result of traveling to and from your appointments at the Movement Science Laboratory or Bohart Cross Country Ski Ranch, Bozeman, MT. Further information regarding medical treatment may be obtained by calling Brian Higginson at (406)587-6117.

You are encouraged to express any questions, doubts, or concerns regarding this study. The investigator will attempt to answer all questions to the best of his ability. The investigator fully intends to conduct the study with your best interest, safety, and comfort in mind. Additional questions about the rights of human subjects can be answered by the Chairman of the Human Subjects Committee, Stephen Guggenheim, (406)994-4411.

STATEMENT OF AUTHORIZATION

I have read the above and understand the discomforts, inconvenience and risks of this study. I, _____ (name of subject), agree to participate in the research described in the preceding pages. I understand that I may later refuse to participate, and that I may withdraw from the study at any time. I have received a copy of this consent form for my own records.

Signed: _____ **Date:** _____
Subject's Signature

Witness: _____ **Date:** _____

Investigator: _____ **Date:** _____
Brian K. Higginson

APPENDIX B

BIATHLON EXPERIENCE AND TRAINING QUESTIONNAIRE

Biathlon Experience and Training Questionnaire

Name:

Include address if you would like a copy of your test results.

Are you currently, or previously a member of a US Biathlon Team (i.e. Olympic, World, National, National Guard, or development team)? If so, specify team and number of years?

Do you compete in winter, as well as summer biathlons?

Would you consider yourself a stronger runner or shooter?

What is your current 5k run time?

What is your average shooting percentage during the summer season? (Specify between prone and standing if known).

How many years have you been shooting competitively?

Describe your shooting training during the summer season (frequency and rounds/week).

How many years have you been running competitively?

Describe your running training during the summer season (frequency and miles/week).

Have you had any recent injuries that may adversely affect your performance?

List any medications, supplements, or ergogenic aids that you are currently using.

APPENDIX C

ANOVA TABLES FOR SHOOTING VARIABLES

Table 7. Shots hit (SH) ANOVA table for Elite subjects (n=7).

SOURCE	DF	SS	MS	F	P
SUBJECT (A)	6	18.4643	3.07738	0.83	0.5867
POSITION (B)	1	0.875	0.875	0.24	0.6444
A*B	6	22.25	3.70833		
INTENSITY (C)	3	12.1964	4.06548	2.47	0.0953
A*C	18	29.6786	1.64881		
B*C	3	6.05357	2.01786	1.88	0.1692
A*B*C	18	19.3214	1.07341		
TOTAL	55	108.839			

Table 8. Shots hit (SH) ANOVA table for all subjects (n=10).

SOURCE	DF	SS	MS	F	P
SUBJECT (A)	9	74.8625	8.31806	2.56	0.089
POSITION (B)	1	0.1125	0.1125	0.03	0.8566
A*B	9	29.2625	3.25139		
INTENSITY (C)	3	9.1375	3.04583	2.16	0.1154
A*C	27	37.9875	1.40694		
B*C	3	5.1375	1.7125	1.85	0.1619
A*B*C	27	24.9875	0.92546		
TOTAL	79	181.488			

Table 9. Accuracy (SA) ANOVA table for Elite subjects (n=7).

SOURCE	DF	SS	MS	F	P
SUBJECT (A)	6	2615.51	435.918	0.71	0.6555
POSITION (B)	1	24809.5	24809.5	40.46	0.0007
A*B	6	3679.48	613.247		
INTENSITY (C)	3	5477.89	1825.96	7.5	0.0018
A*C	18	4379.87	243.326		
B*C	3	3852.82	1284.27	6.17	0.0045
A*B*C	18	3747.71	208.206		
TOTAL	55	48562.8			

Table 10. Accuracy (AC) ANOVA table for all subjects (n=10).

SOURCE	DF	SS	MS	F	P
SUBJECT (A)	9	20819.9	2313.33	3.75	0.0309
POSITION (B)	1	31569.5	31569.5	51.22	0.0001
A*B	9	5547.28	616.364		
INTENSITY (C)	3	4150.84	1383.61	4.77	0.0085
A*C	27	7830.44	290.016		
B*C	3	1568.07	522.691	1.49	0.2387
A*B*C	27	9448.9	349.959		
TOTAL	79	80934.9			

Table 11. Precision (SP) ANOVA table for Elite subjects (n=7).

SOURCE	DF	SS	MS	F	P
SUBJECT (A)	6	11837.5	1972.91	1.7	0.2681
POSITION (B)	1	137323	137323	118.18	0.0000
A*B	6	6972.03	1162		
INTENSITY (C)	3	10839.3	3613.09	5.36	0.0081
A*C	18	12127	673.724		
B*C	3	3104.51	1034.84	1.49	0.2507
A*B*C	18	12492.2	694.013		
TOTAL	55	194695			

Table 12. Precision (SP) ANOVA table for all subjects (n=10).

SOURCE	DF	SS	MS	F	P
SUBJECT (A)	9	80463.9	8940.44	11.14	0.0007
POSITION (B)	1	190720	190720	237.63	0.0000
A*B	9	7223.3	802.589		
INTENSITY (C)	3	11767.5	3922.51	4.81	0.0082
A*C	27	22006.4	815.05		
B*C	3	4752.56	1584.19	1.15	0.3456
A*B*C	27	37081.4	1373.38		
TOTAL	79	354015			

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