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Investigating difference in pacing strategy between biathlon and cross-country skiing over an identical length competition

Master thesis in Sport Science
Department of Physical Performance
Norwegian School of Sport Sciences, 2023

Abstract

Purpose: Biathlon and cross-country skiing are 2 seemingly similar disciplines, but the prospect of shooting might affect the pacing of biathletes and their skiing performance. Therefore, the aim of this thesis was to investigate if there were differences in pacing strategy over an identical length competition between biathlon and cross-country skiing.

Methods: 52 junior athletes (n=28 males, ~ 17yrs), hereby biathletes (n=24, 9 females & 15 males) and cross-country skiers (n=27, 14females & 13 males) performed an individual 6 km (3x2.0km for females) or 7.5 km (3x2.5km for males) simulated competition. For biathletes prone shooting was done after first and second lap, while cross-country skiers skied continuously. Shooting was done on paper targets with 10-point standard rings.

Results: Male biathletes were slower on the first lap and in total course time compared to male cross-country skiers (21sec lap1, 42sec total $P<0.05$). No difference in course time were found for females ($P>0.05$). Male biathletes used an even pacing strategy, while male cross-country skiers applied a positive pacing strategy (33.0% vs 32.4% relative to total course time for lap 1 $P<0.001$, 33.6% vs 34% relative to total course time for lap 2 $P<0.01$). No difference in pacing strategy between females were observed ($P>0.05$). Both male and female biathletes reported lower summated rate of perceived exertion (RPE) over the duration of the competition compared to male and female cross-country skiers (136.6 vs 149.2 for female, 139.2 vs 147.5 for males $P<0.05$). Both sexes reported lower RPE after first shooting compared to second shooting (12 vs 14.9 and 13.2 vs 16.7 for female, 12.3 vs 15.1 and 13.8 vs 16.6 for male, $P<0.01$). No difference in shooting performance was found between the shootings.

Conclusion: Male biathletes showed a more even pacing strategy compared to male cross-country skiers, while female biathletes showed similar pacing strategy as female cross-country skiers but reported lower RPE values. These differences in pacing and RPE alludes to different physical factors affecting skiing performance in biathlon and cross-country skiing, but more research is needed.

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Acknowledgements

With this thesis I am finishing 5 years as a student at the Norwegian School of Sport Sciences. The last 5 years have been filled with many good memories, inspiration, and challenges. Through the school I have made friends that will last a lifetime.

Firstly, I want to thank my supervisor Thomas Losnegard, for great help and guidance throughout this project. You have always answered when I needed it and treated me like an equal throughout the entire project. I also want to thank, Magne Lund-Hansen, Jan Kocbach and Even Granrud for help with collecting and processing data, without you this project would not be possible.

I must thank my friends and family. Your support through this whole project has meant a lot for me. To my NIH friends, I need to thank you for your company during countless hours at the library. I especially have to thank Mai-Sissel who has been tremendous help throughout the whole project, and who has helped straightening my thoughts when they have been a mess.

Lastly, I want to thank the coaches and athletes from NTG Lillhammer. Your impressive effort made this project achievable.

Erland Vedeler Stubbe

Oslo, May 2023

1 Introduction

In this thesis biathletes and cross-country skiers are being observed in a competition like setting. Continuous global navigation satellite system (GNSS) data, rate of perceived exertion (RPE) data, heart rate (HR) data, timing and shooting data have been analysed, with the aim to understand if there was a difference in pacing strategy between biathlon and cross-country skiing. Furthermore, these differences and previous research done on cross-country skiing is explored to understand if there are differences in what physical parameters affects skiing performance in biathlon compared to cross-country skiing. This project was funded by IBU and was conducted by researchers from the Norwegian School of Sport Sciences.

This thesis will be written in article form, with an extended theory section. Methods are described in the article. List of Figures and Tables are presented at the end of the article. The appendices will provide variables such as segment times for all groups, different data for the top 5 athletes of each group and timing data without an outlier for female cross-country skiers.

2 Theory

2.1 Biathlon

Biathlon consists of physical demanding cross-country skiing combined with high precision rifle shooting. Biathlon has been on the Olympic program since 1960 and was originally developed as a military exercise using Big Bore rifles with targets 100-250m away. This changed in 1978 where .22 calibre rifles were introduced. In the 1980s the ski skating technique was invented and has been the only used technique in biathlon since. Today, biathlon is one of the most popular winter sports with the IBU world championship in 2023 showing a record in engagement with 150000 attendees during the championship, and with an average viewership of 8 million for each competition. Biathlon has 4 different individual disciplines, presented in Table I. In addition, there are 3 different relays. The most common discipline in world cup is the sprint competition.

Table I: *shows the different disciplines in biathlon. P = prone shooting. S = standing shooting.*

	Discipline	Skiing distance (km)	Shooting sequence	Penalty.
Men senior	Sprint	10 (3 laps)	P-S	150m Penalty Loop
	Pursuit	12.5 (5 laps)	P-P-S-S	150m Penalty Loop
	Mass start	15 (5 laps)	P-P-S-S	150m Penalty Loop
	Individual	20 (5 laps)	P-S-P-S	60s Added time
Women senior	Sprint	7.5 (3laps)	P-S	150m Penalty Loop
	Pursuit	10 (5laps)	P-P-S-S	150m Penalty Loop
	Mass start	12.5(5laps)	P-P-S-S	150m Penalty Loop
	Individual	15(5laps	P-S-P-S	60s Added time
Men junior	Sprint	7.5(3laps)	P-S	150m Penalty Loop
	Pursuit	10(5laps)	P-P-S-S	150m Penalty Loop
	Mass start	12.5(laps)	P-P-S-S	150m Penalty Loop
	Individual	15(5laps)	P-S-P-S	60s Added time
Women junior	Sprint	6(3laps)	P-S	150m Penalty Loop
	Pursuit	7.5(5laps)	P-P-S-S	150m Penalty Loop
	Mass start	10(5laps)	P-P-S-S	150m Penalty Loop
	Individual	12.5(5laps)	P-S-P-S	60s Added time

Despite the popularity of the sport, the amount of research is low compared to other skiing sports such as cross-country skiing or alpine skiing (136 publications on PubMed for biathlon compared to 945 for cross-country skiing, May 2023). Cross-country skiing and biathlon seemingly share similar physical demands due to similarities such as undulating terrain and technical demanding movements. Hence, one could assume that findings from cross-country skiing research could be applied to biathlon. However, due to shooting, specific demands in biathlon needs more investigating. By comparing the 2 disciplines using pacing strategy, one could get indications on which topics from already established research in cross-country skiing that could also be applied to biathlon. With today's athletes getting more specialized (Jayanthi et al., 2019), one could assume that biathletes could increase performance by tailoring training more towards the specific parameters of biathlon.

2.2 Performance criteria for biathlon cross-country skiing

Few, but an increasing number of studies, have explored determining factors for performance in different biathlon competitions (Luchsinger et al., 2019ab; Luchsinger et al., 2020; Björklund & Laaksonen, 2022). These studies showed that skiing performance correlates highly with overall performance in biathlon. Course time/skiing time accounts for 59-64% of the difference in performance between a top 10 finish and those who finished between 21-30 (Luchsinger et al., 2018). This varies between races and disciplines. According to a sprint competition analysis, course time could explain 84% of the variance in overall performance (Luchsinger et al., 2019b), while for individual races the course time accounted for 42% and 54% of overall performance difference for male and female biathletes respectively (Luchsinger et al., 2019a). The other main determining factor for overall performance in biathlon is shooting performance (Luchsinger et al., 2019a; Luchsinger et al., 2019b; Skattebo & Losnegard, 2018).

However, there is limited research on which physiological factors that correlates with skiing performance in biathlon. One study showed a correlation between skiing speed at lactate threshold, and skiing performance in a 1000m all-out test when carrying a rifle (Kårström et al., 2019). Only one study has tried to correlate competition performance and laboratory tests (Luchsinger et al., 2019b), indicating that lower rate of perceived exertion (RPE) and lower relative heart rate (HR) at submaximal speed on a roller ski treadmill correlated strongly with skiing performance in biathlon for elite biathletes. Using research on cross-country skiing might give more insight into what affects skiing performance in biathlon.

Cross-country skiing is described as one of the most demanding endurance sports, due to its technical and physiological challenges (Stöggl et al., 2018). Physiological factors, such as higher lean body mass and peak oxygen consumption (VO_2 peak) were correlated with performance (Shang et al., 2022). The same study showed and almost perfect correlation (r=0.99) between performance in uphill segments and overall performance, linking higher lean body mass and VO_2 peak to uphill performance and overall skiing performance for national level cross-country skiers (Shang et al., 2022). Similarly for biathlon, a competition analysis showed that ~90% of the variation in course time could be explained by time spent in uphill terrain (Luchsinger et al., 2019b). However, Luchsinger et al. found no correlation between competition performance and VO_2 peak in elite biathletes (Luchsinger et al., 2019b). This then proposes the question if the same parameters are deciders for performance in biathlon and cross-country skiing?

A difference in course profiles could lead to a difference in what physiological parameters that affects skiing performance for the 2 disciplines. However, the courses in cross-country skiing and biathlon seem at first sight similar and are usually divided into 1/3 uphill 1/3 flat and 1/3 downhill. Competition analysis of a male biathlon sprint showed that time spent in uphills is ~50% of total competition time with an average uphill time of 46sec (Luchsinger et al., 2019b). Similar patterns have been found in cross-country skiing were ~50% of total competition time were spent in uphill terrain, with an average of 10-35sec spent in each uphill segment (Losnegard 2019).

As previously mentioned VO_2 peak seem to be one of the most determining factors for skiing performance in cross-country skiing. Although Luchsinger et al. (2019b) found no correlation between VO_2 peak and skiing performance, these findings were for a homogeneous population of elite biathletes. However, high aerobic power seems to be crucial for performance for both biathletes and cross-country skiers. One study investigated peak aerobic power among winter Olympic sports (Tønnessen et al., 2015) and found that both biathletes and cross-country skiers showed significantly higher VO_2 peak values compared to the general population. Both sprinter and distance female cross-country skiers had a higher absolute and relative VO_2 peak compared to female biathletes. Male biathletes had a higher relative, but lower absolute VO_2 peak than sprint cross-country skiers. While compared to distance cross-country skiers both relative and absolute values are lower for male biathletes (Tønnessen et al., 2015). Understanding the impact of VO_2 on skiing performance and how VO_2 changes throughout a competition might be crucial to understand the differences in skiing performance between biathlon and cross-country skiing.

2.2.1 Energy turnover in biathlon and cross-country skiing

3 main energy systems are often referred to when looking at endurance sports: anaerobic release of energy due to splitting creatine phosphate, anaerobic release of energy through glycolysis and aerobic energy release through oxidation of glycogen and fatty acids (Gastin, 2001). A general model for performance in endurance athletes can be made based on the article by Joyner & Coyle and shown in Figure I.

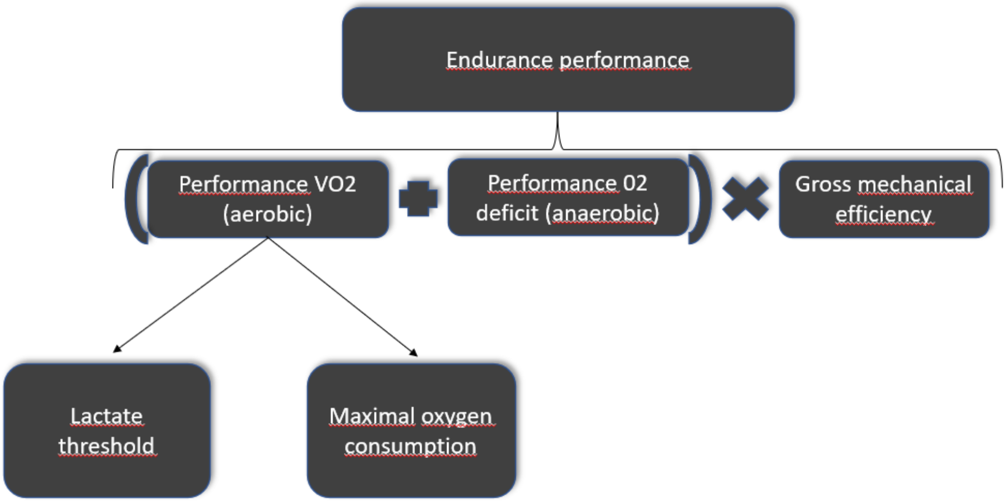

Figure I: *shows a brief overview of the factors that decides endurance performance. There are many underlying factors not shown here. Figure is adapted and modified from (Joyner & Coyle, 2008).*

VO_2 peak is one of the deciding factors for aerobic power, and thus performance in endurance sports. VO_2 peak is decided by the athletes' cardiac output and the muscles' ability to extract oxygen from the blood. An elite endurance athlete could have a maximum cardiac output of 35-40 L/min (Joyner & Casey, 2015) and cardiac output is in turn decided by the stroke volume and HR. HR can fluctuate from around 40 beats per minute (bpm) at rest to around 200 bpm at maximum exertion. The stroke volume would also increase from rest to exercise, and for an elite athlete this increase would be somewhere from 110 ml to 150 ml (Joyner & Casey, 2015). HR is therefore the most deciding factor for acute changes in cardiac output which in turn affects performance VO_2. Therefore, rapid changes in HR will influence the aerobic energy turnover during exercise. Moreover, HR seemingly takes some time to adopt to changes in work intensity, making it hard to use HR as a measure of intensity in biathlon and cross-country skiing (Fritzsche et al., 1999). This lag in HR could be one factor that explains why anaerobic energy turnover is more predominant in biathlon and cross-country skiing (Losnegard, 2019).

Another reason why anaerobic energy turnover affects skiing performance was shown around 1990, when one study showed that while cross-country skiers skied uphill, they would exceed their maximum aerobic power and thusly induce an oxygen dept (Norman et al., 1989). This pattern has been recreated in most research done after this point, showing that athletes during cross-country skiing competitions can reach work intensities as high as 160% of their aerobic power during certain short uphill segments (Gløersen et al., 2019). The elevated energy requirement indicates a substantial contribution from the anaerobic energy systems (Losnegard, 2019). This phenomenon is not fully understood, but research indicate that elite skiers have an elevated ability to recover their anaerobic capacity in sections with lower work intensity compared to recreational skiers, and the researchers hypothesize that this is due to elevated aerobic power (Gløersen et al., 2020; Holsbrekken, 2021).

Anaerobic capacity is often correlated with muscle mass (Sahlin, 2014). An older study found that heavier cross-country skiers have a slight tendency to perform better than lighter skiers (Bergh & Forsberg, 1992), while newer research correlated higher lean body mass with performance (Shang et al., 2022). The authors attributed this to the fact that heavier skiers have an advantage in all terrain except steep uphills. Since most endurance athletes tend to have a low fat-mass, one could assume that greater mass equals greater muscle mass, thusly the heavier athlete will have a higher anaerobic capacity compared to a lighter athlete (Santos et al., 2014). Changes in terrain and performance criteria between different disciplines in cross-country skiing seem to differentiate anthropometric characteristic for the best performing athletes. This is showed by cross-country skiers with a good FIS-point score (a measurement of overall performance) in sprint competitions (finishing time of 2-3 minutes) had a higher body mass compared to cross-country skiers with good FIS-point score in distance competitions (finishing time above 20 minutes) (Losnegard & Hallén, 2014). However previous research seemingly finds no difference in anthropometric data for biathletes and distance skiers (Tønnessen et al., 2015), so if there are differences in anaerobic capacity between biathletes and cross-country skiers it could be explained by other factors.

Aerobic energy turnover using carbohydrates as a substrate and anaerobic energy turnover, which is predominant in high intensity endurance sports such as biathlon and cross-country skiing is limited (Hargreaves & Spriet, 2018; Balsom et al., 1999). Factors like glycogen depletion will affect if endurance athletes can finish the competition in satisfactory manner (Balsom et al., 1999). Distributing energy over the course of the competition is called pacing strategy and has been showed to be crucial for performing optimally (Abbiss & Laursen, 2008).

2.3 Pacing strategy in endurance competition

Pacing is described as the chosen or forced distribution of an athlete's energy resources during the length of the competition, and is an important factor for performance in cross-country skiing (Foster et al., 2023; Losnegard, 2019). Different pacing strategies seemingly fit different types of competitions (Abbiss & Laursen, 2008). For shorter competitions (less than 3 minutes) athletes seem to succeed when adapting a positive pacing (Abbiss & Laursen, 2008). Positive pacing is when the starting power is higher than finishing power (Abbiss & Laursen, 2008). For longer competitions, an even pacing seems to be the most beneficial for faster times during a time-trial competition (Abbiss & Laursen, 2008; Losnegard et al., 2022). Even pacing is consistent speed and/or power throughout the competition. The individual athlete's pacing strategy is hypothesised to be chosen due to the athlete's previous experiences and internal and external stimuli (Foster et al., 2023). Examples of internal stimuli are respiratory rate, blood lactate, HR, or muscle glycogen (Tucker, 2009) while external stimuli could be how other athletes behave; examplewise a rapid increase in speed from a competitor. A study done on a simulated mountain bike competition showed that participants adopted a fast start pacing strategy to gain an advantage early in the competition where it was easier to pass other athletes (Viana et al., 2018), before slowing down in the narrower sections. These findings shows that pacing is not only about having the highest power output over the duration of the competition, but also adapting to the circumstances of the competition.

Different pacing strategies have been well researched in various sports. During a 1500m speedskating simulated competition, researchers imposed a theoretical optimal pacing strategy on high-level ice-skaters and found that they would skate slower when trying to optimize their strategy compared to their self-chosen pacing strategy (Hettinga et al., 2011). The researchers theorized that athletes would develop a pacing strategy that is well suited to the individual. Contrary, recent studies on pacing in cross-country skiing has shown a significant increase in performance by improving an athlete’s pacing strategy (Losnegard et al., 2022). Optimizing pacing strategy seems crucial for performance, but athletes seemingly need time to adopt the most optimized pacing strategy for the athlete.

2.3.1 How to quantify pacing

One of the most used measures to understand pacing strategy is rate of perceived exertion (RPE). RPE has been causally linked with many physiological factors, such as glycogen depletion and blood lactate. Borg described RPE as “the single best indicator of physical strain” (Tucker, 2009, p. 392). A model with 2 main components has been proposed for how athletes regulate their pacing (Tucker, 2009). These 2 components are an anticipatory component and a feedback component. The anticipatory component refers to physiological- and psychological factors (Tucker, 2009), while the feedback component is based on what happens during the competition, often based on the athletes subjective feeling. De Koning et al. (2011) hypothesized that the athletes continuously measure their RPE against a template RPE during a competition. Template RPE is not something that can be measured, but something athletes construct based on previous experiences (Tucker, 2009). Furthermore, research has shown that RPE increases linearly with exercise duration (Noakes, 2004) and has also shown that RPE can be used to anticipatory regulated exercise (Noakes, 2004; Tucker, 2009; Scherr et al., 2013). Combining RPE with a more objective measurement of exercise/work intensity, such as propulsive power could produce a more complete picture of how athletes solve a competition.

Propulsive power is used in many sports as an objective measurement for work intensity and has been shown to correlate well with instantaneous energy demands (Gløersen et al., 2018). This is usually done on an ergometer bike or through watt pedals attached to a road bike (Atkinson et al., 2012). One of the earliest calculations of propulsive power were done on cyclists (Martin et al., 1998). Martin et al., (1998) showed that if you can control all factors, a calculation of the propulsive power is strongly correlated to the measured propulsive power (r = 0.97). Similar calculations have been done in cross-country skiing (Swarén & Eriksson, 2019; Sandbakk et al., 2011) and Gløersen et al. (2018) made a validation article of calculating propulsive power for cross-country skiing using continuous Global Navigation Satellite System (GNSS) data, detailing many of the factors that one must account for when calculating propulsive power for cross-country skiers (Gløersen et al., 2018). The paper showed that there is an uncertainty when calculating propulsive power due to uncontrolled environments, but it can be cautiously used to compare skiers in the same competition (Gløersen et al., 2018).

2.3.2 Pacing in biathlon

Pacing in sprint biathlon follows typically a “J-shaped” curve, where the first lap is the fastest while there is a reduction in pace on the penultimate lap before an increase in pace on the last lap (Björklund & Laaksonen, 2022). It also seems that the best biathletes choose a more even pacing compared to less performing biathletes (Luchsinger et al., 2018). To the authors knowledge, only one intervention study is done on the topic, and it showed a decrease in completion time when athletes chose a more conservative opening strategy to gain a more even pacing (Granrud, 2022). The mentioned study surprisingly found that when biathletes were tasked to open more conservatively a reduction in shooting performance occurred (Granrud, 2022). To better understand how pacing strategy affect skiing performance, one may look to research done on pacing in cross-country skiing.

2.3.3 Pacing in cross-country skiing

Pacing in cross-country skiing can be divided into a macro pacing strategy, which involves how to pace from lap to lap, and a micro pacing strategy that involves how to solve the different segments during a lap (Losnegard, 2019). Even pacing often refers to macro pacing and is as mentioned equal power and speed from lap to lap.

In cross-country skiing, a positive pacing is seemingly the most used, even though even pacing is thought to be more optimal (Stöggl et al., 2018). When choosing an even pacing athletes report lower RPE and is seemingly less fatigued earlier in the competition (Losnegard et al., 2022). This lesser fatigue seems to improve decision making and technical ability, leading to increased performance. Further research showed that a more even pacing had an impact on the speed of the skier in all terrain types (Losnegard et al., 2022). These gains in speed were attributed to more energy on hilltops, better gross efficiency and more energy in easy terrain leading to a more aerodynamic downhill position and more free skating (Losnegard et al., 2022).

While increasing speed in all terrain types is important for skiing performance, time spent in uphills is often what correlates best with overall skiing performance (Shang et al., 2022; Luchsinger et al., 2019). Studies have investigated why cross-country skiers drastically increase their work intensity when skiing in uphills (Karlsson et al., 2018). These studies explained this with reduced air drag in uphills, a larger muscle mass being active in uphills and the possibility to rest in the downhills (Karlsson et al., 2018; Olesen, 1992). The effect on small breaks due to shifts in terrain has been tested indoors, finding that a small break of 15 seconds (roller skiing at 60% of max aerobic power) seems to help to recover some of the athlete’s anaerobic capacity (Holsbrekken, 2021). The elite athletes performed more sprints than recreational skiers when the relative work intensity was equal, showing a seemingly better ability to recover anaerobic capacity (Holsbrekken, 2021).

Research have also shown an increase in work intensity when athletes are nearing the finish of the competition (Karlsson et al., 2018). This can be attributed to the end-spurt phenomenon (Tucker, 2009). Research states that athletes experience a form of uncertainty for when the exercise is ending, or for what amount of energy that is required to complete the exercise in a satisfactory manner (Tucker, 2009). In biathlon this uncertainty might be higher than in other endurance competitions due to how performance on the shooting range could affect the length of the competition. Therefore, a biathlete will not be able to completely estimate the duration of the competition until they have completed the last shooting. A miss in most competitions would lead to increasing the competition length with 150m and subsequently a time loss. More research is needed to investigate how this uncertainty affect pacing strategy earlier in the competition.

2.3.4 Pacing differences between sexes

Newer research has started to investigate the differences in pacing strategy between the sexes. One study found that female skiers were approximately 12% slower over the course of a sprint race and 19% slower in the uphill sections (Andersson et al., 2019). For distance skiing, Losnegard et al. (2016) found that both female and male elite skiers adopted a positive pacing strategy over 10 and 15 km respectively. In the mentioned paper the female participants skied 2 laps of 5 km, giving a somewhat stunted understanding of the macro pacing during the competition (Losnegard et al., 2016).

Looking at endurance running, females tend to have a more even pacing compared to males (Besson et al., 2022), who often use a positive pacing. The reason for this could be attributed to physiological and/or cognitive differences between the sexes. For example, females in general have a higher proportion of type 1 muscle fibres (Besson et al., 2022). Males on the other hand, have a higher anaerobic capacity due to a higher muscle mass, while also having greater proportions of faster muscle fibres, that are more susceptible for muscle glycogen depletion (Besson et al., 2022; Hunter, 2014). Hunter (2014) also stated that the sex differences in muscle fatigue can differ due to contraction speed, activation of different muscle groups and environmental factors among others. If females and males fatigue differently for the same task, this might affect how females and males should pace optimally during similar competition. One study has compared skiing speed between sexes over several seasons in biathlon (Björklund & Laaksonen, 2022). They found that the best performing females had a more even pacing compared to slower females during a 3-lap race, while all males showed a positive pacing strategy. For 5-lap races, a more positive pacing was chosen compared to 3-lap races for both sexes (Björklund & Laaksonen, 2022). More research is needed to understand if there is a difference between sexes in biathlon, and how it affects performance.

2.4 How does shooting affect pacing strategy

Shooting could complicate pacing strategy for biathletes. Biathletes are required to carry their own rifle, usually weighing somewhere between 3.7 and 5kg (Kärström et al., 2019; Stöggl et al., 2015). This extra weight means that biathletes have to produce a higher propulsive power to maintain the same speed as cross-country skiers. Biathletes must gauge their state of fatigue to be able to perform shooting at the high standard required. Medals at elite level of biathlon are often won with a hit rate of over 95% (Laaksonen et al., 2018), meaning that high performing biathletes needs the mental capacity and fine motor skill to perform accurate enough shots for good overall performance. Studies indicate that there might be an inverted U-shape correlation between physical exertion and mental performance (Frey et al., 1997), showing that some physical strain might lead to better cognitive results. A study on elite Norwegian soldiers found a reduction in accuracy, but that the soldiers were still able to hit the target with the same frequency after an intensive bout of exercise (Buskerud et al., 2022). Another study explored the link between RPE and performance in high pressured situations indicating an increase in performance with increase in RPE up to a threshold (Vickers & Williams, 2007). Biathletes must be mindful of their pacing strategy, finding the right intensity to optimize performance on the shooting range.

In addition, the experience of cognitive stress during shooting might lead the biathlete to pace more conservatively on the following lap, due to mental fatigue affecting physical performance (Van Cutsem et al., 2017). Studies have shown that mental fatigue has a negative impact on physical performance, though factors like VO_2 peak, blood lactate and HR seemed unaffected (Marcora et al., 2009). Contrary, a decrease in blood lactate, HR and VO_2 were found in one study investigating mental fatigue at exhaustion (Van Cutsem et al., 2017). Mental fatigue therefore seems to have highest impact on behavioural parameters, and the impact seemed to increase with the length of the session (Van Cutsem et al., 2017). Participants chose a lower power output after a mental fatiguing protocol, compared to the control group during a time to exhaustion test (Marcora et al., 2009). For biathletes, this implies that spending a great amount of mental capacity hitting shots in the early stages of the competition, could impose mental fatigue and thereby influence skiing performance. Most misses happen on the first or last shot of the last shooting (Luchsinger et al., 2019). Therefore, juggling skiing speed and both physical and mental fatigue seem to be important for better overall performance in biathlon. To understand the interplay between mental and physical fatigue in biathlon, more research is needed.

2.4.1 How does the stop for shooting affect pacing strategy

A biathlete is forced to stop 2-4 times during a competition to shoot, which could lead to changes in energy turnover. Similar to cross-country skiing, biathlon is characterized by fluctuations in speed, power output and thereby HR. Uniquely for biathletes is the stop for shooting which results in periodically no external work and thereby a large drop in HR. One study showed that stopping to shoot reduced the HR from ~90% to ~60% of maximal HR (Hoffman et al., 1992). This differentiates biathlon from cross-country skiing, where athletes are fluctuating between 85% to 95% of maximal HR during most of the competition (Karlsson et al., 2018). Research has shown that athletes can get a substantial increase in force production with 1 minute of rest after exhaustive work (Froyd et al, 2013). Biathletes usually have a range time (time between entering and exiting the shooting range) of 50 seconds during one shooting in a sprint competition (Björklund & Laaksonen, 2022). This indicates that biathletes might somewhat physically recover during shooting, and therefore have the possibility for a higher power output after exiting the shooting range. However, a 30% drop in HR comes with substantial changes in the body's ability to transport oxygen to working muscles. A 30% reduction in cardiac output and a sudden increase in work intensity would force the body to cover the energy demand using a substantial contribution from the anaerobic energy system.

2.4.2 Does carrying a rifle affect pacing

Some research has been done on rifle carriage (Kårström et al., 2019; Stöggl et al., 2015). The extra weight seems to affect the technique of the biathletes imposing increased cycle rate and decreased cycle length (Stöggl et al., 2015). Studies have shown varying results when looking at the physiological aspects of rifle carrying. Kärström et al. (2019) showed that there was an increase in HR, blood lactate and VO_2 consumption when skiing with rifle compared to no rifle on submaximal speed. Contrary, Stöggl et al. (2015) showed no significant difference in blood lactate but found a difference in VO_2 consumption and HR on submaximal speed. For race pace there has also been some conflicting results, probably due to slight variations in methods. Stöggl et al. (2015) had a set race pace and found that carrying a rifle led to an increase in all physiological values mentioned above when compared to no rifle. For Kärström et al. (2019) the athletes set their own pace for an all-out test, and researchers found no difference in physiological parameters, but an increased completion time when carrying a rifle.

In addition, carrying a rifle might affect an athlete's ability to solve terrain changes optimally. Measurement of gross efficiency could give an indication if the athletes get less economic when carrying a rifle. Research shows conflicting results for gross efficiency with Stöggl et al. (2015) showing that there was no change in gross efficiency between race pace and submaximal intensities, while Kärström et al. (2019) showed an increase in gross efficiency with an increase in pace. Another finding was that there was no difference in gross efficiency between carrying a rifle and not carrying a rifle for elite biathletes (Stöggl et al., 2015).

Both aforementioned studies were done in laboratory settings and under conditions rarely found in a biathlon (or cross-country skiing) competition. A 1000m all out segment with constant incline is something biathletes and cross-country skiers rarely meet in a competition (Kärström et al., 2019) . Carrying a rifle seem to affect biathletes in some way, but understanding how carrying a rifle affects performance and micro pacing in constantly changing terrain requires more research.

2.5 Summary

Research on what physiological factors affects skiing performance in biathlon is scarce. Comparing the pacing strategy, RPE, propulsive power and HR of biathletes and cross-country skiers during an identical length simulated competition might give insight in what physiological factors that are crucial for skiing performance in biathlon. Exploring the difference between the 2 disciplines might give insight if there are some physical parameters that are more determining for skiing performance in biathlon compared to cross-country skiing. This knowledge might lead researchers to better understand biathlon and might help coaches and athletes to craft more theoretical sound training programs to increase skiing performance in biathlon.

2.6 References

Abbiss, C. R., & Laursen, P. B. (2008). Describing and understanding pacing strategies during athletic competition. *Sports medicine (Auckland, N.Z.), 38*(3), 239–252. https://doi.org/10.2165/00007256-200838030-00004

Andersson, E. P., Govus, A., Shannon, O. M., & McGawley, K. (2019). Sex Differences in Performance and Pacing Strategies During Sprint Skiing. *Frontiers in physiology*, *10*, 295. https://doi.org/10.3389/fphys.2019.00295

Atkinson, G., Peacock, O., St Clair Gibson, A., & Tucker, R. (2007). Distribution of power output during cycling: impact and mechanisms. *Sports medicine (Auckland, N.Z.), 37*(8), 647–667. https://doi.org/10.2165/00007256-200737080-00001

Balsom, P. D., Gaitanos, G. C., Söderlund, K., & Ekblom, B. (1999). High-intensity exercise and muscle glycogen availability in humans. *Acta physiologica Scandinavica*, *165*(4), 337–345. https://doi.org/10.1046/j.1365-201x.1999.00517.x

Besson, T., Macchi, R., Rossi, J., Morio, C. Y. M., Kunimasa, Y., Nicol, C., Vercruyssen, F., & Millet, G. Y. (2022). Sex Differences in Endurance Running. *Sports medicine (Auckland, N.Z.), 52*(6), 1235–1257. https://doi.org/10.1007/s40279-022-01651-w

Binkley, S., Foster, C., Cortis, C., de Koning, J. J., Dodge, C., Doberstein, S. T., Fusco, A., Jaime, S. J., & Porcari, J. P. (2021). Summated Hazard Score as a Powerful Predictor of Fatigue in Relation to Pacing Strategy. *International journal of environmental research and public health*, *18*(4), 1984. https://doi.org/10.3390/ijerph18041984

Björklund, G., & Laaksonen, M. S. (2022). The Determinants of Performance in Biathlon World Cup Sprint and Individual Competitions. *Frontiers in sports and active living*, *4*, 841619. https://doi.org/10.3389/fspor.2022.841619

Borg G. A. (1982). Psychophysical bases of perceived exertion. *Medicine and science in sports and exercise*, *14*(5), 377–381.

Buskerud, J. E., Abrahamsen, F. E., & Solberg, P. A. (2022). Physical Stress and Determinants of Shooting Performance Among Norwegian Special Forces Operators. *Frontiers in psychology*, *13*, 894169. https://doi.org/10.3389/fpsyg.2022.894169 de Koning, J. J., Foster, C., Bakkum, A., Kloppenburg, S., Thiel, C., Joseph, T., Cohen, J., & Porcari, J. P. (2011). Regulation of pacing strategy during athletic competition. *PloS one*, *6*(1), e15863. https://doi.org/10.1371/journal.pone.0015863

Foster, C., de Koning, J. J., Hettinga, F. J., Barroso, R., Boullosa, D., Casado, A., Cortis, C., Fusco, A., Gregorich, H., Jaime, S., Jones, A. M., Malterer, K. R., Pettitt, R., Porcari, J. P., Pratt, C., Reinschmidt, P., Skiba, P., Splinter, A., St Clair Gibson, A., St Mary, J., … van Tunen, J. (2023). Competition Between Desired Competitive Result, Tolerable Homeostatic Disturbance, and Psychophysiological Interpretation Determines Pacing Strategy. *International journal of sports physiology and performance*, *18*(4), 335–346. https://doi.org/10.1123/ijspp.2022-0171

Frey, Y. A., Ferry. A., Hofe. A. V. & Rieu. M. (1997). Effect of physical exhaustion on cognitive functioning. *Percetptual and Mortor Skills*, *84*, 291-298. https://journals.sagepub.com/doi/pdf/10.2466/pms.1997.84.1.291

Fritzsche, R. G., Switzer, T. W., Hodgkinson, B. J., & Coyle, E. F. (1999). Stroke volume decline during prolonged exercise is influenced by the increase in heart rate. *Journal of applied physiology (Bethesda, Md. : 1985)*, *86*(3), 799–805. https://doi.org/10.1152/jappl.1999.86.3.799

Froyd, C., Beltrami, F. G., Millet, G. Y., & Noakes, T. D. (2016). Central Regulation and Neuromuscular Fatigue during Exercise of Different Durations. *Medicine and science in sports and exercise*, *48*(6), 1024–1032. https://doi.org/10.1249/MSS.0000000000000867

Froyd, C., Millet, G. Y., & Noakes, T. D. (2013). The development of peripheral fatigue and short-term recovery during self-paced high-intensity exercise. *The Journal of physiology*, *591*(5), 1339–1346. https://doi.org/10.1113/jphysiol.2012.245316

Gastin P. B. (2001). Energy system interaction and relative contribution during maximal exercise. *Sports medicine (Auckland, N.Z.)*, *31*(10), 725–741. https://doi.org/10.2165/00007256-200131100-00003

Gløersen, Ø., Gilgien, M., Dysthe, D. K., Malthe-Sørenssen, A., & Losnegard, T. (2020). Oxygen Demand, Uptake, and Deficits in Elite Cross-Country Skiers during a 15-km Race. *Medicine and science in sports and exercise*, *52*(4), 983–992. https://doi.org/10.1249/MSS.0000000000002209

Gløersen, Ø., Kocbach, J., & Gilgien, M. (2018). Tracking Performance in Endurance Racing Sports: Evaluation of the Accuracy Offered by 3 Commercial GNSS Receivers Aimed at the Sports Market. *Frontiers in physiology, 9*, 1425. https://doi.org/10.3389/fphys.2018.01425

Gløersen, Ø., Losnegard, T., Malthe-Sørenssen, A., Dysthe, D. K., & Gilgien, M. (2018). Propulsive Power in Cross-Country Skiing: Application and Limitations of a Novel Wearable Sensor-Based Method During Roller Skiing. *Frontiers in physiology*, *9*, 1631. https://doi.org/10.3389/fphys.2018.01631

Granrud E. D. (2022). *How a change to a more controlled start pace affects biathletes with a fast-start pacing pattern.* [Masterthesis, Norwegian School of Sport Sciences] Brage NIH. https://hdl.handle.net/11250/3006522

Hargreaves, M., & Spriet, L. L. (2018). Exercise Metabolism: Fuels for the Fire. *Cold Spring Harbor perspectives in medicine*, *8*(8), a029744. https://doi.org/10.1101/cshperspect.a029744

Hettinga, F. J., De Koning, J. J., Schmidt, L. J., Wind, N. A., Macintosh, B. R., & Foster, C. (2011). Optimal pacing strategy: from theoretical modelling to reality in 1500-m speed skating. *British journal of sports medicine*, *45*(1), 30–35. https://doi.org/10.1136/bjsm.2009.064774

Hoffman, M. D., & Street, G. M. (1992). Characterization of the heart rate response during biathlon. *International journal of sports medicine, 13*(5), 390–394. https://doi.org/10.1055/s-2007-1021286

Holsbrekken E (2021). *Competitive cross-country skiers have a longer time to exhaustion and a larger accumulation of oxygen deficit than recreational cross-country skiers during an intermittent interval protocol standardized for maximal aerobic power.* [Masterthesis, Norwegian School of Sport of Sciences]. Brage NIH. https://hdl.handle.net/11250/2770175

Hunter S. K. (2014). Sex differences in human fatigability: mechanisms and insight to physiological responses. *Acta physiologica (Oxford, England)*, *210*(4), 768–789. https://doi.org/10.1111/apha.12234

Jayanthi, N. A., Post, E. G., Laury, T. C., & Fabricant, P. D. (2019). Health Consequences of Youth Sport Specialization. *Journal of athletic training*, *54*(10), 1040–1049. https://doi.org/10.4085/1062-6050-380-18

Jonsson Kårström, M., McGawley, K., & Laaksonen, M. S. (2019). Physiological Responses to Rifle Carriage During Roller-Skiing in Elite Biathletes. *Frontiers in physiology*, *10*, 1519. https://doi.org/10.3389/fphys.2019.01519

Joyner, M. J., & Casey, D. P. (2015). Regulation of increased blood flow (hyperemia) to muscles during exercise: a hierarchy of competing physiological needs. *Physiological reviews*, *95*(2), 549–601. https://doi.org/10.1152/physrev.00035.2013

Joyner, M. J., & Coyle, E. F. (2008). Endurance exercise performance: the physiology of champions. *The Journal of physiology*, *586*(1), 35–44. https://doi.org/10.1113/jphysiol.2007.143834

Karlsson, Ø., Gilgien, M., Gløersen, Ø. N., Rud, B., & Losnegard, T. (2018). Exercise Intensity During Cross-Country Skiing Described by Oxygen Demands in Flat and Uphill Terrain. *Frontiers in physiology*, *9*, 846. https://doi.org/10.3389/fphys.2018.00846

Laaksonen, M. S., Finkenzeller, T., Holmberg, H. C., & Sattlecker, G. (2018). The influence of physiobiomechanical parameters, technical aspects of shooting, and psychophysiological factors on biathlon performance: A review. *Journal of sport and health science*, *7*(4), 394–404. https://doi.org/10.1016/j.jshs.2018.09.003

Losnegard T. (2019). Energy system contribution during competitive cross-country skiing. *European journal of applied physiology*, *119*(8), 1675–1690. https://doi.org/10.1007/s00421-019-04158-x

Losnegard, T., Kjeldsen, K., & Skattebo, Ø. (2016). An Analysis of the Pacing Strategies Adopted by Elite Cross-Country Skiers. *Journal of strength and conditioning research*, *30*(11), 3256–3260. https://doi.org/10.1519/JSC.0000000000001424

Losnegard, T., Tosterud, O. K., Kjeldsen, K., Olstad, Ø., & Kocbach, J. (2022). Cross-Country Skiers With a Fast-Start Pacing Pattern Increase Time-Trial Performance by Use of a More Even Pacing Strategy. *International journal of sports physiology and performance*, *17*(5), 739–747. https://doi.org/10.1123/ijspp.2021-0394

Losnegard, T., Tosterud, O. K., Kjeldsen, K., Olstad, Ø., & Kocbach, J. (2022). Cross-Country Skiers With a Fast-Start Pacing Pattern Increase Time-Trial Performance by Use of a More Even Pacing Strategy. *International journal of*

sports physiology and performance, *17*(5), 739–747. https://doi.org/10.1123/ijspp.2021-0394

Luchsinger, H., Kocbach, J., Ettema, G., & Sandbakk, Ø. (2018). Comparison of the Effects of Performance Level and Sex on Sprint Performance in the Biathlon World Cup. *International journal of sports physiology and performance*, *13*(3), 360–366. https://doi.org/10.1123/ijspp.2017-0112

Luchsinger, H., Kocbach, J., Ettema, G., & Sandbakk, Ø. (2019). The Contribution From Cross-Country Skiing and Shooting Variables on Performance-Level and Sex Differences in Biathlon World Cup Individual Races. *International journal of sports physiology and performance*, *14*(2), 190–195. https://doi.org/10.1123/ijspp.2018-0134

Luchsinger, H., Kocbach, J., Ettema, G., & Sandbakk, Ø. (2020). Contribution from cross-country skiing, start time and shooting components to the overall and isolated biathlon pursuit race performance. *PloS one*, *15*(9), e0239057. https://doi.org/10.1371/journal.pone.0239057

Luchsinger, H., Talsnes, R. K., Kocbach, J., & Sandbakk, Ø. (2019). Analysis of a Biathlon Sprint Competition and Associated Laboratory Determinants of Performance. *Frontiers in sports and active living*, *1*, 60. https://doi.org/10.3389/fspor.2019.00060

Marcora, S. M., Staiano, W., & Manning, V. (2009). Mental fatigue impairs physical performance in humans. *Journal of applied physiology (Bethesda, Md. : 1985)*, *106*(3), 857–864. https://doi.org/10.1152/japplphysiol.91324.2008

Martin, J. C., Milliken, D. L., Cobb, J. E., McFadden, K. L., & Coggan, A. R. (1998). Validation of a Mathematical Model for Road Cycling Power. *Journal of applied biomechanics*, *14*(3), 276–291. https://doi.org/10.1123/jab.14.3.276

Noakes T. D. (2004). Linear relationship between the perception of effort and the duration of constant load exercise that remains. *Journal of applied physiology (Bethesda, Md. : 1985)*, *96*(4), 1571–1573. https://doi.org/10.1152/japplphysiol.01124.2003

Norman, R.W., Õunpuu, S., Fraser, M., & Mitchell, R.B. (1989). Mechanical Power Output and Estimated Metabolic Rates of Nordic Skiers During Olympic Competition. *International journal of sport biomechanics,* 5, 169-184. https://doi.org/10.1123/ijsb.5.2.169

Olesen H. L. (1992). Accumulated oxygen deficit increases with inclination of uphill running. *Journal of applied physiology (Bethesda, Md. : 1985), 73*(3), 1130–1134. https://doi.org/10.1152/jappl.1992.73.3.1130

Sahlin K. (2014). Muscle energetics during explosive activities and potential effects of nutrition and training. *Sports medicine (Auckland, N.Z.), 44 Suppl 2*(Suppl 2), S167–S173. https://doi.org/10.1007/s40279-014-0256-9

Sandbakk, Ø., Ettema, G., Leirdal, S., *Jakobsen, V. & Holmberg, H. C.* Analysis of a sprint ski race and associated laboratory determinants of world-class performance. *European Journal of Applied Physiology* **111**, 947–957 (2011). https://doi.org/10.1007/s00421-010-1719-9

Santos, D. A., Dawson, J. A., Matias, C. N., Rocha, P. M., Minderico, C. S., Allison, D. B., Sardinha, L. B., & Silva, A. M. (2014). Reference values for body composition and anthropometric measurements in athletes. *PloS one*, *9*(5), e97846. https://doi.org/10.1371/journal.pone.0097846

Scherr, J., Wolfarth, B., Christle, J. W., Pressler, A., Wagenpfeil, S., & Halle, M. (2013). Associations between Borg's rating of perceived exertion and physiological measures of exercise intensity. *European journal of applied physiology*, *113*(1), 147–155. https://doi.org/10.1007/s00421-012-2421-x

Shang, L., Sandbakk, Ø., Shi, R., Chen, X., & Talsnes, R. K. (2022). Analysis of a Skating Time-Trial Competition and Associated Performance-Determinants in Cross-Country Skiers. *International journal of environmental research and public health*, *19*(18), 11580. https://doi.org/10.3390/ijerph191811580

Skattebo, Ø., & Losnegard, T. (2018). Variability, Predictability, and Race Factors Affecting Performance in Elite Biathlon. *International journal of sports physiology and performance*, *13*(3), 313–319. https://doi.org/10.1123/ijspp.2017-0090

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

Stöggl, T., Pellegrini, B., & Holmberg, H. C. (2018). Pacing and predictors of performance during cross-country skiing races: A systematic review. *Journal of sport and health science*, *7*(4), 381–393. https://doi.org/10.1016/j.jshs.2018.09.005

Swarén, M., & Eriksson, A. (2019). Power and pacing calculations based on real-time locating data from a cross-country skiing sprint race. *Sports biomechanics*, *18*(2), 190–201. https://doi.org/10.1080/14763141.2017.1391323

Tucker R. (2009). The anticipatory regulation of performance: the physiological basis for pacing strategies and the development of a perception-based model for exercise performance. *British journal of sports medicine*, *43*(6), 392–400. https://doi.org/10.1136/bjsm.2008.050799

Tønnessen, E., Haugen, T. A., Hem, E., Leirstein, S., & Seiler, S. (2015). Maximal aerobic capacity in the winter-Olympics endurance disciplines: Olympic-medal benchmarks for the time period 1990-2013. *International journal of sports physiology and performance*, *10*(7), 835–839. https://doi.org/10.1123/ijspp.2014-0431

Van Cutsem, J., Marcora, S., De Pauw, K., Bailey, S., Meeusen, R., & Roelands, B. (2017). The Effects of Mental Fatigue on Physical Performance: A Systematic Review. *Sports medicine (Auckland, N.Z.)*, *47*(8), 1569–1588. https://doi.org/10.1007/s40279-016-0672-0

Viana, B. F., Pires, F. O., Inoue, A., & Santos, T. M. (2018). Pacing Strategy During Simulated Mountain Bike Racing. *International journal of sports physiology and performance*, *13*(2), 208–213. https://doi.org/10.1123/ijspp.2016-0692

Vickers, J. N., & Williams, A. M. (2007). Performing under pressure: the effects of physiological arousal, cognitive anxiety, and gaze control in biathlon. *Journal of motor behavior*, *39*(5), 381–394. https://doi.org/10.3200/JMBR.39.5.381-394

3 Article

3.1 Abstract

Purpose: Biathlon and cross-country skiing are 2 seemingly similar disciplines, but the prospect of shooting might affect the pacing of biathletes and their skiing performance. Therefore, the aim of this thesis was to investigate if there were differences in pacing strategy over an identical length competition between biathlon and cross-country skiing.

Methods: 52 junior athletes (n=28 males, ~ 17yrs), hereby biathletes (n=24, 9 females & 15 males) and cross-country skiers (n=27, 14females & 13 males) performed an individual 6 km (3x2.0km for females) or 7.5 km (3x2.5km for males) simulated competition. For biathletes prone shooting was done after first and second lap, while cross-country skiers skied continuously. Shooting was done on paper targets with 10-point standard rings.

Results: Male biathletes were slower on the first lap and in total course time compared to male cross-country skiers (21sec lap1, 42sec total $P<0.05$). No difference in course time were found for females ($P>0.05$). Male biathletes used an even pacing strategy, while male cross-country skiers applied a positive pacing strategy (33.0% vs 32.4% relative to total course time for lap 1 $P<0.001$, 33.6% vs 34% relative to total course time for lap 2 $P<0.01$). No difference in pacing strategy between females were observed ($P>0.05$). Both male and female biathletes reported lower summated rate of perceived exertion (RPE) over the duration of the competition compared to male and female cross-country skiers (136.6 vs 149.2 for female, 139.2 vs 147.5 for males $P<0.05$). Both sexes reported lower RPE after first shooting compared to second shooting (12 vs 14.9 and 13.2 vs 16.7 for female, 12.3 vs 15.1 and 13.8 vs 16.6 for male, $P<0.01$). No difference in shooting performance was found between the shootings.

Conclusion: Male biathletes showed a more even pacing strategy compared to male cross-country skiers, while female biathletes showed similar pacing strategy as female cross-country skiers but reported lower RPE values. These differences in pacing and RPE alludes to different physical factors affecting skiing performance in biathlon and cross-country skiing, but more research is needed.

3.2 Introduction

Biathlon is a winter sport combining physically demanding cross-country skiing with rifle shooting requiring fine motor control skills. Biathlon has been on the Olympic program since 1960 and athletes today compete in 4 different individual competitions: sprint (7.5km and 10km), individual (15km and 20km), mass start (12.5km and 15km) and pursuit (10km and 12.5km) (female distances reported first). Biathletes must stop to shoot 2 to 4 5-shot series depending on the competition. While being one of the most popular winter sports, biathlon is under-researched compared to other skiing sports like alpine skiing or cross-country skiing (136 publications on PubMed for biathlon compared to 945 for cross-country skiing, May 2023).

Pacing strategy might help enlighten some of the differences between biathlon and cross-country skiing. Pacing is described as the chosen or forced distribution of an athlete's energy resources during the length of the competition and is an important factor for performance in cross-country skiing and biathlon (Foster et al., 2023; Losnegard, 2019). For biathlon and cross-country skiing 3 different pacing strategies have mostly been observed: Positive pacing (starting power is higher than finishing power), even pacing (even distribution of power throughout the competition) and J-shaped pacing (high starting power, followed by a dip in the mid part and then a resurge of power towards the end) (Abbiss & Laursen, 2008; Losnegard et al., 2022; Björklund & Laaksonen, 2022). Using an even pacing strategy is seemingly most optimal for better performance in time-trial competition with duration over 3 minutes, such as in biathlon and cross-country skiing (Abbiss & Laursen, 2008; Losnegard et al., 2022).

The most obvious factor that could lead to differences in pacing strategy between the 2 disciplines is the shooting component of biathlon. Shooting forces the biathletes to stop for about 50 seconds 2-4 times during a competition (Björklund & Laaksonen, 2022). This leads to a great decrease in physical workload for biathletes. Physical rest of 1 min has shown to substantially increase force production (Froyd et al., 2013). A reduction in heart rate (HR), from ~90% to ~60%, has also been shown to accompany the stopping to shoot (Hoffman et al., 1992). These factors seemingly indicate that biathletes must distribute their energy differently compared to cross-country skiers to achieve optimal pacing strategy. However, no direct comparison between the 2 disciplines have been done to understand if this is the case. Pacing strategy accompanied with rate of perceived exertion (RPE) might give insight in what differentiates biathlon and cross-country skiing.

RPE has been described as “the single best indicator of physical strain” (Tucker, 2009, p. 392) and has shown correlation with performance in both biathlon and cross-country skiing (Luchsinger et al., 2019; Talsnes et al., 2021). RPE is a subjective measurement often based on 2 components: anticipatory component and feedback component, and these 2 components are constantly compared to a template RPE the athlete constructs based on previous experiences (Tucker, 2009; De Koning et al., 2011). Combining the subjective feeling from the athlete with more objective measured parameters, such as HR, propulsive power and speed might be used to better understand what areas in biathlon is different from cross-country skiing. Furthermore, similarities in these parameters might give insight in how already established research on cross-country skiing can be applied to biathlon.

The aim of this thesis is to investigate the difference in pacing between biathletes and cross-country skiers during an identical length competition, to further understand the physical parameters that can attribute to a better skiing performance in biathlon.

3.3 Methods

3.3.1 Participants

There was a total of 57 athletes, where 52 athletes consisting of 25 females (17 ±1 yrs) and 27 males (17 ± 1 yrs) finished the simulated competition. Furthermore, the athletes were divided into 4 groups: Female biathletes (n=9), female cross-country skiers (n=14), male biathlon (n=15) and male cross-country skiers (n=13). Anthropometric data for the athletes are presented in Table 1. Female biathletes had a higher weight compared to female cross-country skiers when weighed with all equipment ($P<0.05$). All participants were recruited through Norges Toppidretts Gymnas Lillehammer and are highly competitive athletes in their age group. This thesis followed the ethical guidelines of the Helsinki declaration and were approved by the Norwegian Centre for Research Data (reference number 133231) and the Norwegian School of Sport Sciences ethical committee. All athletes were recruited through their coaches at their school, who in turn was contacted by the researchers for this project. Athletes were informed about the project and gave their written consent prior to the data collection.

Table 1: *shows the anthropomorphic data of the participants for this thesis (mean ± standard of deviation (SD)). Weight with equipment includes rifle for biathletes. B = biathletes and CCS = cross-country skiers. * = P < 0.05*

	Female B	**Female CCS**	**Male B**	**Male CCS**
Height(cm)	173 ± 4	168 ± 7	182 ± 5	180 ± 8
Weight including rifle (kg)	69.4 ± 3.6*	64.7 ± 6.0*	78.2 ± 6.1	73.6 ± 9.4
Weight excluding rifle (kg)	65.7 ± 3.6	64.7 ± 6.0	74.5 ± 6.1	73.6 ± 9.4

3.3.2 Design

To investigate the difference in pacing strategy between biathletes and cross-country skiers, athletes performed a simulated time trial competition of 3x2.0km for females and 3x2.5km for males (Figure 1a). These distances were chosen because these are the distances used by juniors in biathlon for the sprint competition. During the simulated competition, RPE, continues global navigation satellite system (GNSS) data, HR data and shooting data were collected. In addition, propulsive power was calculated based on factors such as rolling resistance and air resistance. The biathletes had one prone shooting at the end of the first and second lap, while the cross-country skiers roller skied 3 consecutive laps. For the simulated competition, the biathletes did not roller ski penalty loops when they missed a target. The biathletes carried their own rifle during the simulated race. Due to limited amount of equipment, 3 simulated competitions were conducted over the duration of 4 hours. Athletes were divided into 3 competition groups, in each group biathletes and cross-country skiers were mixed based on age and sex. Biathletes had odd numbered bibs while cross-country skiers had even numbered bibs to account for changes in conditions. There was a 30 second gap between each athlete.

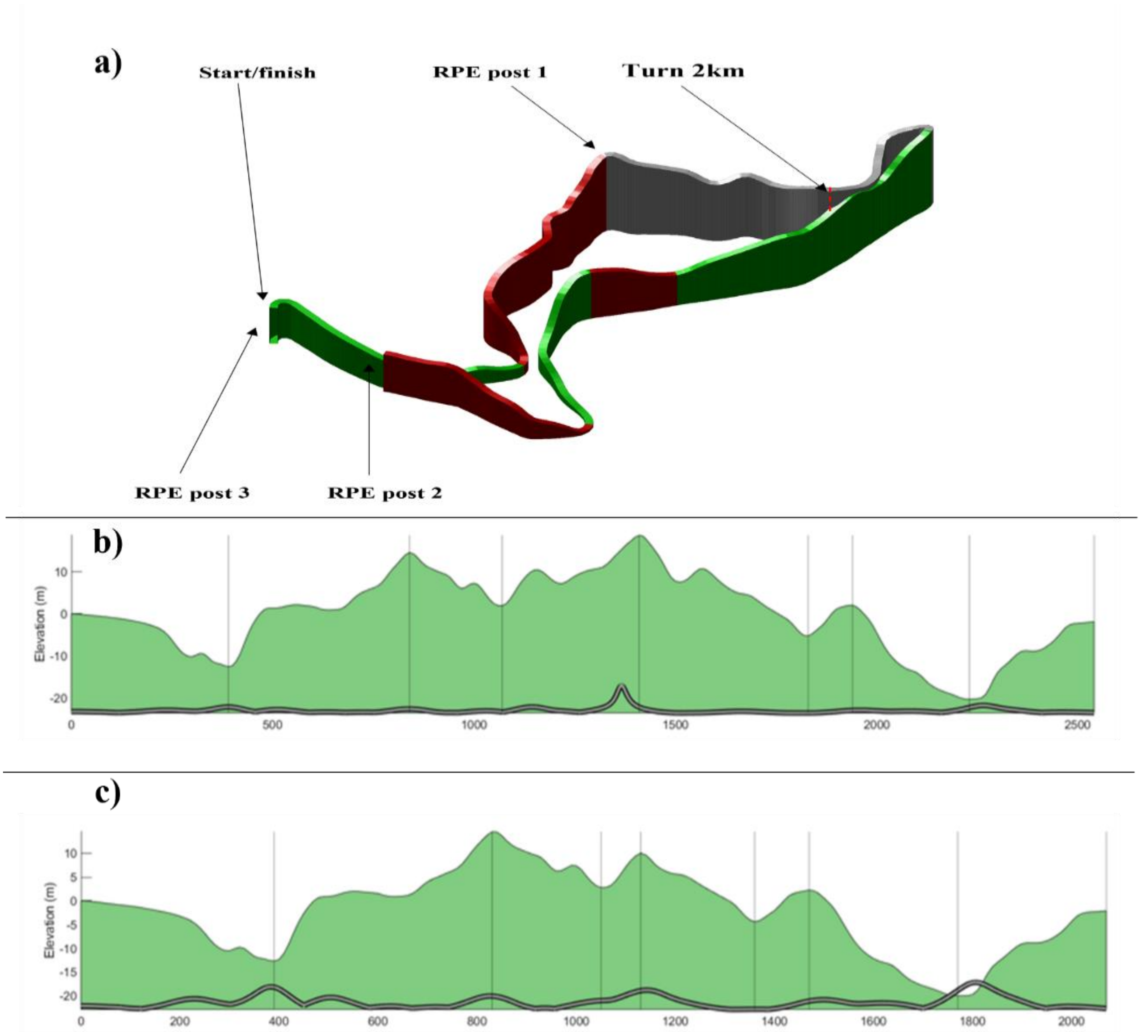

Figure 1: *shows the course and the course profiles of the 2 courses roller skied during the simulated competition. Figure 1a shows the GPS mapping of the course. Females turned at the 2km turn. RPE post 1 was 800m from the start of the lap, RPE post 2 was right before shooting and RPE post 3 was directly after shooting. Figure 1b shows the 2.5km course profile used by men. The course was divided into 8 segments, green with a net downhill gradient, and red with a net uphill gradient. Figure 1c shows the 2.0km course profile used by the women.*

3.3.3 Protocol

Approximately one hour before competition start, zeroing for the biathletes was conducted. At zeroing biathletes shot to adjust the scope for the wind and weather of the day. After zeroing and before warm-up, height and weight were measured for all athletes. The biathletes were weighed with the weapon in addition to their roller skis, helmets, and poles that both biathletes and cross-country skiers was weighed with. Later the weight of the rifles was measured to ~3.7 kg. A 30-minute standardized warm-up was conducted by all the athletes on their own roller skis. The first 15 min was done as a low intensity warm up (~60-70% of HRmax). When the 15 min of low intensity warm-up was completed, athletes moved to a 5 min of mid to high work intensity warm-up (~ 85% of HRmax) (Skarli et al., 2022). The last 10 minutes of the warm-up were done on competition roller skis (Swenor, Sarpsborg, Norway) to ensure familiarity and to ensure that the rolling resistance was stable (Ainegren et al., 2009).

Approximately 5 minutes before the start of the simulated competition monitoring equipment was attached to the athletes. HR monitor (Polar Verity Sense, Polar, Finland) was attached on the opposite arm of the strap that aids biathletes in shooting. A GNSS unit (weight 67g) was attached to the athlete's upper back (between thoracic vertebrae 4 and 5) in the pocket of a small vest that the athletes had to wear during the simulated competition. Neither the HR monitor nor the GNSS receiver was describe by the athletes to be inhibiting to their movement. The athletes were all familiar with the course as it was used in their daily training. During the competition, athletes were not allowed to slip-stream other athletes and were allowed no feedback from coaches. The athletes orally reported RPE when passing 3 different posts during each lap. The posts for each lap were approximately 800m after start of each lap and before and after the shooting range (shown in Figure 1a). Posts on first lap will henceforth be known as L1P1, L1P2 and L1P3 respectively in the order they appear along the course (L = Lap and P = Post). The same pattern is used for lap 2 and lap 3, and thus the remaining RPE posts will be, L2P1, L2P2, L2P3, L3P1, L3P2 and L3P3.

While the first group were competing, the next group of biathletes were able to zero their rifles. New targets were set up before the start of each simulated competition. There was an hour between the start of each competition. Since the groups had to use the same monitoring equipment, used GNSS receivers and HR monitors was collected right after the athletes finished the simulated competition. The GNSS receivers and HR monitors were turned off and put to recharge to ensure enough battery, and to have a clear indication of which athlete used the monitoring equipment at different times. Roller skis were also collected and put back into the pool of roller skis for the next athletes to choose from.

3.3.3.1 Protocol for shooting setup

During the simulated competition, biathletes were given their own lane on the shooting range. Targets were 50m from the shooting range and prone targets are 4.5cm in diameter. For competition, the biathletes shot at cardboard targets with a point-scale from 0-10. For each shooting the biathletes shot one bullet in sequence into each cardboard target mirroring what the athletes usually do during competition. After each simulated competition, pictures were taken of every cardboard target and all targets were collected for further analysis. Every target was marked with the athlete's bib number and shooting number. Example of the shooting setup is showed in Figure 2.

Figure 2: *The setup of the targets during the simulated competition. The row on the top was first shooting, while the bottom row was the last. Athletes placed one shot in each target for each shooting. Athletes used their preferred shooting direction to best mimic what they do during competition. Athletes later reported shooting direction.*

3.3.3.2 Protocol for measuring rolling resistance

To calculate propulsive power, the coefficient of rolling resistance is required. In this thesis 2 methods for measuring rolling resistance were used. Firstly, a towing test on roller ski treadmill was done as in accordance with the descriptions of Hoffman et al. (Hoffman et al., 1990). The second method was a tarmac test done as a rolling test between 2 laser timing apparatus (TCI system, Brower Timing systems, Draper, USA). The tarmac test was done on a flat surface of the course, where entrance speed was measured as an average over the first meter of a 22m track. The athletes then glided over 20m in a tucked position to reduce air resistance. The average exit speed was calculated over the last meter at the end of the 22m glide. Air resistance was not accounted for during the rolling test.

3.3.4 Measuring equipment

3.3.4.1 RPE and Hazard score

The Borg scale (Borg, 1982) was used to report RPE, since athletes were familiar with this method. The Borg scale is a scale from 6-20, where 6 is no work perceived while 20 is the maximum work imaginable (Figure 3). In cases where a RPE value was missing for an athlete that completed the simulated race, the average increase in RPE for the athlete's group was added to the athlete's previous value to estimate the missing value. Males roller skied 500m more between RPE post 1 and RPE post 2 on each lap compared to females. Hazard score was calculated by multiplying the RPE data with the relative distance left of the competition, in accordance with Binkley et al. (2021). Summated Hazard score is the hazard score summated over the course of the simulated competition. Figure 3 shows the Borg scale that was printed out and presented to the athletes during the simulated competition.

6	
7	**Veldig, veldig lett**
8	
9	**Veldig lett**
10	
11	**Nokså lett**
12	
13	**Behagelig anstrengende**
14	
15	**Anstrengende**
16	
17	**Veldig anstrengende**
18	
19	**Veldig, veldig anstrengende**
20	

Figure 3: *The Borg scale from 6-20. Scale was shown to the athletes in Norwegian since the athletes were all Norwegian.*

3.3.4.2 GPS/GNSS and timekeeping

The GNSS receiver consisted of an integrated Inertial Measurement Unit (IMU) and GNSS unit (Optimeye S5, Catapult Innovations, Melbourne, Australia), validated by Gløersen et al, 2018a. The unit consisted of a 10Hz GNSS-receiver, tracking both Global Positioning System (GPS) and Global Navigation Satellite System (GLONASS) data, a 3D accelerometer (100Hz), a 3D magnetometer (100Hz) and a 3D, 2000 deg·sec^{-1} gyroscope (100Hz). The rifle had a contact point in the same area as where the GNSS receiver was attached, but these did not seem to interfere with each other. The GNSS receiver was used to collect positional and time data for all athletes. Each lap was divided into 8 segments (Appendix 1) based on changes in the terrain, shown in Figure 1a. Racesplitter timekeeping system (Makalu Logistics Inc., Fontana, CA, USA) was used to time the entire competition shooting time included for biathletes. A few athletes also had to use their backup GPS from their own training watches, due to missing data from the GNSS receivers. GPS watches usually has a 1 Hz sampling frequency.

3.3.4.3 Propulsive power

Propulsive power of the athletes was calculated for the entirety of the competition. The first uphill segment was then chosen for comparison between the groups. This segment was chosen because it was the longest uphill segments that both females and males roller skied. Equation 1 describes the calculation of propulsive power (P_{prop}).

$$P_{prop} = \frac{m_1 * g * v * \sin(\alpha) + Crr * \cos(\alpha) + \frac{1}{2} * CdA * p * v^2}{m_2} \quad (1)$$

Here m_1 is the athlete's mass with all equipment, g is acceleration due to gravity, v is the velocity of the athlete and α is the angle of the course. Crr is the coefficient of rolling resistance and Cd is the coefficient of drag. A is the frontal area of the athlete, p is the air density and m_2 is the mass of the athlete excluding rifle for biathletes.

The velocity of the athlete and angle of the terrain was derived and calculated from the positional data provided by the GNSS receiver. Rolling resistance measurement showed that the median Crr for the roller skis was 0.021 on a roller ski treadmill, and was found to be approximately 1.4 times greater on the tarmac surface of the competition. For this thesis the rolling resistance found by the treadmill towing test was chosen to use in the calculations. Air density was calculated using equation 2.

$$\rho = \frac{PM_a}{RTZ} \tag{2}$$

ρ is the air density, P is the absolute pressure measured in Pascal, M_a is the molar mass of dry air, R is the gas constant, T is the temperature measured in Kelvin and Z is the compressibility factor. The calculations are based on the article from Jones E. (1978).

Coefficient of drag is a constant that is usually measured in a wind tunnel. For this project, testing biathletes in a wind tunnel was not possible. However, there are a few tests done on cross-country skiers which showed different results. Spring et al. (1988) reported values for Area of Coefficient of drag (C_DA) at around 0.6-0.7m^2 in an upright position and 0.3m^2 for a tucked position. Moxnes et al. (2013) reports a C_DA of 0.45m^2 for a standing position based on the measurements done in a wind tunnel by Leirdal et al. (2006). In this thesis we use the C_DA reported by Moxnes et al. since we are only interested in athletes skiing in the upright position (Moxnes et al., 2013). Furthermore, the principal of scaling skiers with different body masses proposed by Carlsson et al. (2011) was applied to the athletes that participated in this thesis. C_DA was scaled by using equation 3.

$$CdA = \left(\frac{m_1}{m_2}\right) * 0.45 \tag{3}$$

C_DA is the area of Coefficient of drag, *$m1$* is the mass of the chosen athlete and *m_2* is the mass of a template athlete as described in Moxnes et al. (2013) (77,5 kg and 182cm). The weight of the rifle was excluded when scaling the frontal area of the biathletes.

The C_DA of roller skis and poles (0.045 m^2), that Gløersen et al. (2018b) measured was added to the C_DA of each athlete. The C_DA of the part of the rifle that was visible for the wind was calculated using the C_DA of cylinders and rectangles. The C_DA for the rifle parts (~0.002 m^2) was then added to the overall C_DA of biathletes.

3.3.4.4 Cycle length and cycle rate

Cycle length and cycle rate was investigated using the IMU unit that is in the GNSS receiver. Analyzing the data showed mixed results leading to the exclusion of this criteria.

3.3.5 Data analysis

All data are presented as mean ± standard deviation (SD). The calculation of differences between biathletes and cross-country skiers was done using an un-paired T-test, while a paired T-test was chosen when investigating difference in values within one group. A P-value of ≤ 0.05 was considered statistically significant, while a P-value between 0.1 and 0.05 was considered a trend. All GPS data were treated in MatLab (MatLab R2021a; Math-Works, Inc, Natick, MA) or Python (Python Software Foundation, https://www.python.org/). All RPE, timing and shooting data were entered into Excel (Microsoft, Redmond, WA, USA). Statistical analyses like ANOVA and Mann Whitney test were done in SPSS (IBM Corp. Released 2021. IBM SPSS Statistics for Windows, Version 28.0. Armonk, NY: IBM Corp), while T-tests were done in Excel and checked in SPSS. Figures were created in Excel, MatLab and Python. Shooting performance was analysed in 2 ways. First the number of targets hit was counted. A hit for prone shooting was registered if the hit was in the 8-10 points circle. Secondly the points scale on the target was used for a more accurate assessment of the shooting accuracy. The difference in shooting performance was calculated using an un-paired T-test. In total, 39 HR profiles were collected. Most of the HR data had errors. Due to this, only 8 HR profiles (4 biathletes and 4 cross-country skiers) were used in this thesis. No statistical test was done on the HR profiles.

3.4 Results

3.4.1 Timing

The total competition time for biathletes was 22:20±1:20 min (21:34±2:17 for women and 22:59±1:06 min for men) and 20:06±0:57 min for cross-country skiers (20:05±1:14 for women and 20:07±30 min for men). Cross-country skiers used shorter time to complete the competition compared to biathletes (134sec, P<0.001). No significant difference in overall competition time was found between female biathletes and female cross-country skiers (134sec, P=0.07). Male cross-country skiers used shorter time to complete the competition compared to male biathletes (173sec, P<0.001).

Course time for the 4 groups is presented in Figure 4. Biathletes were significantly slower on all 3 laps (P<0.05), leading to an overall difference in course time of 46sec (P<0.01). No difference in course time between female biathletes and female cross-country skiers was found. Male biathletes were slower in course time compared to male cross-country skiers (42sec, P<0.05). There was a significant difference in course time between male biathletes and male cross-country skiers on the first lap (21sec, P<0.05), while no significance was found for lap 2 or 3.

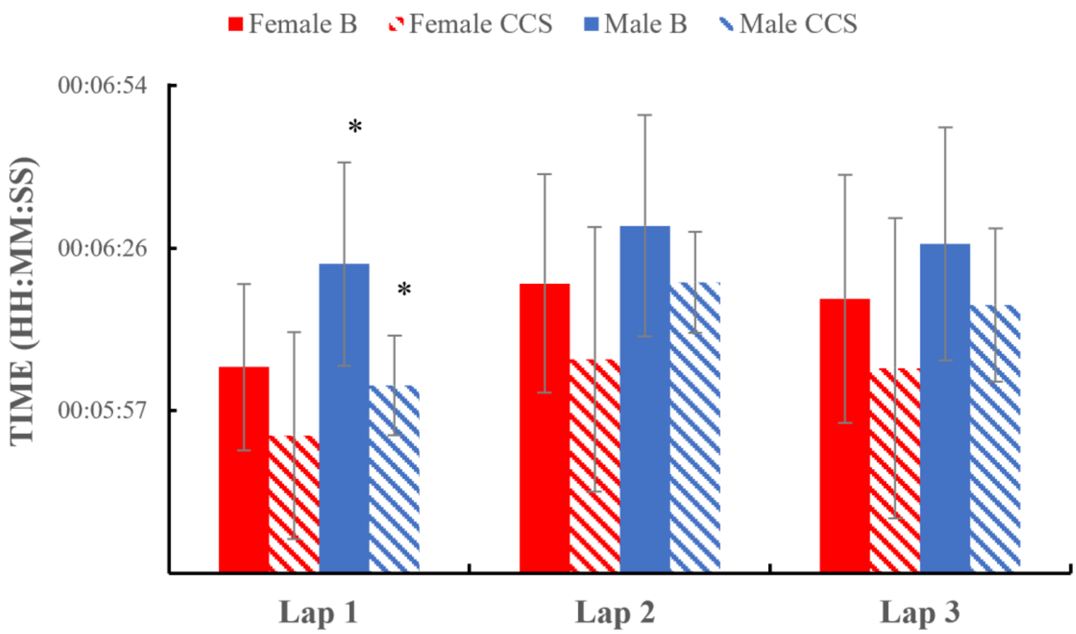

Figure 4: *shows absolute course time for all groups (mean ± SD). Solid red = female biathletes, shaded red = female cross-country skiers, solid blue = male biathletes and shaded blue = male cross-country skiers. * = P<0.05 between disciplines within sex.*

Differences in relative time (calculated as the percentage of the total course time) is presented in Figure 5. Cross-country skiers used relatively less time on the first lap (0.38%, P<0.05). No difference was found for lap 2 and 3. No difference in the relative time was observed between female biathletes and female cross-country skiers. Male cross-country skiers used relatively less time on the first lap compared to male biathletes (0.68%, P<0.001) . Male biathletes used relatively less time than male cross-country skiers on the second lap (0.38%, P<0.01). No difference in relative time was observed for the last lap.

Female biathletes, female cross-country skiers and male biathletes had a significant lower relative time on their first lap compared to lap 2 and 3 (Figure 5, P<0.05). Male biathletes had a significantly lower relative time on the first lap compared to their second lap (P<0.05). No difference in relative time was found between the first and last lap for male biathletes. No difference in relative time was found between the second and last lap for all groups.

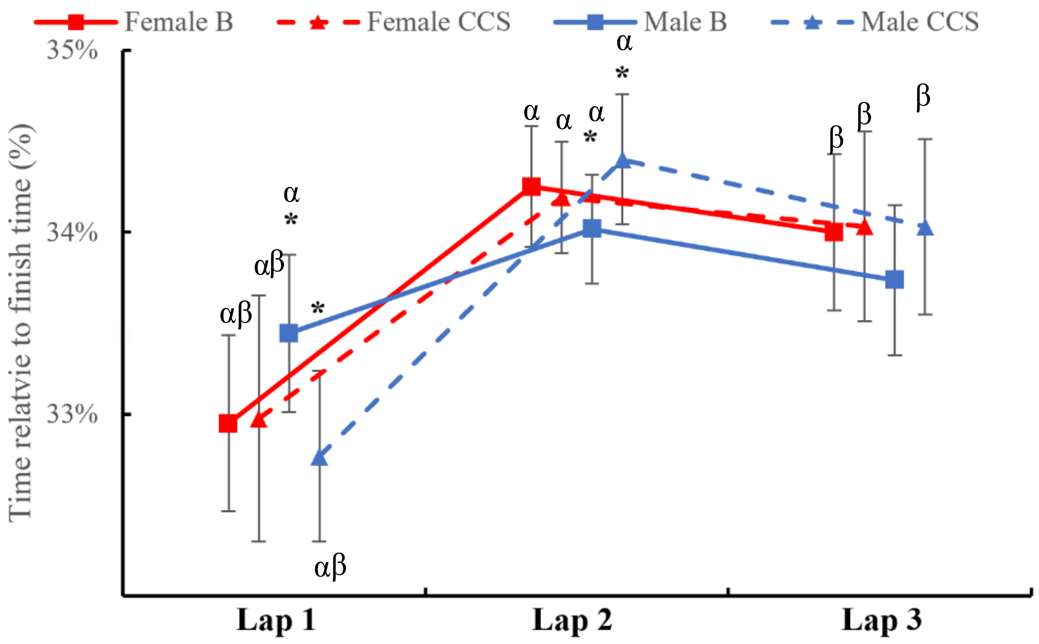

Figure 5: *Shows the difference in relative time between the four groups (mean ± SD). Red solid line = female biathletes, red dotted line = female cross-country skiers, blue solid line = male biathletes and blue dotted line = male cross-country skiers. * = P<0.05 between same sex but different discipline. α = significant differences between first and second lap. β = significant difference between first and last lap.*

3.4.2 RPE

3.4.2.1 Difference in RPE between biathlon and cross-country skiing

RPE over the course of the simulated race is presented in Figure 6. Cross-country skiers reported higher summated RPE compared to biathletes (148±11 versus 138±10, P<0.001). When the posts right after shooting were excluded no difference in summated RPE were observed. Cross-country skiers reported significantly higher RPE at posts L1P1, L1P2, L1P3 and L2P3 compared to biathletes (P<0.05).

3.4.2.2 Difference in RPE between sex within the same discipline

No difference in RPE was observed between male and female biathletes or male and female cross-country skiers for both summated RPE and RPE for each separate post during the entirety of the simulated competition.

3.4.2.3 Difference in RPE between discipline within sex.

Summated RPE for female biathletes were lower compared to cross-country skiers (136.6 vs 149.2, P<0.01). Female biathletes reported lower RPE for L1P3 and L2P3 compared to female cross-country skiers (P<0.001) (Figure 6). Male biathletes reported lower summated RPE compared to cross-country skiers (139.2 vs 147.5, P<0.05). Male biathletes reported lower RPE than male cross-country skiers for L1P3 and L2P3 (P<0.01) (Figure 6). Female biathletes had a greater increase in RPE between L1P3 and L2P1, and L2P3 and L3P1 compared to female cross-country skiers (4.0 vs 1.4 and 4.3 vs 1.1 respectively, P<0.001) (Figure 6). Male biathletes had a greater increase in RPE between L1P3 and L2P1, and L2P3 and L3P1 compared to male cross-country skiers (3.5 vs 1.5 and 4.1 vs 1.2 respectively, P<0.001) (Figure 6).

3.4.2.4 Difference in RPE before and after shooting

Reported RPE was significant lower at L1P3 compared to L2P3 for all biathletes (12.2 vs 13.6, P<0.001), as well as significantly lower at L1P2 compared to L1P3 (12.2 vs 13.8, P<0.001) (Figure 6). Similarly, RPE reported at L2P2 was significantly lower compared L2P3 (16.1 vs 13.6, P<0.001) (Figure 6). Reported RPE at L1P2 was significantly lower compared to L2P2 (13.8 vs 16.1, P<0.001) (Figure6).

Female biathletes reported significantly lower RPE for L1P2 compared to L1P3, L2P2 compared to L2P3, L1P2 compared to L2P2, and L1P3 compared to L2P3 (P<0.05)

(Figure 6). Male biathletes reported significantly lower RPE for L1P2 compared to L1P3, L2P2 compared to L2P3, L1P2 compared to L2P2, and L1P3 compared to L2P3 (P≤0.001) (Figure 6).

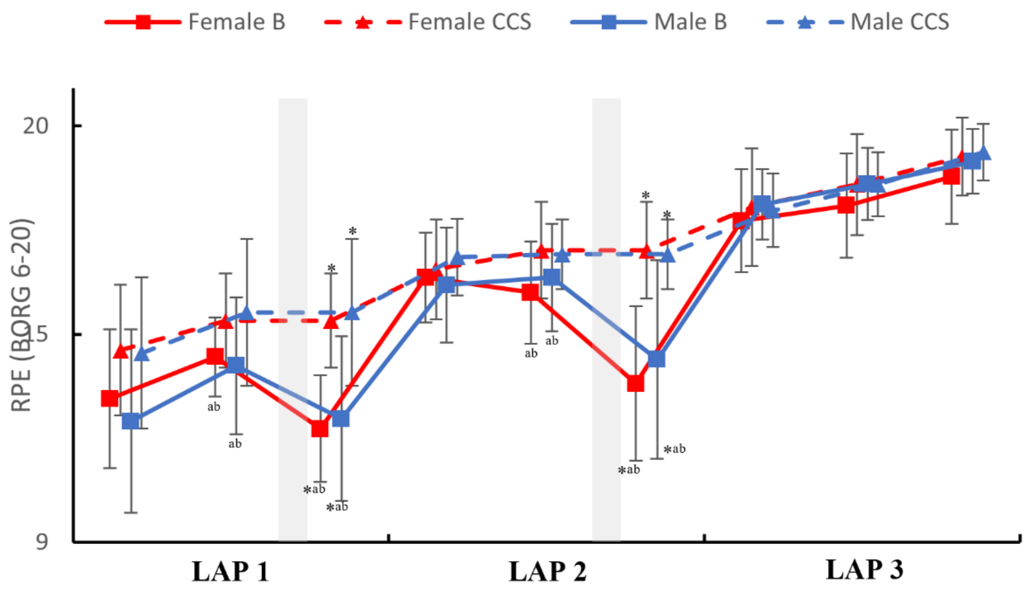

Figure 6: *Shows the development of RPE over the duration of the simulated competition (mean ± SD). Red solid line = female biathletes, red dotted line = female cross-country skiers, blue solid line = male biathletes and blue dotted line = male cross-country skiers. * = P<0.05 between disciplines within sex. a = significant difference between in and out shooting within each lap. b = significant difference between in and out shooting between lap 1 and lap 2.*

3.4.2.5 Hazard score

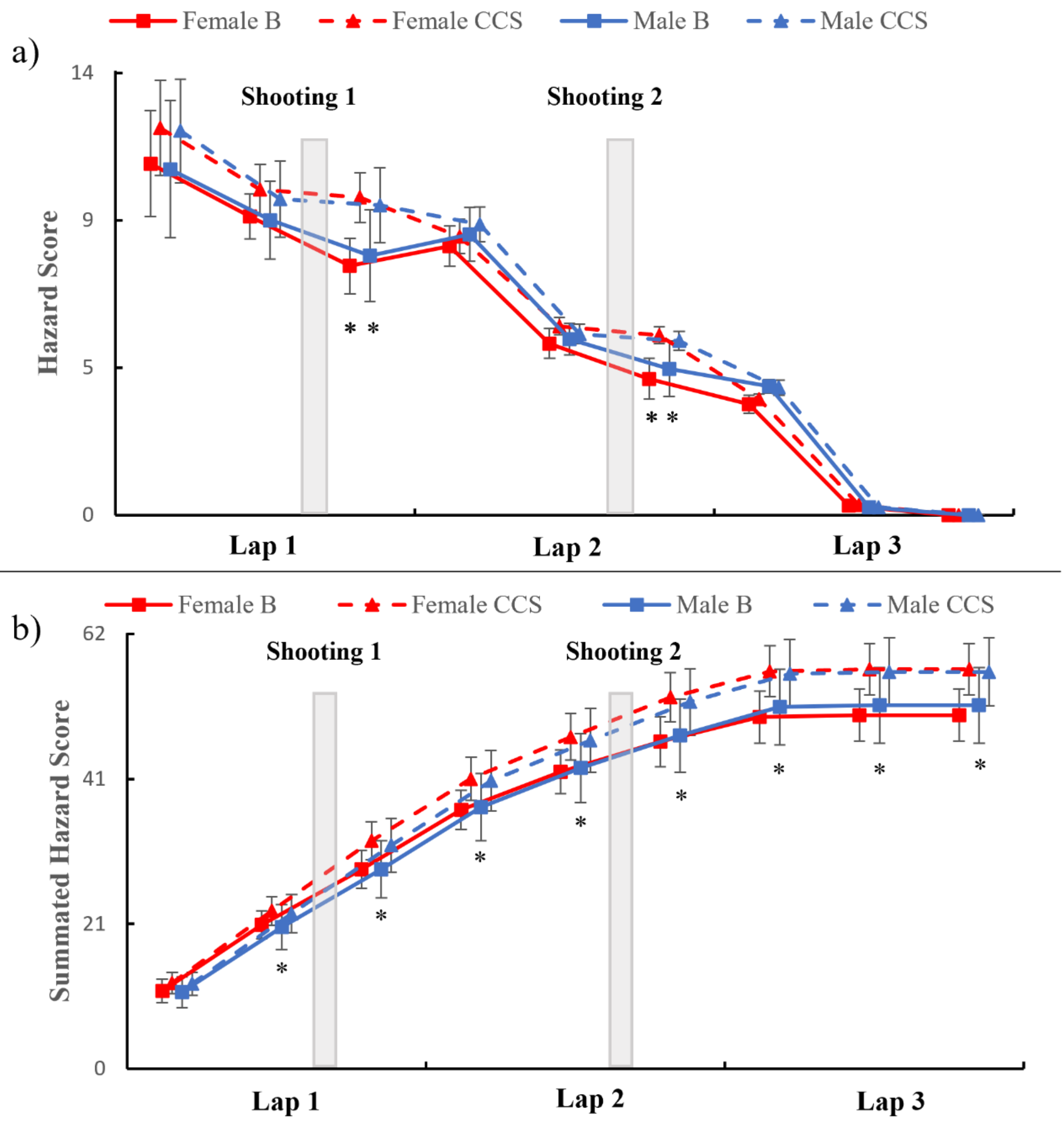

Figure 7: *shows hazard score of the 4 groups during competition (mean ± SD). Figure 7a shows the development of hazard score during competition, while 7b shows the summated hazard score over the duration of the competition. Red solid line = female biathletes, red dotted line = female cross-country skiers, blue solid line = male biathletes and blue dotted line = male cross-country skiers. * = P<0.05 between disciplines within sex.*

Figure 7a shows the Hazard score while Figure 7b shows the summated hazard score. Female biathlete showed a lower hazard score at L1P3 and L2P3 (P <0.001) compared to female cross-country skiers. No significant difference in summated hazard score was found for females.

Male biathletes showed significantly lower hazard score for L1P2 and L2P2 ($P<0.01$) compared to male cross-country skiers. The summated hazard score is significantly lower for male biathletes at all post except L1P1 ($P<0.05$).

3.4.3 Shooting results

Biathletes scored 40 ± 3 points on the first shooting and 40 ± 3 on the second shooting ($P=0.73$). On average, 3.5 ± 1.1 out of 5 shots were hits on the first shooting, while 3.4 ± 1.1 out of 5 shots were hits on the second shooting ($P=0.76$).

Females scored 40 ± 5 points on the first shooting and 41 ± 3 points on the second shooting ($P=0.40$). Female hit on average 3.6 ± 1.1 targets on the first shooting and 3.8 ± 1.0 on the last shooting ($P=0.38$). Males scored 40 ± 3 points on the first shooting and 40 ± 3 on the last shooting ($P=0.68$). Males hit 3.4 ± 1.1 target on the first shooting and 3.1 ± 1.1 on the last shooting ($P=0.47$). Shooting performance between genders showed no difference.

3.4.4 Heart rate

Due to problems collecting HR from many of the athletes, only 8 HR profiles were analysed. Therefore, only examples of HR profiles for biathletes and cross-country skiers are presented in Figure 8 and 9 respectively.

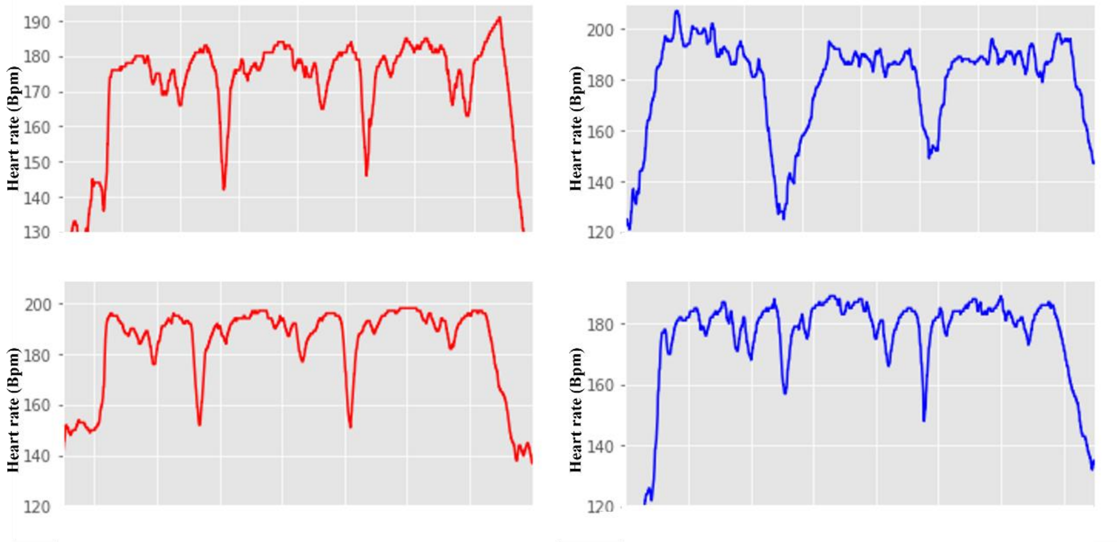

Figure 8: *shows heart rate profiles for 4 biathletes during the competition. One graph is one athlete. Top left and bottom left = females. Top right and bottom right = males.*

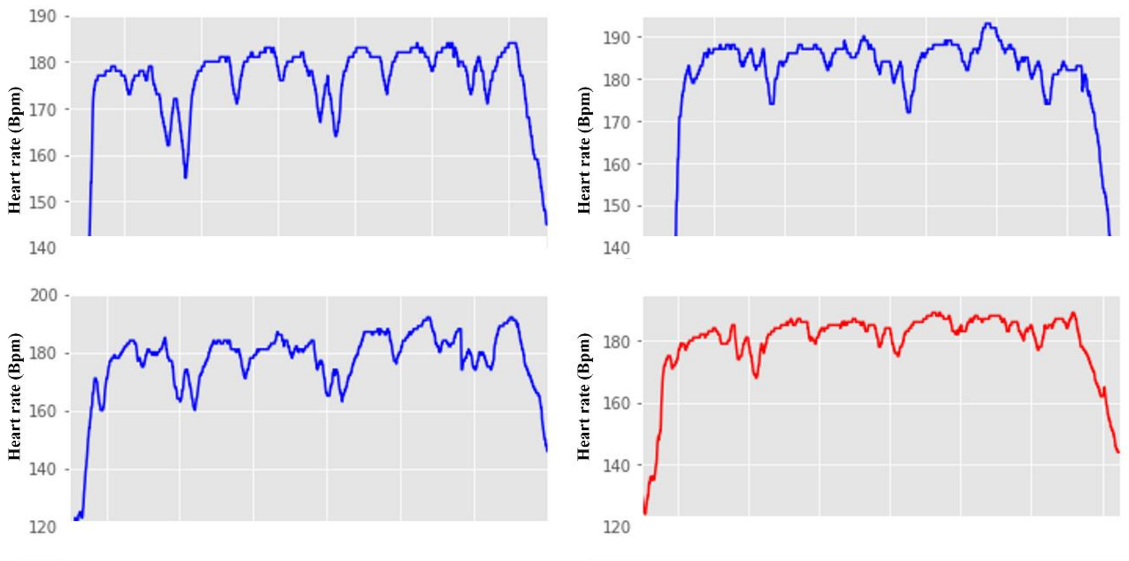

Figure 9: *shows heart rate profiles for 4 cross-country skiers during competition. One graph is one athlete. Top left, top right, and bottom left = males. Bottom right = female.*

3.4.5 Propulsive power

No significant differences in propulsive power were found between biathletes and cross-country skiers. No significant differences were found between female biathletes and female cross-country skiers. There was a significant difference in propulsive power between male biathletes and male cross-country skiers on lap 1 ($P<0.05$) else no difference in propulsive power was found (Table 2).

Table 2: *Shows the work done in the first uphill segment of each lap (length = 440m, elevation = 27.2m). All values are presented as $W*kg^{-1}$. * = $P<0.05$ between disciplines within sex. B = biathletes and CCS = cross-country skiers.*

	CCS	Biathlon	Female CCS	Female B	Male CCS	Male B
Lap 1	3.83±0.54	3.88±0.47	3.39±0.26	3.35±0.21	4.39±0.11*	4.11±0.36*
Lap 2	3.64±0.45	3.76±0.54	3.27±0.24	3.18±0.25	4.10±0.11	4.01±0.43
Lap 3	3.60±0.49	3.74±0.51	3.24±0.33	3.20±0.26	4.07±0.14	3.98±0.41

3.5 Discussion

This thesis investigated if there were differences in pacing strategy between biathletes and cross-country skiers during an identical length simulated competition. The main findings were that male biathletes were the only group that showed a somewhat even pacing over the duration of the competition. This was accompanied by biathletes reporting a lower RPE on the first lap compared to cross-country skiers. Furthermore, shooting inflicts a drop in RPE for biathletes, followed by a rapid increase in RPE for biathletes between L1P3 and L2P1 and between L2P3 and L3P1 compared to cross-country skiers. Higher RPE both before and after last shooting, compared to first shooting did not seem to affect shooting performance for biathletes.

3.5.1 Pacing and race strategy

Male biathletes seemingly use a different pacing strategy compared to the 3 other groups (Figure 5). The J-shaped pacing that male biathletes showed was in accordance with the pacing strategy for elite biathletes (Björklund & Laaksonen, 2022). The other 3 groups showed a more positive pacing (Figure 5), seemingly underestimating the amount of energy required to produce the same propulsive power for 3 laps. Combining relative course time and RPE indicate that the 2 disciplines solve competitions differently (Figure 5 & Figure 6). Biathletes reported a significantly lower RPE on the first lap compared to cross-country skiers which might be due to the prospect of shooting, this might indicate that biathletes chose a more cautious starting strategy when skiing to ensure optimal shooting performance. Uncertainty seemingly affects the pacing strategy of athletes (Tucker, 2009). Although biathletes did not roller ski penalty loops for missed shots in this thesis, which in theory should remove some of the uncertainty, their pacing were likely based on previous experience (Tucker, 2009) and would therefore be hard to alter when not explicitly asked to.

Since range time for biathletes is around 50s (Björklund & Laaksonen, 2022), shooting acts as physical recovery, which seem to coincide with the results of this thesis, where a reduction in HR and RPE for biathletes during shooting was found (Figure 6 & Figure 8). These findings suggests that biathletes could choose a more aggressive pacing strategy. However, stopping to shoot also reduces the HR of the biathletes (Figure 8). Aerobic power is seemingly crucial for skiing performance in both biathlon and cross-country skiing (Tønnessen et al., 2015), and a reduction in HR might lead to a decrease in momentary aerobic energy turnover (Joyner & Casey, 2015). This reduction in aerobic energy turnover could force the biathlete to use their limited anaerobic energy capacity to compensate for the high energy demand they seemingly have after each shooting (Figure 6). Since HR uses some time to acclimatize to work intensity (Fritzsche et al., 1999), anaerobic energy turnover could impact skiing performance in biathlon. This is in accordance with previous research done on cross-country skiing, which states that anaerobic energy turnover plays a more predominant role in cross-country skiing performance compared to other endurance sports (Losnegard, 2019). Moreover, the short period with reduced HR (Figure 8), overlapping with the prolonged period of seemingly elevated work intensity indicates that anaerobic capacity might affect skiing performance in biathlon (Figure 6). This supports Luchsinger et al. (2018) who found no correlation between maximal oxygen consumption and performance in elite biathletes and hypothesised that other factors such as anaerobic capacity might be important for skiing performance in biathlon. One thing to note is that the first RPE post of each lap (LxP1) is on the highest part of the course and the terrain gets easier after the point which could explain the more equal RPE at the next post (LxP2). Pacing strategy should be adjusted to the course profile, and for this course most of the uphill is at the start of the lap. Therefore, a more aggressive use of energy after shooting might be more beneficial due to athletes being more energy efficient in uphills. Courses like these might further favour biathletes with a higher anaerobic capacity. Understanding how much biathletes physically recover while shooting and how to best utilize this recovery needs further investigation.

One could speculate how to best distribute the energy biathletes recover from the shooting. In this thesis, the rapid increase in RPE seen for biathletes between L1P3 and L2P1 and between L2P3 and L3P1 (segments after each shooting) suggests an increased work intensity compared to cross-country skiers (Tucker, 2009). If one count the start of each lap as a somewhat fresh start for the biathlete due to physical recovery the biathletes get from stopping to shoot, a debate should be had whether an even or a positive energy distribution within each lap is the most optimal for skiing performance in biathlon. Due to the short lap nature of biathlon, biathletes have limited time to spend the recovered energy gained from each shooting. Even distribution of the energy over the duration of the lap, could lead to less accumulated propulsive power for that lap, due too passive pacing. Contrary, producing too much propulsive power at the start of the lap, might overfatigue the athlete and thusly impact skiing performance. More detailed research on micro pacing in biathlon is needed to understand how to best solve energy distribution within each lap.

Established research on pacing strategy shows that females often use a more even pacing strategy compared to males (Björklund & Laaksonen, 2022). This is contrary to the findings in this thesis where female biathletes reported the same RPE values as male biathletes, which seemed to facilitate a more even pacing strategy, but instead used a positive pacing strategy (Figure 5 & 6). Some differences between sexes in RPE have been observed in other projects. Losnegard et al. (2021) found that female cross-country skiers reported lower RPE on same relative values for lower work intensity. This might explain why there is a difference in pacing strategy between female and male biathletes despite reporting the same RPE values. However, female biathletes in this thesis tended to report lower RPE values ($P=0.07$) on the first lap compared to female cross-country skiers. RPE is thought to increase linearly with duration of exercise (Noakes, 2004), and since all groups end on the same RPE (Figure 6), one would think that over an identical length competition the athlete with the lower RPE would manage to better maintain their pace towards the end of the competition. This is seemingly not the case for the female athletes in this thesis, and one can only speculate why this phenomenon occurs.

One reason could be that RPE is a subjective measurement of exertion and athletes might report different RPE values on objectively identical work intensities. There seems to be a consensus of what the RPE values should be at different points in the race within each discipline (Figure 6). Most of the coaches in biathlon and cross-country skiers are males, there might therefore be a male precedent in how exerted an athlete should feel at a given point in a competition. Female biathletes might compare themselves to male biathletes, and by using feedback from male coaches, female biathletes might create a RPE template that is not suited to them (Tucker et al., 2009; De Koning et al., 2011), due to female biathletes having a different physiology compared to male biathletes. These differences among others might hinder female biathletes to physically recover as well as males during the physical stop while shooting (Besson et al., 2022). Females' anaerobic capacity is usually lower due to less muscle mass compared to males (Sahlin, 2014). Also, a reduced aerobic energy turnover, might lead to less ability to recover their oxygen dept during shooting (Gløersen et al., 2020). Therefore, their increase in RPE might not coincide with the same increase in speed on laps 2 and 3 as seen among male biathletes (Figure 6). In cross-country skiing however, there are no 50sec stop during the competition, leading to less fluctuations in energy turnover. No prolonged rests make prolonged anaerobic work more punishing, and thus the difference in anaerobic capacity plays less role in pacing in cross-country skiing. This might be a reason for why there were less differences in pacing and RPE for female and male cross-country skiers compared to male and female biathletes. It is difficult to know if this pattern was a onetime occurrence or if it can be repeated in other scenarios. However, more research on sports with small breaks inserted into the competition is needed to understand if sex can differentiate how to obtain optimal pacing strategy.

3.5.2 Difference in training status

The difference in course time found between biathletes and cross-country skiers could be attributed to several factors. One factor could be the training status of the present athletes. Cross-country skiers might be a more homogenous group when it comes to physical training status, due to skiing performance being the only crucial parameter for performance. Thusly, less competitive cross-country skiers see worse result early in their career and this might lead to an early retierment. In biathlon however, shooting performance also affects the overall performance, meaning that slower skiers can compensate with higher performance on the shooting range to be competitive. Therefore, it could be hypothesized that there was greater variation in physical training status for biathletes compared to cross-country skiers in this thesis. One indication of this phenomenon can be gathered from the coefficient of variation (CV) for course time. Male biathletes had almost twice as high CV as male cross-country skiers (0.049 vs 0.025 respectively), while for female athletes the pattern was reversed, with a lower CV for female biathletes compare to female cross-country skiers (0.049 vs 0.061 respectively). However, for female cross-country skiers there was one outlier, who were 2.5 min slower than the next slowest skiers and removing this skier changes the CV for female cross-country skiers to 0.034 (Appendix 5). Due to this, exploring differences between biathlon and cross-country skiers should preferably be done on elite biathletes that are more homogeneous in terms of skiing performance.

3.5.2.1 Pacing differences between the best performing athletes

Due to the assumed difference in physical training status between biathletes and cross-country skiers in this thesis, investigating the 5 best performing athletes regarding skiing performance in each group might give another insight to the differences between the disciplines. The 5 best athletes in each group had a more even pacing strategy compared to the rest of their groups (Appendix 3). This is in accordance with previous research which showed that better athletes have a more even pacing compared to lower performing athletes (Luchsinger et al., 2018). Interestingly, because the skiing distance was divided into 3 short laps, all groups adopted a J-shaped pacing pattern, most likely due to the end-spurt phenomenon (Tucker, 2009). This finding seemingly indicate that the best athletes have an ability to better distribute energy over the entirety of the competition.

Results for propulsive power look slightly different for the top 5 male athletes compared to the whole group (Appendix 4). Looking at all athletes, male cross-country skiers produce a higher propulsive power compared to male biathletes on the first lap with no difference on the 2 last laps (Table 3). For the 5 best male athletes, no difference was found between disciplines on the first and last lap, while there was a trend towards higher propulsive power from biathletes on the second lap ($P=0.07$) (Appendix 4).

Furthermore, the best male biathletes showed no difference in propulsive power between all laps, while the best male cross-country skiers' propulsive power on the first lap is significantly higher compared to the other 2 laps ($P<0.01$) (Appendix 4). This might indicate that the best male biathletes utilize the physical rest of the shooting to increase their propulsive power right after shooting, while the best male cross-country skiers might have chosen a slightly too aggressive pacing strategy. This coincides with the apparent greater jump in RPE for male biathletes compared to male cross-country skiers after both shootings (Figure 6). Previous studies on cross-country skiing found that the work intensity in similar length uphills can vary with previous terrain (Sollie et al, 2021, p. 557). When there is a large downhill with more time to recover, work intensity in the next uphill increases. Stopping to shoot might have the same effect for male biathletes, enabling them to increase the amount of propulsive power for a short period. The impact of anaerobic energy turnover on skiing performance in biathlon needs more investigation.

3.5.3 Effect of differences in RPE in relation to shooting performance

The RPE reported before and after first shooting was lower compared to RPE reported before and after second shooting for both sexes. This follows established literature as the RPE seemingly increase linearly with the duration of the exercise (Figure 6) (Noakes, 2004). Interestingly, the shooting performance does not differ from shooting 1 to shooting 2, indicating that the increase in reported RPE is not directly related to the shooting performance (Figure 6). Controlling other parameters, such as ventilation and HR could be more important than lowering RPE for prone shooting performance. Since RPE has seemingly limited effect on shooting performance, biathletes might use pacing strategy as a tool to better their skiing performance instead of controlling shooting performance. In this thesis, only prone shootings were done, and more investigating is needed to understand if RPE could affect standing shooting performance differently.

3.5.4 Methodical considerations

Comparing biathletes and cross-country skiers is seemingly a good way to investigate the differences between the disciplines. However, understanding if the difference occurs due to parameters set by the disciplines, or if it's a difference in training regime chosen by the athletes in the 2 disciplines could be of interest. Therefore, comparing rifle carrying biathletes to non- rifle carrying biathletes in a competition like setting, could yield interesting results. This was not achievable in this thesis due to limited participants, and due to the fact that if one should compare athletes the simulated competitions should all happen on the same day.

For female cross-country skiers there were one outlier that was approximately 2.5 minutes slower than the next slowest skier in that group. This had an impact on the data presented in this thesis. The skier met no exclusion criteria, other than being slower compared to the rest of the group. However, in appendix 5, data is presented that excluded this skier from timing data. When this skier is excluded, there is a significant difference in absolute time between female cross-country skiers and female biathletes for all laps and in total, showing a bigger difference in skiing performance between females, compared to males. Since the rifle weighs relatively more for females, this might affect skiing performance more for female biathletes compared to male biathletes.

The length of the roller ski course was chosen to equal a sprint competition for biathletes. This means that the length might be more familiar for biathletes than for cross-country skiers, which usually compete over either 5-or 10km, not 6- or 7.5km. This difference in familiarity might lead to a difference in pacing strategy. Another factor to consider is that a sprint competition has only 2 shootings (one prone and one standing), meaning that comparing shooting results would not be valid. To solve this, 2 prone shootings was done during the simulated competition. Further research should focus on longer distance with 4 shootings so that one can compare both prone and standing shooting and understand how longer competition affects both shooting performance and pacing strategy for biathletes compared to cross-country skiers.

3.5.5 Limitations

The HR data that was collected was mostly of poor quality, resulting in only a few useable cases across the 2 disciplines. Presenting the HR data as case by case, can give us some indication of the difference between biathlon and cross-country skiing, but is not enough to perform any statistical analysis. A more detailed HR data for the 2 disciplines could give a better understanding of the choice of pacing and how RPE, HR and shooting performance all correlates. In this thesis a standardized HR monitoring equipment was used, but it seems that these armband sensors were disturbed by clothing or other equipment. Another type of monitor might be better suited, such as a chest strap since it is not as exposed to interference as the armband sensor.

IMU data was also collected but discarded because of the quality of data especially for biathletes. This might be due to the placement of the IMU. It was placed directly below the contact point of the rifle, and the rifle seem to have interfered with the IMU data. Looking at the placement of the GNSS/IMU receiver to optimize collection of data was done. However, the program that recognized IMU data as different techniques for cross-country skiing required the IMU to be placed on the upper back of the athletes. Therefore, placing the IMU differently did not seem like an option in this thesis.

This thesis was done on roller skis which is not the type of ski or surface that these athletes usually compete on. There might be slight differences in what parameters affect skiing performance compared to roller ski performance. However, roller skiing performance seems to correlate with cross-country skiing performance in the winter season (Carlsson et al., 2014).

The female groups are quite uneven, with female biathletes being 9 in total while female cross-country skiers were 14. This led to some uneven comparisons when comparing the 2 disciplines, since females and males skied different distances and produces different propulsive power values. An example of how this affects the results is seen in Table 3, where in total the biathletes produce more propulsive power, but both female and male biathletes produce less propulsive power than their counterparts. Also, since there was a limited pool of athletes in each group, statistical power is quite low for each of the 4 groups, especially for female biathletes.

Another limitation is that athletes at this age often competes in both disciplines making them less specialized than elite biathletes and cross-country skiers. Meaning that if one did a similar study on more elite athletes, there could be greater differences between the 2 disciplines. This thesis gives a slight indication on the differences between biathlon and cross-country skiers, but further research is needed to gain a deeper understanding of what separates the 2 disciplines, and this research should focus on older and more elite athletes.

The measured rolling resistance found during the tarmac rolling test was greater than the rolling resistance measured on a roller ski treadmill. The findings of this thesis are not in accordance with previous papers, where tests on a roller ski treadmill seem to correlate well with measurements on tarmac (Gløersen et al., 2018b). The difference in this thesis is most likely due to the different methods applied between the tarmac test and the treadmill test. In this thesis, rolling resistance measured on the treadmill was chosen, but the difference between the methods is noted. Another limitation is that the rolling resistance was not tested separately for all skis, and that an average of 7 pairs of roller skis was used. This means that there might be differences in rolling resistance for each athlete that is not accounted for.

3.5.6 Practical implications

This thesis found that there were differences in pacing strategy between biathletes and cross-country skiers. The decrease in RPE during shooting and raping increase in RPE immediately after shooting, and the subsequent changes in work intensity could have high impact on energy turnover for the biathletes. These special conditions should be incorporated into the training of biathletes. Furthermore, RPE had seemingly no effect on prone shooting performance, at least up to the values found in this thesis. This indicates that biathletes should use pacing strategy mostly to optimize skiing performance. Biathletes should also be aware that there might be differences in how to obtain optimal pacing strategy between males and females and coaches should instruct the athletes on energy distribution based on if the biathletes are females or males.

3.5.7 Conclusions

In this thesis, male biathletes had a more even pacing compared to the other 3 groups. Biathletes had a reduction in RPE during shooting, followed by rapid increase in RPE after each shooting compared to cross-country skiers. Male biathletes seemingly used this reduction and subsequent increase in RPE to keep the even pacing, while female biathletes seemed unable to do the same. The difference in micro pacing strategy seemingly indicates slight differences in what physical parameters affect skiing performance in biathlon and cross-country skiing, indicating that anaerobic turnover and capacity might play a more prominent role for skiing performance in biathlon. Moreover, an increase in RPE before and after last shooting compared to first shooting did not seem to affect shooting performance.

3.6 References

Abbiss, C. R., & Laursen, P. B. (2008). Describing and understanding pacing strategies during athletic competition. *Sports medicine (Auckland, N.Z.)*, *38*(3), 239–252. https://doi.org/10.2165/00007256-200838030-00004

Ainegren, M., Carlsson, P. & Tinnsten, M. Roller ski rolling resistance and its effects on elite athletes' performance. *Sports Eng* **11**, 143–157 (2009). https://doi.org/10.1007/s12283-009-0016-5

Binkley, S., Foster, C., Cortis, C., de Koning, J. J., Dodge, C., Doberstein, S. T., Fusco, A., Jaime, S. J., & Porcari, J. P. (2021). Summated Hazard Score as a Powerful Predictor of Fatigue in Relation to Pacing Strategy. *International journal of environmental research and public health*, *18*(4), 1984. https://doi.org/10.3390/ijerph18041984

Björklund, G., & Laaksonen, M. S. (2022). The Determinants of Performance in Biathlon World Cup Sprint and Individual Competitions. *Frontiers in sports and active living*, *4*, 841619. https://doi.org/10.3389/fspor.2022.841619

Borg G. A. (1982). Psychophysical bases of perceived exertion. *Medicine and science in sports and exercise*, *14*(5), 377–381.

Carlsson, M., Carlsson, T., Hammarström, D., Malm, C., & Tonkonogi, M. (2014). Time trials predict the competitive performance capacity of junior cross-country skiers. *International journal of sports physiology and performance*, *9*(1), 12–18. https://doi.org/10.1123/ijspp.2012-0172

Carlsson, P., Tinnsten, M., & Ainegren, M. (2011). Numerical simulation of cross-country skiing. *Computer methods in biomechanics and biomedical engineering*, *14*(8), 741–746. https://doi.org/10.1080/10255842.2010.493885

de Koning, J. J., Foster, C., Bakkum, A., Kloppenburg, S., Thiel, C., Joseph, T., Cohen, J., & Porcari, J. P. (2011). Regulation of pacing strategy during athletic competition. *PloS one*, *6*(1), e15863. https://doi.org/10.1371/journal.pone.0015863

Foster, C., de Koning, J. J., Hettinga, F. J., Barroso, R., Boullosa, D., Casado, A., Cortis, C., Fusco, A., Gregorich, H., Jaime, S., Jones, A. M., Malterer, K. R., Pettitt, R., Porcari, J. P., Pratt, C., Reinschmidt, P., Skiba, P., Splinter, A., St Clair Gibson, A., St Mary, J., … van Tunen, J. (2023). Competition Between Desired Competitive Result, Tolerable Homeostatic Disturbance, and Psychophysiological Interpretation Determines Pacing Strategy. *International* *journal of sports physiology and performance*, *18*(4), 335–346. https://doi.org/10.1123/ijspp.2022-0171

Fritzsche, R. G., Switzer, T. W., Hodgkinson, B. J., & Coyle, E. F. (1999). Stroke volume decline during prolonged exercise is influenced by the increase in heart rate. *Journal of applied physiology (Bethesda, Md. : 1985)*, *86*(3), 799–805. https://doi.org/10.1152/jappl.1999.86.3.799

Froyd, C., Millet, G. Y., & Noakes, T. D. (2013). The development of peripheral fatigue and short-term recovery during self-paced high-intensity exercise. *The Journal of physiology*, *591*(5), 1339–1346. https://doi.org/10.1113/jphysiol.2012.245316

Gløersen, Ø., Gilgien, M., Dysthe, D. K., Malthe-Sørenssen, A., & Losnegard, T. (2020). Oxygen Demand, Uptake, and Deficits in Elite Cross-Country Skiers during a 15-km Race. *Medicine and science in sports and exercise*, *52*(4), 983–992. https://doi.org/10.1249/MSS.0000000000002209

Gløersen, Ø., Kocbach, J., & Gilgien, M. (2018). Tracking Performance in Endurance Racing Sports: Evaluation of the Accuracy Offered by 3 Commercial GNSS Receivers Aimed at the Sports Market. *Frontiers in physiology*, *9*, 1425. https://doi.org/10.3389/fphys.2018.01425

Gløersen, Ø., Losnegard, T., Malthe-Sørenssen, A., Dysthe, D. K., & Gilgien, M. (2018). Propulsive Power in Cross-Country Skiing: Application and Limitations of a Novel Wearable Sensor-Based Method During Roller Skiing. *Frontiers in physiology*, *9*, 1631. https://doi.org/10.3389/fphys.2018.01631

Hoffman, M. D., & Street, G. M. (1992). Characterization of the heart rate response during biathlon. *International journal of sports medicine*, *13*(5), 390–394. https://doi.org/10.1055/s-2007-1021286

Hoffman, M. D., Clifford, P. S., Bota, B., Mandli, M & Jones, G. M. (1990). Influence of Body Mass on Energy Cost of Roller Skiing. *Journal of Applied Biomechanics*, *6(4), 374-385.* https://doi.org/10.1123/ijsb.6.4.374

Jones F. E. (1978). The Air Density Equation and the Transfer of the Mass Unit. *Journal of research of the National Bureau of Standards (1977)*, *83*(5), 419–428. https://doi.org/10.6028/jres.083.028

Joyner, M. J., & Casey, D. P. (2015). Regulation of increased blood flow (hyperemia) to muscles during exercise: a hierarchy of competing physiological needs. *Physiological reviews*, *95*(2), 549–601. https://doi.org/10.1152/physrev.00035.2013

Joyner, M. J., & Coyle, E. F. (2008). Endurance exercise performance: the physiology of champions. *The Journal of physiology*, *586*(1), 35–44. https://doi.org/10.1113/jphysiol.2007.143834

Leirdal, S., Saetran, L., Roeleveld, K., Vereijken, B., Bråten, S., Løset, S., Holtermann, A., & Ettema, G. (2006). Effects of body position on slide boarding performance by cross-country skiers. *Medicine and science in sports and exercise*, *38*(8), 1462–1469. https://doi.org/10.1249/01.mss.0000227536.13175.52

Losnegard T. (2019). Energy system contribution during competitive cross-country skiing. *European journal of applied physiology*, *119*(8), 1675–1690. https://doi.org/10.1007/s00421-019-04158-x

Losnegard, T., Tosterud, O. K., Kjeldsen, K., Olstad, Ø., & Kocbach, J. (2022). Cross-Country Skiers With a Fast-Start Pacing Pattern Increase Time-Trial Performance by Use of a More Even Pacing Strategy. *International journal of sports physiology and performance*, *17*(5), 739–747. https://doi.org/10.1123/ijspp.2021-0394

Losnegard, T., Skarli, S., Hansen, J., Roterud, S., Svendsen, I. S., R Rønnestad, B., & Paulsen, G. (2021). Is Rating of Perceived Exertion a Valuable Tool for Monitoring Exercise Intensity During Steady-State Conditions in Elite Endurance Athletes?. *International journal of sports physiology and performance*, *16*(11), 1589–1595. https://doi.org/10.1123/ijspp.2020-0866

Luchsinger, H., Kocbach, J., Ettema, G., & Sandbakk, Ø. (2018). Comparison of the Effects of Performance Level and Sex on Sprint Performance in the Biathlon World Cup. *International journal of sports physiology and performance*, *13*(3), 360–366. https://doi.org/10.1123/ijspp.2017-0112

Luchsinger, H., Talsnes, R. K., Kocbach, J., & Sandbakk, Ø. (2019). Analysis of a Biathlon Sprint Competition and Associated Laboratory Determinants of Performance. *Frontiers in sports and active living*, *1*, 60. https://doi.org/10.3389/fspor.2019.00060

Micklewright, D., Parry, D., Robinson, T., Deacon, G., Renfree, A., St Clair Gibson, A., & Matthews, W. J. (2015). Risk perception influences athletic pacing strategy. *Medicine and science in sports and exercise*, *47*(5), 1026–1037. https://doi.org/10.1249/MSS.0000000000000500

Moxnes, J. F., Sandbakk, O., & Hausken, K. (2013). A simulation of cross-country skiing on varying terrain by using a mathematical power balance model. *Open* *access journal of sports medicine*, *4*, 127–139. https://doi.org/10.2147/OAJSM.S39843

Noakes T. D. (2004). Linear relationship between the perception of effort and the duration of constant load exercise that remains. *Journal of applied physiology (Bethesda, Md. : 1985), 96*(4), 1571–1573. https://doi.org/10.1152/japplphysiol.01124.2003

Norman, R.W., Õunpuu, S., Fraser, M., & Mitchell, R.B. (1989). Mechanical Power Output and Estimated Metabolic Rates of Nordic Skiers During Olympic Competition. *International journal of sport biomechanics,* 5, 169-184. https://doi.org/10.1123/ijsb.5.2.169

Sahlin K. (2014). Muscle energetics during explosive activities and potential effects of nutrition and training. *Sports medicine (Auckland, N.Z.), 44 Suppl 2*(Suppl 2), S167–S173. https://doi.org/10.1007/s40279-014-0256-9

Skarli S., Svendsen I., Paulsen G., Mentzoni, F. & Losnegard T. (2022, 11 August). OLT I-Skala. Olympiatoppen. https://olt-skala.nif.no/

Sollie, O., Gløersen, Ø., Gilgien, M., & Losnegard, T. (2021). Differences in pacing pattern and sub-technique selection between young and adult competitive cross-country skiers. *Scandinavian journal of medicine & science in sports, 31*(3), 553–563. https://doi.org/10.1111/sms.13887

Spring, E., Savolainen, S., Erkkilä, J., Hämäläinen, T., & Pihkala, P. (1988). Drag Area of a Cross-Country Skier, *International Journal of Sport Biomechanics*, *4*(2), 103-113. Retrieved Mar 20, 2023, from https://doi.org/10.1123/ijsb.4.2.103

Tucker R. (2009). The anticipatory regulation of performance: the physiological basis for pacing strategies and the development of a perception-based model for exercise performance. *British journal of sports medicine*, *43*(6), 392–400. https://doi.org/10.1136/bjsm.2008.050799

Tønnessen, E., Haugen, T. A., Hem, E., Leirstein, S., & Seiler, S. (2015). Maximal aerobic capacity in the winter-Olympics endurance disciplines: Olympic-medal benchmarks for the time period 1990-2013. *International journal of sports physiology and performance, 10*(7), 835–839. https://doi.org/10.1123/ijspp.2014-0431

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Appendix 1

Table 1: *Shows the different segment times for each of the group, Up = an increase in elevation throughout the segment, down = a decrease in elevation throughout the segment. * = P<0.05 between disciplines within sex. T = 0.1>P>0.05 between disciplines within sex*

	Female B	**Female CCS**	**Male B**	**Male CCS**
1 Down	52.8	51.4	47.3	45.7*
2 Up	111.2	106.2	88.0	81.2*
3 Down	35.5	34.0	30.5	30.0
4 Up	14.9	13.9*	12.7	11.7*
5 Down	30.8	29.2*	99.1	94.5*
6 Up	20.2	19.2*	16.5	15.5*
7 Down	30.3	29.6	27.6	27.2
8 Up	72.6	69.3*	58.8	54.0*
Lap 2				
1 Down	56.6	56.4	49.8	50.5
2 Up	116.6	110.0T	90.5	87.2
3 Down	36.6	34.8*	30.8	31.6
4 Up	15.4	14.2T	12.5	11.9T
5 Down	30.6	30.0	100.3	98.1
6 Up	20.7	19.6	16.6	16.1
7 Down	30.6	29.8T	27.5	27.4
8 Up	75.7	71.2	58.4	55.3*
Lap 3				
1 Down	56.1	56.6	49.9	50.9
2 Up	117.7	111.3	91.2	88.1
3 Down	36.8	35.5T	31.7	31.8
4 Up	15.0	13.9T	12.3	11.6*
5 Down	30.3	29.9	100.2	96.6*
6 Up	20.9	19.3*	16.3	15.8
7 Down	30.5	29.4*	27.2	26.9
8 Up	72.8	68.6	55.4	52.4*

Appendix 2

Table 2: *Shows the development of RPE for the top 5 athletes in each group (mean±SD). * = P<0.05 between disciplines within sex.*

Lap	Position	Female B	Female CCS	Male B	Male CCS
1	L1P1	12.6±2.3	13.2±1.9	12.4±2.8	14.6±2.1
	L1P2	14.2±0.8	14.2±0.8	13.4±2.1*	16.2±1.5*
	L1P3	12±1.1*	14.2±0.8*	11.8±1.3*	16.2±1.5*
2	L2P1	15.6±0.8	16.0±0.6	15.8±1.2*	17.2±0.8*
	L2P2	15.6±0.8	16.4±0.5	16.0±0.9*	17.2±0.8*
	L2P3	13.2±2.0*	16.4±0.5*	14.0±1.7*	17.2±0.8*
3	L3P1	17.8±0.8	17.8±0.4	18.0±0	18.2±0.4
	L3P2	17.8±1.2	18.8±0.4	18.8±0.4	18.6±0.5
	L3P3	18.8±1.0	19.7±0.4	19.6±0.8*	20.0±0*
Total1		137.6±7.8	146.7±2.5	139.8±6.4*	155.4±7.3*
Total2		112.4±5.1	116.1±2.1	114±5.4*	122.0±5.2*

Appendix 3

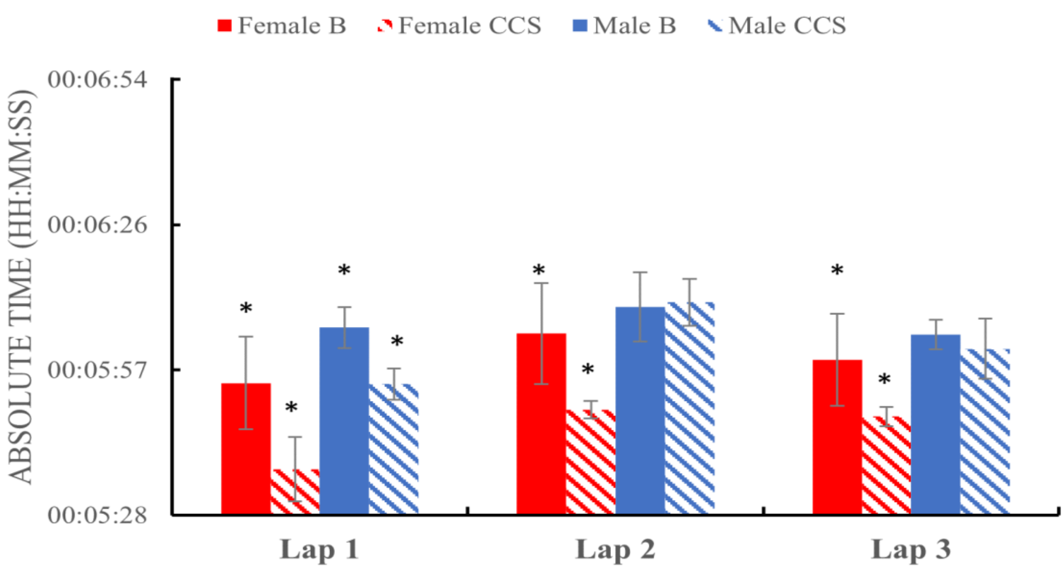

Figure 1: *Shows absolute course time for the top 5 athletes of all groups. Solid red = female biathletes, shaded red = female cross-country skiers, solid blue = male biathletes and shaded blue = male cross-country skiers. * = P<0.05 between disciplines within sex. Times are presented as means, while error bars are standard deviation.*

Appendix 4

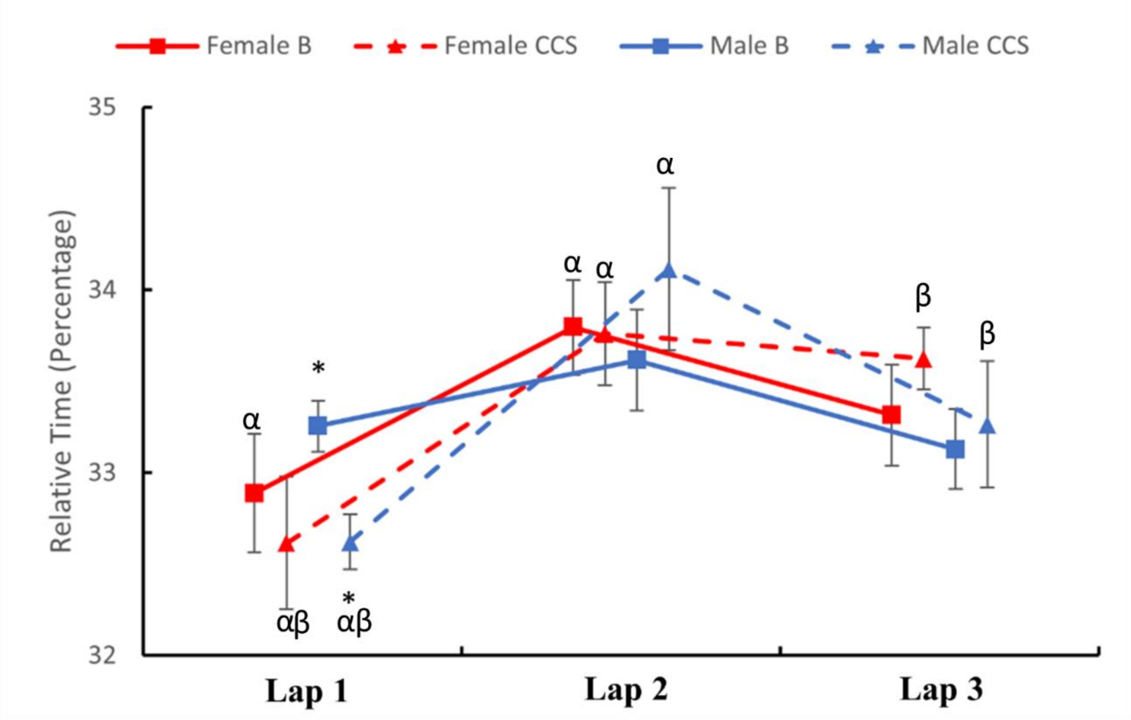

*__Figure 2:__ Shows the difference in relative time between the top 5 athletes for the four groups. Red solid line = female biathletes, red dotted line = female cross-country skiers, blue solid line = male biathletes and blue dotted line = male cross-country skiers. * = P<0.05 between same sex but different discipline. α = significant differences (P<0.05) between first and second lap. β = significant difference P<0.05) between first and last lap. Times are presented as means, while error bars are standard deviation.*

Appendix 5

__Table 3:__ Shows the difference in propulsive power for the top 5 athletes in first uphill segment of each lap (length = 440m, elevation = 27.2m). All values are presented as $W*kg^{-1}$. T = 0.1>P>0.05 between disciplines within sex

	Female B	**Female CCS**	**Male B**	**Male CCS**
Lap 1	3.47±0.10	3.58±0.14	4.45±0.17	4.43±0.07
Lap 2	3.29±0.15	3.44±0.14	4.41±0.24T	4.13±0.11T
Lap 3	3.34±0.15	3.46±0.15	4.39±0.25	4.20±0.06

Appendix 6

Table 4: *Shows course time for female biathletes (Female B), female cross-country skiers (Female CCS) and female cross-country skiers without excluded female skier (Female CCS/wo last place). * = significant difference between biathletes and cross-country skiers (P<0.05).*

	Female B (min:sec)	**Female CCS (min:sec)**	**Female CCS/wo last place (min:sec)**
Lap 1	06:05 ± 00:15	05:53 ± 00:18	05:49 ± 00:14*
Lap 2	06:19 ± 00:19	06:06 ± 00:23	06:01 ± 00:13*
Lap 3	06:17 ± 00:22	06:04 ± 00:26	05:58 ± 00:12*
Total	18:41 ± 00:55	18:03 ± 01:06	17:48 ± 00:36*

Abbreviations

C_DA	Area of coefficient of drag.
Crr	Coefficient of rolling resistance.
CV	Coefficient of variation.
GLONASS	Russian Global Navigation Satellite System
GNSS	Global navigation satellite system.
GPS	Global Positioning System
HR	Heart rate.
IBU	Internationl biathlon union.
IMU	Inertial measurement unit.
P_{prop}	Propulsive power.
RPE	rate of perceived exertion.
VO_2 peak	Peak/maximal oxygen consumption.
VO_2	Oxygen consumption.

Attachments

I. Godkjenning fra Etisk komité ved Norges Idrettshøgskole

II. NSDs godkjennelsesbrev

III. Samtykkeskriv til deltakere

Thomas Losnegard
Institutt for fysisk prestasjonsevne

OSLO 13. juni 2022

Søknad 231 – 160622 – Differences in exercise intensity when comparing a roller ski competition for biathlon and cross-country skiing.

Vi viser til søknad, prosjektbeskrivelse, informasjonsskriv og innsendt melding til NSD.

I henhold til retningslinjer for behandling av søknad til etisk komite for idrettsvitenskapelig forskning på mennesker, har leder av komiteen på fullmakt fra komiteen konkludert med følgende:

Vurdering

Deltakerne i prosjektet er aktive skiskyttere og langrennsløpere som er 17 år og eldre. Begge kjønn inngår i utvalget. For å redusere et mulig opplevd press til deltakelse, presiseres det i informasjonsskrivet at dersom et «team» velger å delta skal det ikke påvirke forholdet til trener eller medutøvere hvis man ikke ønsker å delta. Leder av komiteen forutsetter at det gjennomføres en screening som sikrer at deltakere som pga sykdom, skader eller lignende ikke bør inkluderes. I tillegg bør det etableres en form for beredskap dersom det oppstår skader under gjennomføringen av testene. Det anbefales at det i informasjonsskrivet opplyses om at utøverne vil bli veid med utstyr før start.

Vedtak

På bakgrunn av forelagte dokumentasjon finner leder av komiteen at prosjektet er forsvarlig og at det kan gjennomføres innenfor rammene av anerkjente etiske forskningsetiske normer nedfelt i NIHs retningslinjer. Til vedtaket har leder av komiteen lagt følgende forutsetning til grunn:

- *Vilkår fra NSD følges*
- *Det gjennomføres en screening av deltakerne*
- *Det etableres en form for beredskap for eventuelle skader under gjennomføring av testene*
- *Det opplyses om veiing før start i informasjonsskrivet*

Leder av komiteen gjør oppmerksom på at vedtaket er avgrenset i tråd med fremlagte dokumentasjon. Dersom det gjøres vesentlige endringer i prosjektet som kan ha betydning for deltakernes helse og sikkerhet, skal dette legges fram for komiteen før eventuelle endringer kan iverksettes.

Med vennlig hilsen

Anne Marte Pensgaard

Professor Anne Marte Pensgaard
Leder, Etisk komite, Norges idrettshøgskole

Besøksadresse: Sognsveien 220, Oslo
Postadresse: Pb 4014 Ullevål Stadion, 0806 Oslo
Telefon: +47 23 26 20 00, postmottak@nih.no
www.nih.no

Sikt

Meldeskjema / Investigating the differences in work intensity between biathlets and cr... / Vurdering

Vurdering av behandling av personopplysninger

Referansenummer	Vurderingstype	Dato
133231	Standard	23.06.2022

Prosjekttittel
Investigating the differences in work intensity between biathlets and cross-country skiers during i rollerski competition.

Behandlingsansvarlig institusjon
Norges idrettshøgskole / Institutt for fysisk prestasjonsevne

Prosjektansvarlig
Thomas Losnegard

Student
Erland Vedeler Stubbe

Prosjektperiode
01.08.2022 - 01.08.2023

Kategorier personopplysninger
Alminnelige

Lovlig grunnlag
Samtykke (Personvernforordningen art. 6 nr. 1 bokstav a)

Behandlingen av personopplysningene er lovlig så fremt den gjennomføres som oppgitt i meldeskjemaet. Det lovlige grunnlaget gjeldertil 01.08.2023.

Meldeskjema

Kommentar
OM VURDERINGEN
Personverntjenester har en avtale med institusjonen du forsker eller studerer ved. Denne avtalen innebærer at vi skal gi deg råd slik atbehandlingen av personopplysninger i prosjektet ditt er lovlig etter personvernregelverket.

Personverntjenester har nå vurdert den planlagte behandlingen av personopplysninger. Vår vurdering er at behandlingen er lovlig, hvisden gjennomføres slik den er beskrevet i meldeskjemaet med dialog og vedlegg.

VIKTIG INFORMASJON TIL DEG
Du må lagre, sende og sikre dataene i tråd med retningslinjene til din institusjon. Dette betyr at du må bruke leverandører forspørreskjema, skylagring, videosamtale o.l. som institusjonen din har avtale med. Vi gir generelle råd rundt dette, men det er institusjonens egne retningslinjer for informasjonssikkerhet som gjelder.

DEL PROSJEKTET MED PROSJEKTANSVARLIG
For studenter er det obligatorisk å dele prosjektet med prosjektansvarlig (veileder). Del ved å trykke på knappen «Del prosjekt» i menylinjen øverst i meldeskjemaet. Prosjektansvarlig bes akseptere invitasjonen innen en uke. Om invitasjonen utløper, må han/huninviteres på nytt.

TYPE OPPLYSNINGER OG VARIGHET
Prosjektet vil behandle alminnelige kategorier av personopplysninger frem til den datoen som er oppgitt i meldeskjemaet.

LOVLIG GRUNNLAG
Prosjektet vil innhente samtykke fra de registrerte til behandlingen av personopplysninger. Vår vurdering er at prosjektet

legger opp tilet samtykke i samsvar med kravene i art. 4 og 7, ved at det er en frivillig, spesifikk, informert og utvetydig bekreftelse som kan dokumenteres, og som den registrerte kan trekke tilbake.

Lovlig grunnlag for behandlingen vil dermed være den registrertes samtykke, jf. personvernforordningen art. 6 nr. 1

bokstav a.PERSONVERNPRINSIPPER
Personverntjenester vurderer at den planlagte behandlingen av personopplysninger vil følge prinsippene i personvernforordningen om:

lovlighet, rettferdighet og åpenhet (art. 5.1 a), ved at de registrerte får tilfredsstillende informasjon om og samtykker til behandlingen

formålsbegrensning (art. 5.1 b), ved at personopplysninger samles inn for spesifikke, uttrykkelig angitte og berettigede formål, og ikkebehandles til nye, uforenlige formål

dataminimering (art. 5.1 c), ved at det kun behandles opplysninger som er adekvate, relevante og nødvendige for formålet medprosjektet

lagringsbegrensning (art. 5.1 e), ved at personopplysningene ikke lagres lengre enn nødvendig for å oppfylle formåletDE

REGISTRERTES RETTIGHETER
Så lenge de registrerte kan identifiseres i datamaterialet vil de ha følgende rettigheter: innsyn (art. 15), retting (art. 16), sletting (art. 17),
begrensning (art. 18), og dataportabilitet (art. 20).

Personverntjenester vurderer at informasjonen om behandlingen som de registrerte vil motta oppfyller lovens krav til form og innhold,jf. art. 12.1 og art. 13.

Vi minner om at hvis en registrert tar kontakt om sine rettigheter, har behandlingsansvarlig institusjon plikt til å svare

innen en måned.FØLG DIN INSTITUSJONS RETNINGSLINJER
Personverntjenester legger til grunn at behandlingen oppfyller kravene i personvernforordningen om riktighet (art. 5.1 d), integritet og
konfidensialitet (art. 5.1. f) og sikkerhet (art. 32).

Ved bruk av databehandler (spørreskjemaleverandør, skylagring eller videosamtale) må behandlingen oppfylle kravene til bruk avdatabehandler, jf. art 28 og 29. Bruk leverandører som din institusjon har avtale med.

For å forsikre dere om at kravene oppfylles, må dere følge interne retningslinjer og/eller rådføre dere med behandlingsansvarlig institusjon.

MELD VESENTLIGE ENDRINGER
Dersom det skjer vesentlige endringer i behandlingen av personopplysninger, kan det være nødvendig å melde dette til oss ved å oppdatere meldeskjemaet. Før du melder inn en endring, oppfordrer vi deg til å lese om hvilke type endringer det er nødvendig å melde: https://www.nsd.no/personverntjenester/fylle-ut-meldeskjema-for-personopplysninger/melde-endringer-i-meldeskjema

Du må vente på svar fra oss før endringen gjennomføres.OPPFØLGING AV PROSJEKTET
Personverntjenester vil følge opp ved planlagt avslutning for å avklare om behandlingen av personopplysningene er avsluttet.

Lykke til med prosjektet!

NORGES IDRETTSHØGSKOLE

Vil du delta i forskningsprosjekt om løpsstrategi i skiskyting?

Dette er en forespørsel om å delta i et forskningsprosjekt der formålet er å se på betydningen av ulike åpningsstrategier i skiskyting, og dets effekt på prestasjonen i skyting og på ski. I dette informasjonsskrivet vil jeg beskrive prosjektet og hva en deltakelse vil innebære for deg som forsøksperson.

Formål

Skiskyting er en kompleks idrett som krever en kombinasjon av langrenns- og skyteferdigheter på et høyt nivå. Innfor litteraturen er det gjort flere studier som ser på løpsstrategi i langrenn, men innenfor skiskyting er litteraturen mangelfull. Det er ved flere anledninger vist at skiløpere har en tendens til å åpne hardt for så å senke hastigheten utover i konkurransen. De aller beste har en tendens til å ha jevnere fart gjennom hele konkurransen, og derfor vil vi undersøke om en jevnere fart med en roligere åpning også vil være gunstig for skiskyttere. Derfor vil vi over to dager se om utøvere som vanligvis går med en rask åpningsfart ville hatt fordel av å redusere denne farten.

Hva deltakelse i studien innebærer

Deltakelse i prosjektet innebærer to testløp på to dager. Testløpene går på rulleski med en total distanse på 6 km med to liggende skytinger. På dag 2 vil vi dele opp deltakerne i to ulike grupper basert på åpningshastigheten fra dag 1. Deltakere får utdelt en GPS-enhet av typen Catapult, som festes på hjelmen. Det bes også om at deltakere i prosjektet bruker pulsbelte gjennom begge løpene, med tilhørende pulsklokke med GPS-funksjon.

For så pålitelige resultater som mulig, bes deltakere om å forberede seg til testløpene som man ville forberedt seg til en vanlig konkurranse.

Hvorfor får du spørsmål om å delta?

Du får spørsmål om å delta på dette prosjektet da du er elev ved Norges Toppidrettsgymnas (NTG) i Geilo og er aktiv skiskytter.

Fordeler og ulemper med å delta på prosjektet

Som deltaker i prosjektet får man et innblikk i idrettsforskning og hvordan dette foregår. I tillegg vil du kunne få personlige opplysninger om GPS-data fra løpene som kan være nyttig kunnskap å ta med seg videre med tanke på løpsstrategier fremover. Du vil også være med på å tilføre ny kunnskap om skiskyting.

Deltakelse i prosjektet innebærer to testløp på to dager. I tillegg er deltakelsen fysisk krevende, da det kreves maksimal innsats. Eventuelle farer ved deltakelsen i dette prosjektet er høy fart på rulleski.

Opplysninger om deltakere

Opplysningene som registreres om deg skal kun brukes slik som beskrevet i hensikten med prosjektet. Du har rett til innsyn i hvilke opplysninger som er registrert om deg og rett til å få korrigert eventuelle feil i de opplysningene som er registrert. Du har også rett til å få innsyn i sikkerhetstiltakene ved behandling av opplysningene.

Alle opplysningene vil bli behandlet uten navn og fødselsnummer eller andre direkte gjenkjennende opplysninger (avidentifisert). En tallkode knytter deg til dine opplysninger gjennom en navneliste. Det er kun forskerne i prosjektet som har tilgang til denne listen. Prosjektet vil avsluttes 31.12.2022, men av dokumentasjonshensyn oppbevarer vi opplysningene dine til 31.12.2027. Opplysningene dine lagres elektronisk hos Norges idrettshøgskole, og bare forskerne i prosjektet har tilgang. Den 31.12.2027 anonymiseres opplysningene ved at navnelisten destrueres. Det vil ikke være mulig å gjenkjenne den enkelte deltaker i den endelige masteroppgaven.

Frivillig deltakelse

Deltakelse i prosjektet er helt frivillig, og man kan når som helst trekke seg fra prosjektet uten å oppgi noen grunn. Det vil ikke ha noen negative konsekvenser for deg hvis du ikke vil delta eller senere velger å trekke deg. Det vil ikke påvirke ditt forhold til skolen, trener eller lærer om du ikke ønsker å delta.

Godkjenninger

Prosjektet gjennomføres etter godkjenning av lokal-etisk komite ved Norges Idrettshøgskole. Prosjektet meldes også inn til Norsk senter for forskningsdata (NSD). Norges Idrettshøgskole er ansvarlig forskningsinstitusjon og prosjektleder er Thomas Losnegard. Alle opplysninger behandles basert på ditt samtykke.

Dine rettigheter

Så lenge du kan identifiseres i datamaterialet, har du rett til:

- innsyn i hvilke opplysninger vi behandler om deg, og å få utlevert en kopi av opplysningene
- å få rettet opplysninger om deg som er feil eller misvisende
- å få slettet personopplysninger om deg
- å sende klage til Datatilsynet om behandlingen av dine personopplysninger

Hvor kan jeg finne ut mer?

Hvis du har spørsmål til studien, eller ønsker å vite mer om eller benytte deg av dine rettigheter, ta kontakt med:

- Norges Idrettshøgskole ved prosjektleder Thomas Losnegard
  - E-post: thomasln@nih.no
  - Telefon: 23262377
- Vårt personvernombud: Rolf Haavik
  - E-post: personvernombud@nih.no
  - Telefon: 90733760

Hvis du har spørsmål knyttet til NSD sin vurdering av prosjektet, kan du ta kontakt med:

- NSD – Norsk senter for forskningsdata AS på epost (personverntjenester@nsd.no) eller på telefon: 55 58 21 17.

Samtykkeerklæring

Jeg har mottatt og forstått informasjonen om dette prosjektet.

Jeg samtykker til:

å delta i prosjektet og at mine opplysninger behandles og oppbevares frem til prosjektet er avsluttet

--------------------------	--
(dato)	(signatur deltaker)
--------------------------	--
(dato)	(signatur prosjektmedarbieder)