Faculty of health

Pacing Strategy in Long Distance Cross-Country Skiing

A study looking at female and male cross-country skiers at different performance level and how the track topography may influence their pacing strategy.

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Abstract

Background: The pacing strategy applied by athletes has significant effect on their performance in endurance sports. Although several studies have investigated pacing in different endurance sports, little information is known about pacing strategies in long distance cross-country (XC) skiing, for both sexes. This master thesis presents a novel approach to investigate what kind of pacing strategy elite and non-elite skiers perform during a long distance XC skiing race, and if different terrain will influence their pacing strategy. We've estimated the skiers lap times on every passed 10 km, uphill and downhill terrain.

Method: On the same day 100 XC skiers (50 female and 50 male skiers) completed an individual time trial in a Norwegian national championship, of long distance. Female XC skiers completed a 30 km race, while male XC skiers completed a 50 km in free technique. The trial was 10 km long. Emit Time Station ETS1 recorder split times of number of laps, time used in one chosen uphill terrain and one downhill terrain.

Results: Independent of performance level, both groups of female and male XC skiers decrease in average lap times in all measured distances (10 km lap, uphill and downhill terrain) with strong statistical significant $p<0.01$. Female and male elite group (EG) adopt a more even positive pacing strategy, than female and male non-elite group (NEG).

Conclusion: The main findings of the current study were (I) XC skiers employ a general positive pacing on a lap-to-lap basis, independent on terrain, sex and performance level. (II) Non-elite skiers tend to have a fast start with difficulty to optimize even pacing strategy and significant fall in performance. (III) Pacing strategy in uphill terrain reflects overall pacing strategy of the performance.

Sammendrag

Bakgrunn: Løpsutviklingen som utholdenhetsidretter har stor innflytelse på prestasjonen. Selv om flere studier har undersøkt løpsutvikling i flere idretter, er det lite informasjon om løpsutviklingen til langdistanse langrennsløpere, og for begge kjønn. Denne masteroppgaven undersøker hva slags løpsutviklingen utøverne adapterer i et langdistanseløp, og om ulike terreng vil påvirke deres løpsutvikling. Vi har gjennomsnitt tid på hver passerte 10 km, tid i motbakke og i utforkjøring.

Hensikt: Målet med denne studien var (1) å undersøke forskjellene i løpsutvikling hos utøvere på ulike prestasjonsnivåer (elite og ikke-elite utøvere) i langrenn, hos 50 kvinner og 50 menn på langdistanse renn, fristil. Videre, (2) undersøke hvordan rundetid og ulikt terreng påvirker prestasjonen og hvordan forskjellene mellom to ulike nivåer kan påvirke sluttiden og resultatene.

Metode: 100 deltakere, 50 kvinner (25 eliteutøvere og 25 ikke-elite utøvere) og 50 menn (25 eliteutøvere og 25 ikke-elite utøvere) som har gått NM-mesterskap på 30 km og 50 km, fristil. Målinger av rundetid (hver 10 km), tid i motbakke hver runde, og tid i motbakke hver runde

Resultat: Uavhengig av prestasjonsnivå, reduserer kvinnelige og mannlige langrennsløpere gjennomsnittstiden i alle målte distanser (10 km runde, motbakke og nedoverbakke) med sterk statistisk signifikant $p<0.01$. Kvinnelige og mannlige eliteutøvere (EG) gjennomfører en jevnere løpsutvikling enn kvinnelige og mannlige ikke-elite-utøvere (NEG).

Konklusjon: De viktigste funnene i den nåværende studien var (I) langrennsløpere anvender en positiv løpsutvikling i et runde-til-runde grunnlag, uavhengig av terreng, kjønn og prestasjonsnivå. (II) Ikke-elite skiløpere har en tendens til å ha en rask start med vanskeligheter med å opprettholde en jevn løpsutvikling og har betydelig fall i prestasjon. (III) Løpsutviklingen i motbakke terreng reflekterer løpsutviklingen generelt i løpet.

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Alta, May 2019

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1 Introduction

In winter season, cross-country skiing (XCS) is one of the earliest known physical activities (Eisenman, Johnson, Bainbridge, & Zupan, 1989), and has the greatest popularity mainly in countries characterized by low temperature and high snowfall, particularly in Scandinavia (Carlsson, Assarsson, & Carlsson, 2016). The first documented XCS race was held March 30th 1843 in Tromsø, in northern Norway. It was a 5 km long competition (Gotaas, 2013).

XCS has been an Olympic event since the first Winter Games in Chamonix, France, in 1924 (Sandbakk & Holmberg, 2014). At the same time, the Fédération Internationale de Ski (FIS) was founded to organize and standardize the sport. At this point, only men were allowed to compete in XCS, and it took another 28 years before the inclusion of female XC skiers in the Olympics games. At the time, was thought that sweating would result in sterility in women (Nordberg, 1984).

As the endurance sport it is, the main goal in XCS is to cover the course distance in the shortest possible time (Hanley, 2015). This is regarded as a "closed-loop design". How the athlete choose to distribute work output and energy reserves throughout an exercise task is recognized as the athlete's "pacing strategy" (Abbiss & Laursen, 2008).

> *"However, evidence suggests that during these events well trained athletes tend to adopt a positive pacing strategy, whereby after peak speed is reached, the athlete progressively slows" (Abbiss & Laursen, 2008, p. 239).*

Even though the definition of pacing strategy is relatively new, Fridtjof Nansen was nearby during the first 50 km competition in Holmenkollen in 1888. The race of two rounds of 25 km, and 12 out of 17 skiers completed the competition. One year they imposed a 5 minutes break when you were half way (Gotaas, 2013). Nansen, a Norwegian polar explorer and scientist, was already that time looking at the competition trough a scientific lens. He would ask himself what kind of technique would economically best to save energy? What kind of equipment would fit the best? Few studied XCS with the same interest and seriousness as Nansen (Gotaas, 2013, p. 22).

Similar to Fridtjof Nansen, several scientists have looked at pacing strategy in endurance sport, not only in XCS. Examples include track cycling (de Koning, Bobbert, & Foster, 1999), running and long distance running (marathon and ultra-marathon) (Adriano et al., 2009; Bossi et al., 2017; Hanley, 2015; Knetchle, Rosemann, Zingg, Stiefel, & Rust, 2015), rowing (Garland, 2005) and XCS (Andersson et al., 2010; Bolger, Kocbach, Hegge, & Sandbakk, 2015; Formenti et al., 2015; Losnegard, Kjeldsen, & Skattebo, 2017; Pantelis T Nikolaidis & Beat Knechtle, 2018).

The requirements for achieving good results in XCS have developed excessive for the past 10-15 years. XCS is and always will be an endurance sport, and as new equipment, new drills and slopes have improved, the requirements have become more specific, depending on the style and distance (Sandbakk & Tønnessen, 2012, p. 35). XCS has developed a lot the past decades. Better equipment and trails, new competitions forms like sprint and mass starts, as well as better topography have led to increase in velocity during XCS competitions (Losnegard, 2013).

When investigating pacing strategy, no study has yet focused on how the different terrain types and how pacing strategy may affect the performance in a long distance national championship, for both sexes on different level. The existing literature on long-distance XCS involves aspects of sex, age, nationality, and performance level on pacing and performance (based on race times), and uphill treadmill roller skiing (investigating technique in steep uphill terrain) (Engseth, 2018; Nikolaidis & Knechtle, 2017; Pantelis T Nikolaidis & Beat Knechtle, 2018; Pantelis T Nikolaidis & B Knechtle, 2018; Sagelv et al., 2018).

Since the free technique was introduced around the early 1980s, the performance in XCS has been significantly improved, although the physiological variables of skiers have not changed significantly. It applies, for example, to heart rate at maximum speed which is similar for both diagonal passage and skating, but nevertheless, the one who skates can move 11-14% faster than that using classical technique (Boulay, Rundell, & King, 1994). Mostly, the same muscle groups work in classic XC and in skating, but the load ratio varies. Since the muscles can predominantly work at lower contraction rates during skating, the possibilities of increasing greater muscle strength (Skard, 1986).

This thesis will focus on the characteristics of pacing strategy in long distance XCS, concentrating on female and male skiers at elite and non-elite performance level. Considering they've competed in difference distances (30 km and 50 km), there still might be differences in tactic (pacing strategy) when it comes to XCS and competitions. Will it be to have a fast and controlled start, increase the speed during the race, or would they rather save the energy until the last kilometres?

How they chose to predispose their race, doesn't only depend on the athlete's pacing strategy, it's characterized by the skiers physiological and psychological factors, skiing efficiency, and technique skills, for example. As well as the athlete's assumptions, materialistic products or weather conditions may also influence the athlete's performance. It should be mentioned that the topography, terrain and duration might influence the pacing.

Even though researchers have investigated sex differences in pacing strategy (Carlsson, Assarsson, et al., 2016; March, Vanderburgh, Titlebaum, & Hoops, 2011; Peter, Rust, Knetchle, Rosemann, & Lesper, 2014; Stöggl et al., 2018), little is know about how up-and downhill might influence the pacing strategies among female and male. And if there's a difference in-between the sexes, of elite and non-elite performance level.

1.1.1 How the thesis is organized

The theoretical frame of reference is presented in chapter two, which begins with some conceptual clarifications. Then, an introduction of the history of XCS, where there will be focus on the development of the competition sport, techniques and modern XCS. The chapter continuous with presentation of what pacing strategy is, and what influence the pacing strategy to an athlete. Later, an overview of the different performance factors on XCS. The chapter will end with previous studies on sex differences in pacing strategy in both XCS and long distance running.

Chapter three deals with the method, in which design, procedures for data collection will be presented. The quality of the collected data is discussed, and finally there will be some methodical reflections.

Chapter four present the result in the given study. The hypothesis and questions will be elucidated and analysed on the basis of the results from the collected data from measured lap times.

In chapter five the findings are discussed, also up against the theoretical frame of reference. Then, some methodological reflections are made. Finally, it will be concluded and presented proposals for further research, which can attribute to what the individual skier or coaches should focus on to perform an optimal pacing strategy during a long distance XCS race.

2 Theory

1.1 The History of Cross-Country Skiing (XCS)

Cross-country skiing (XCS) popularity started in the 1860's due to health benefits and the fact that XCS was fun for competing and for entertainment. That, and military causes, since Norway was in union with Sweden, needed a winter army with experienced XC skiers (Sandbakk & Tønnessen, 2012). Towards the dissolution of the union in 1905, XCS had an essential bond to the nation's heyday, Viking age. Where they also used XCS in war (Sandbakk & Tønnessen, 2012).

During the Second World War (WW) from 1939-1945, all kinds of sports and organized physical activity were forbidden in Norway. Still, people would meet up in secret to socialize trough sports and train XCS. When the war was over, Norway performed poorly in championships. Finland and Norway lost many men during the war, and several were bruised for life. Sweden, who was neutral during WW, dominated in XCS from 1948 to 1950. From the 1950's to 1980's the rival were between Sweden, Norway, Finland and Russia (Sandbakk & Tønnessen, 2012)

The Norwegian term for XCS is "langrenn", which means a long race. This term got more usual in the 1880's. In the years to come, the term got more familiar, and the modern XCS spread out in the country. Fridtjof Nansen expedition over Greenland in 1888 was essential for strengthening the self-image of Norway, who ambitious wanted to become free. The social elite announced XCS to something typically Norwegian (Sandbakk & Tønnessen, 2012).

During the 1970's, XCS changed as television and international exposure from championships increase the income opportunities. XCS turns out to be popular all over the world. Surprisingly the interest for backcountry skiing in North America is blooming, and this is at the same time as the exercise wave took place at the 70's. The total marked of XC skis in the world were over 3 millions pairs skis, today that number is halved (NRK, 2009a; Sandbakk & Tønnessen, 2012).

With exposure through mass media, the sport was seen live by huge audience numbers. This attributed to a chain reaction within the sport. This opportunity of media gave advertising and profiling, which provided income that again professionalized the top sport. This provides support and equipment, and the investment was getting bigger. This turn meant that you become more dependent on professional performance and good results to have success in the sport (NRK, 2009a).

To always be ahead of everybody else requires that you're up to date on technological innovation, equipment and type of training. And to make the right decisions can sometimes be difficult. Synthetic doping like blood doping and erythropoietin (EPO) was becoming more common. The doping discussion first started in the 1960's, but it wasn't until the World Champion in Lathi in 1989, blood samples were taken for the first time (NRK, 2009a).

Nations who have participated in World Championship, Olympic events and international competitions from the beginning include: Sweden, Norway, Finland, Soviet Union, Italy, France, Eastland and Czechoslovakia, Czech republic, Germany, Russia, Switzerland Kazakhstan, Poland, Austria, Spain, East-Germany, are some of them (Elster, 2011).

2.1.1 History of Cross-Country Skiing (XCS) and Women

In the 18th century women started skiing. Although they had been skiing before, for everyday purposes, they wanted to compete and join the skiing clubs just like the men at that time. There was only one problem: the men didn't want them to join. At the time, it was thought that women should be indoors, tending the family, and they should certainly not sweat, which could happen if they started skiing in competitions (Nordberg, 1984).

Already in 1917 Sweden arranged national championships for women, and in Zakopane in 1929 the female skiers raced 6 kilometres, though without any Norwegian participants.

One of them, who fought for women's right to go outside and ski, was the wife of Fritjof Nansen, Eva Helene Nansen. She would say that skiing outside was beneficial for women, to go outside and ski in the cold and get rosy cheeks (Nordberg, 1984).

In 1949, the Fédération Internationale de Ski (FIS) gathered to congress in Oslo to discuss female participation in XCS competitions. The Swiss delegate Hans Feldmann had a simple and straightforward conclusion: the woman's right place is in the kitchen. How could the men be active athletes in sports unless the women would take their full responsibility for their home and children?

While the Finn, Arvo Himberg, spoke warmly for the women in the competition track, he couldn't see any meaning for proposal of a test period with international races. He fought for women's right to compete in World Cup. He wanted them to be joined from that day- with effect from the Olympic games in 1952 (Nordberg, 1984).

At that congress, women's participation in World Cup was agreed and settled. This significant decision was going to play a big role for the development of women's XCS, both national and international. Interesting enough, Norway was the only nation voting against female competitors (Nordberg, 1984).

It wasn't until the Olympics in 1952, in Oslo, that the Norwegian women were allowed to compete in XCS. The best performance out of the women was Rakel Wahl earning 6^{th} place (Nordberg, 1984). By now the men had already been competing for 68 years, with the onset in the first XC race in 1884 (Gotaas, 2013). In 1966, the Norwegian women called "Jentutn", placed second in the World Championship in XCS relay.

Berit Mørdre is referred to as the woman behind the breakthrough in Norwegian female XCS. She would break barriers that no one thought was possible, and became a role model for a whole generation of female skiers. Best remembered for the impressing relay giving Norway Olympic gold in 1968 (Norberg, 2019).

During the late 1970's, XCS was no longer a sport driven by men. There was no longer any perception that women didn't tolerate as men, and that they could turn out sterile. Even though the women had to work or study beside the sport, the prizes of winning got better, and the sponsors were growing (Norberg, 2019). Today, female XC skiers participate in all the same competitions as men do, though in traditional Olympic distances, competitions are not longer than 30 km for women.

Recently, the most successful female XC skier ever retired from the sport. With eight Olympic gold medals, 18 gold medals at the World Championship, and 110 World Cup victories, the Norwegian Marit Bjørgen is the most winning winter Olympic ever (Solli, Tønnessen, & Sandball, 2017).

2.2 Characteristics of Long Distance Cross-Country Skiing (XCS)

The 50 km competition was exact 50 km because it was a whole number. Besides, it was longer than any Norwegian XC race and the distance was bearable (Gotaas, 2013).

The length of a XCS race is varying from 1.8 to 220 km, where the worlds longest XCS competition is the Swedish Nordenskiöldloppet (Bolger et al., 2015; Nordenskiöldloppet). The course of the race also determines certain characteristics, claimed by the Fédération Internationale de Ski (FIS) (“The International Ski Competition Rules: Book II Cross-country”, 2015). FIS state that a World Cup XC ski course should consist of approximately one third ascending, one third flat and one third descending terrain. Sandbakk, Ettema, and Holmberg (2013) writes how this influence to a great adaptations for the athletes both in speed (5-70 $km \cdot h^{-1}$) and terrain (-20 to 20% inclination). Long distance XCS is characterized by competitions from 5-50 km long. In traditional Olympic distances, competitions are not longer than 30 km for women.

These include both mass start and individual start. Today, Visma Ski Classics (VSC), Wordloppet, Euroloppet and Nordenskiöldsloppet, are some of the longer distance races (14-220 km) who have seem to gain more attention from skiers, public and media (Sandbakk & Holmberg, 2017).

The VSC “was created in cooperation between sports media, the athletes and the events representatives in order to enhance the world of long distance skiing” (VismaSkiClassic, 2018). The Ski Classics is unique by having Pro Teams, Amateurs, men and women at the same start line. The long distance skiing events still symbolize the strong traditions of classical XCS, and is the most traditional long distance XCS event in Europe (VismaSkiClassic, 2018).

As in any other sport, certain physiological demands are required to perform optimal in long distance XCS. With variations of terrain types, moving fast and be physically required to ski long distances, maximal oxygen uptake (Hallén, 2013), aerobic capacity (Wilmore & Costill, 1994), heart and blood (Martini, Nath, & Bartholomew), lungs

The general demands in XCS are written later in the theory chapter.

2.3 Development in The Competition Form Cross-Country Skiing (XCS)

Sports in general, and XCS, went trough much progress and development in the 1900. A podium performance from the year before wouldn't necessary mean victory to the upcoming generation. It was happening in purpose of the achievement, and was laying in the nature of sport: faster, higher and stronger. More people recruited to XC and the competition got harder. Some skiers didn't like this development, and wanted to develop a class division for elite skiers (Sandbakk & Tønnessen, 2012).

The very first mass start was held in Castelrotto, Italy in 1987. Many of the skiers as well as the crew, were sceptic to this new trend. Especially when 108 skiers had to start at the same time. Going uphill, the skiers got packed together so the group almost stopped. The group of skiers was going to slow that one athlete, Arild Monsen, took of his skis and ran past 20 competitors. A not so impressed skier over this mass start experiment was Vegard Ulvang. Though being the best Norwegian skier in the race, getting a 5th place, he couldn't see how this trend would contribute in future competitions. He specified how it was not achievable to pass skiers wherever you wanted to, especially not skiing free technique. Maybe this mass start could benefit in XCS classic style (Wassberg).

The competition forms has been plenty, especially the distance. For about ten decades, the men competed in 30 km, 15 km and 50 km, and relay. The female XC skiers competed in 5 km, 10 km and relay of 3 x 5 km. During the 1970's they finally got to compete in 20 km from VM in 1978 (Sandbakk & Tønnessen, 2012).

In the new competition form that arrived around 2012, called skiathlon, the athlete changes equipment midways (poles and skis) and technique. They start out in classical technique and perform second half with free technique. The main reason for organizing this form of competition is to make to more exciting for the audience. Other competitions came too, inspired by the cycling sport, like tours to Tour de Ski (from season 2006/2007). An overall victory goes to the one winning the most during the tour (Sandbakk & Tønnessen, 2012).

In national championship, World Cup – and championship, as well as Olympics, athlete compete both in mass start races and individual time trials. When competing in mass start races, the skiers are required to compete against each other in direct "head to head". While in individual time trials, each skier competes against the clock (Hanley, 2015).

Throughout the years, the sport XCS has changed in many ways. Equipment like skis, poles, shoes and clothes have become lighter and better. They compete both in mass- and interval start. The track preparations of the course, skiing technique, especially in free technique, and tactic for the race have grown (Sandbakk & Tønnessen, 2012). XCS is today influences by more effective and specific training, as well as tremendous improvements in equipment and track preparations (Sandbakk & Holmberg, 2014).

Throughout the years, mass starts and sprint races have been introduces to XC. "Indeed, 10 of the 12 current Olympic competitions in XCS involve mass starts, in which tactics play a major role and the outcome is often decided in the final spring" (Sandbakk & Holmberg, 2014, p. 117).

Especially in free technique, the velocity during competition has increased significant over the years. When the larger grooming machines came, which leave the snow surface relatively smooth and firm, this influenced a higher speed in XCS. Compared to running, in Figure 1, where maybe only running shoes and more specific training have an influence (Sandbakk & Holmberg, 2014).

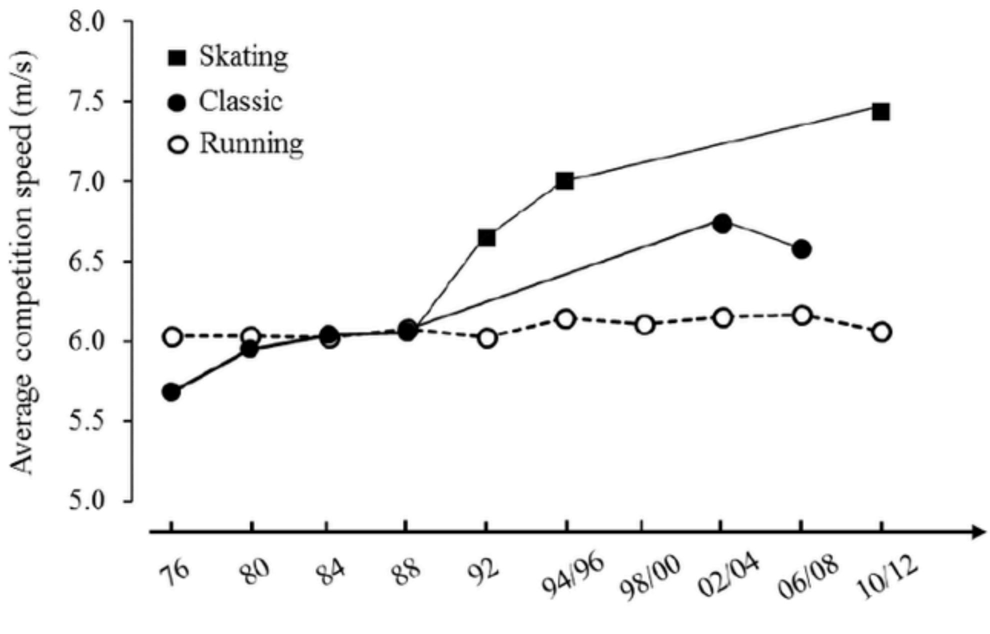

Figure 1 Shows average speed for the male winners of 15-km XCS and 10,000-m running during Olympic competitions from 1976 to 2012 (Sandbakk & Holmberg, 2014)

All the factors that have influence the skiers for decades have improved excessively. From new and lighter equipment, groomed tracks and better topography, more specificity in training and more knowledge about physiological and psychological demands have contributed to a massive decrease in performance time during competition. In 1888 the world first 50 km was arranged in Holmenkollen, Norway. Torjus Hemmestvejt from Telemark (27 years old) won the first 50 km with 4:26:30.

2.4 Performance Factors and Demands in Cross-Country Skiing (XCS)

XCS is considered as full-body work (Calbet et al., 2004), where various sub-techniques provide different movements and different muscle activation (Calbet et al., 2004; Sandbakk, Leirdal, & Etteme, 2014).

Like in every sport, XCS requires certain success factors. The success factors describe the performance-enhancing aspects, which will benefit good results in the given sport. In several studies by: Gjerset, 1992; Schnabel, Harre, and Borde, 1997; Weineck, 1990; Tønnesen, 2009 (Cited in Gjerset, Holmstad, Raastad, Haugen, & Giske, 2012, p. 171). These factors contains following variables:

- Techniques
- Coordination
- Tactics
- Physical characteristics
- Psychological characteristics
- Social characteristics
- Anthropometrics
- Equipment/gear

How important these performance factors are, depends on the sport.

Olympiatoppen (2007) have presented the different success factors in a scale, which makes it easier to see what's more important. Figure 3 below shows the work requirements and capacity analysis, where 10 is the highest level ever achieved at each factor (Olympiatoppen, 2007). The figure reflects the demands for a general XC skier, and not specific long distance

XC skiers. In long distance XC, high aerobic capacity and tactic is requirements that stand out importantly.

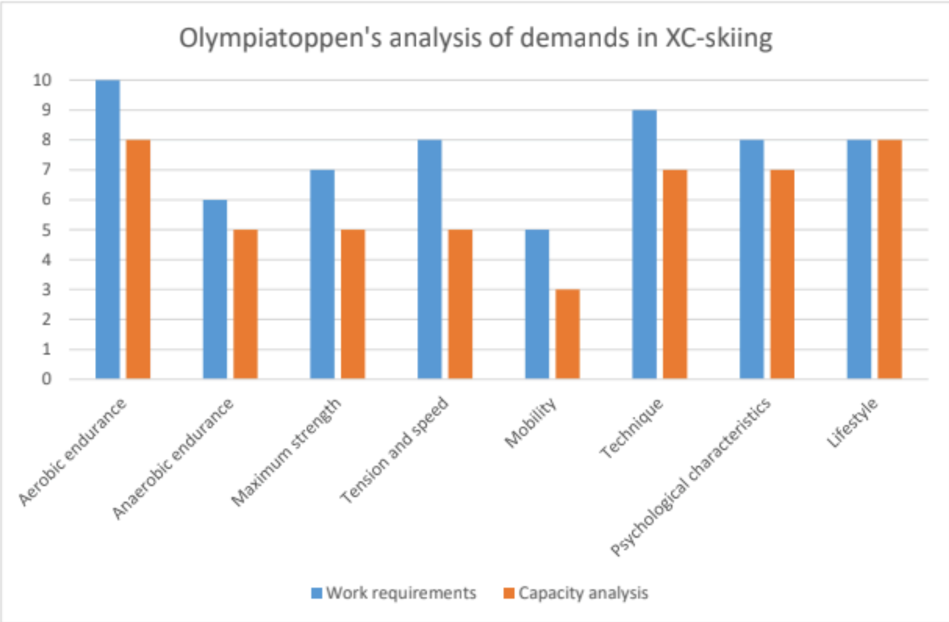

Figure 2 Olympiatoppen work requirement and capacity analysis in XCS. The capacity analysis is based on male skiers, while the work requirements is the parameter for the maximum of what is achievable for an athlete at his age

2.5 Physiological Demands in Long Distance Cross-Country Skiing (XCS)

What physically requires moving fast and in long race XCS, with variation in terrain types?

- Maximal oxygen uptake (2.15)
- Anaerobic and anaerobic capacity (2.16)
- Heart and blood (2.14)
- Lungs (2.15)
- Training and performance
- Load (2.16)
- Specificity (2.2.7)
- Skiing efficiency (2.4)

2.6 Heart and Blood

> *"Blood flows through a network of blood vessels that extend between the heart ad peripheral tissues. Those blood vessels make up a pulmonary circuit, which carries blood to and from gas exchange surface of the lungs, and a systemic circuit, which transports blood to and from the rest of the body" (Martini et al., p. 685)*

Driven by the pumping of the heart, blood flows through the pulmonary and systemic circuits in sequence. Each circuit begins and ends at the heart and contains arteries, capillaries, and veins" (Martini et al., p. 685), photo from (UrgoMedical, 2019). The arteries and blood vessels in the heart have different jobs. The arteries, or efferent vessels, carry blood away from the heart. The veins, or afferent vessels, return blood to the heart. Even though the heart is a small organ, the heart pumps about 8000 litres of blood though the body each day (Martini et al.).

The red blood cells, contains haemoglobin, have the task to transport O_2 in the body. How much oxygen that can be transported depends on the haemoglobin concentration (Hb-concentration) in the blood. If the person wants to increase the Hb-concentration, altitude training is most common used. Even though this training can be very risky, because offensive training can lead to lower level of performance, it may have a minor impact on younger or not so practitioners athletes at lower level (Hallén, 2013)

The quantity of blood getting pumped out through the body, is relatively depending on how much oxygen the muscles needs. When you're resting, the heart pumps between 35-75 strokes per minute. The better trained-person you are, the fewer times will the heart pumps per minute (Hallén, 2013). On the other hand, maximum heart rate will not say anything about the persons physically form, and this cannot be affected by training. Normally, maximum heart rate is between 160-220 strokes per minute. This is depending on how much blood the heart pumps out in every stroke, and is varying from person to person, depending on inheritance and training. Thus larger stroke volume you have, the higher VO^2max you have (Hallén, 2013).

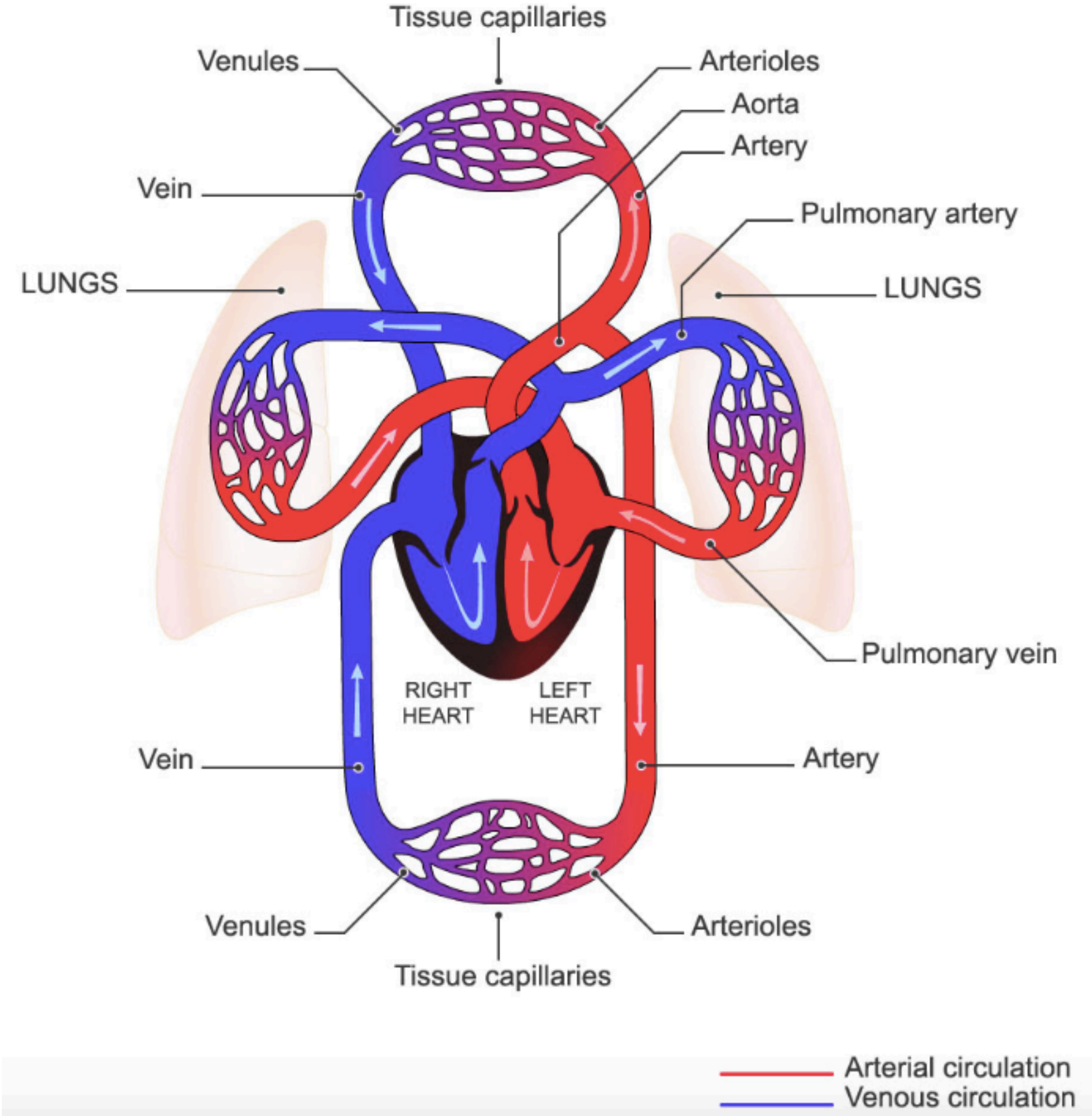

Figure 3 The cardiovascular system from UrgoMedical (2019).

Lactate acid is continuously produced in our skeletal muscles, also when training. With an increasing workload the production of lactate acid also increases (Holmberg, 2015). As the energy requirement will exceed throughout the duration, the aerobic energy liberation processes and the anaerobic energy liberation processes are linked. The limit for this turnover, the anaerobic threshold (AT), seems to be highly correlated with performance level in endurance sports (Tjelta, 2013).

This study is done without any lactic acid blood test, however, the lactate concentration in the blood tells us what intensity the athlete is at and will influence the performance. Olympiatoppen has listed an 8-split intensity scale with estimated duration time for exercises performed in each intensity zone (Table 1).

Table 1 Olympiatioppen's intensity scale (Olympiatoppen, 2013).

Intensity zone	% of VO_{2max}	% of HR_{max}	Lactate	Total duration
i8	...	...	...	1 - 3 min
i7	...	...	...	3 - 6 min
i6	...	...	...	6 - 15 min
i5	94 - 100	92 - 97	6,0 -10,0	15 - 30 min
i4	87 - 94	87 - 92	4,0 - 6,0	30 - 50 min
i3	80 - 87	82 - 87	2,5 - 4,0	50 - 90 min
i2	65 - 80	72 - 82	1,5 - 2,5	1 - 3 hours
i1	45 - 65	60 - 72	0,8 - 1,5	1 - 6 hours

2.7 Maximal oxygen uptake

World-class XC skiers usually have higher VO_{2max} compared with lower level skiers. VO_{2max} is important for long distance races (<10km) (Sandbakk & Holmberg, 2017). XC skiers both female and male have measured some of the highest maximal oxygen uptake (VO_{2max}) ever (Holmberg, Rosdahl, & Svedenhag, 2007; Ingjer, 1991; Losnegard & Hallén, 2014a; Sandbakk et al., 2016). In an endurance sport as XCS VO_{2max} is one of the most highly depending factors of the performance, and not at least how you take advantage of your VO_{2max} (Hallén, 2013). "During prolonged exercise (lasting 2-3 h) 60-90% of max of V_{O2} can be used" (Rusko, Rahkila, & Karvinen, 1980, p. 263).

Costill, Thomasson, and Roberts (1973) and Wyndham, Strydom, van Rosenburg, and Benade (1969) suggested "that the endurance of athletes can be characterized physiologically, in addition to max V_{O2} as the highest intensity of exercise at which the production of lactic acid is not increased" (Rusko et al., 1980, p. 263). Which has been confirmed by the definition of Rud (2011) " VO_{2max} is defined as 'a measure of the maximal energy output by aerobic processes' and is quantified as the body's volume of oxygen consumed per minute" (Rud, 2011, p. 1).

The workload of any activity requires a certain amount of energy. If the person is running on a treadmill, at a given speed and incline, the energy consumption regarded of the person's weight is how much energy the workload requires. With a greater velocity and steeper elevation, the oxygen uptake will increase. To reach VO_{2max}, the speed increases to the oxygen uptake stagnate. This is the lungs limit to absorb oxygen and is referred as VO_{2max}, and is measured as the absolute value "litre per minute" ($l \bullet min^{-1}$) (Gjerset et al., 2012; Hallén, 2013). The maximal oxygen uptake is a relative value as "millilitre per kilogram bodyweight per minute" ($ml \bullet kg^{-1} \bullet min^{-1}$), which will say that an untrained person can reach their VO_{2max} at 2 $l \bullet min^{-1}$ (Gjerset et al., 2012).

In fact, in major XCS championships, there are few male skiers winners with a VO_{2max} values that are less than 6 $l \bullet min^{-1}$ (Holmberg, 2015). Because of the lungs genetic not everyone can use exercise as a way to transfer more O_2 to the blood, which is the main job to the lungs. For well-trained individuals the limitation of lung capacity can be a drawback (Rud, 2011).

2.8 Aerobic and Anaerobe Capacity

XCS is one of the most demanding endurance sports in the world (Holmberg, 2015). Endurance training is a combination of intensity, duration, and frequency that lasts over days, weeks and months (Seiler, 2010). For best possible performance, the athlete's goal is to minimize the risk of negative training outcomes. They have to regulate period training and timing peak fitness to achieve when it matters the most (Seiler, 2010).

We differ between aerobic and anaerobic capacity. Aerobic, which refers to "… your body's ability to sustain prolonged exercise" (Wilmore & Costill, 1994, p. 217), is one of the fundamental requirements in XCS. By applying long, slow distance training; either on skis, roller skis, cycling or running, the aerobic capacity will slowly increase.

> *"Throughout a year's cycle, elite level cross-country skiers should compete 500 to 550 training sessions per year. This should contain about 800 to 900 hours of training. In order du maximize the practitioner's capacity, the training must be*

individualized, but in most cases a distribution/prioritization is recommended" (Sandbakk & Tønnessen, 2012, p. 101).

"Endurance training has always been the major component of an elite XC skier's training. The 750 to 950 hours of annual training (including 700 to 850 hours of endurance) by the best skiers include approximately 80% at low intensity, 4% to 5% moderate- and 5% to 8% high-intensity endurance training, and 10% training strength and speed" (Sandbakk & Holmberg, 2017)

In the figure below of Sandbakk and Holmberg (2017), a yearly training plan is presented for a world-class XC skiers which compete in both sprint and distance races. The annual illustrate how a typical training and preparation period is listed and competitions period.

"Abbreviations: T, laboratory testing; L, training camp at low altitude; H = training at high altitude; LIT, low-intensity training, blood lactate concentration <2.5 mmol/L, heart rate (HR) <81% HRmax; MIT, moderate-intensity training, blood lactate concentration 2.5-4.0 mmol/L, heart rate 81-87% HRmax; HIT, high-intensity training blood lactate concentration 4.0.10.0 mmol/L, heart rate >87% HRmax" (Sandbakk & Holmberg, 2017, p. 1007).

	1. preparation period			2. preparation period			Competition period					Recovery	
Testing	T		T	T	T	T	T			T	T		
Training camps	L	L L		L H H H	L	H H H	L	H H		H H			
	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	March	April	**Sum**
Training, h	70	75	80	85	85	85	70	60	60	50	45	35	**800**
Sessions/mo, n													
Sprint races		1		1			2	3	3	3	2	2	**17**
Distance races	1	1		3	1		3	4	5	5	4	4	**31**
HIT	2	3	3	2	3	4	2	2	1	1	2		**25**
MIT	4	4	5	4	5	5	1	1	1	1	1	1	**33**
LIT >2.5 h	4	6	8	8	8	8	5	4	3	2	2	5	**63**
LIT 1.5–2.5 h	10	9	10	11	11	12	11	12	12	11	8	5	**122**
LIT <1.5 h	6	6	6	8	8	8	10	10	11	12	11	2	**98**
Speed	3	4	4	4	5	5	4	4	3	3	2		**41**
Plyometrics	2	3	3	2	2	2	2	1	1	1	1		**20**
Strength	8	7	7	5	5	4	3	2	2	2	2	2	**49**
Sum	**40**	**44**	**46**	**48**	**48**	**48**	**43**	**43**	**43**	**41**	**35**	**21**	**500**

Figure 4 Annual training plan for a world XC skier competing both sprint and distance races.

Even though sprint and distance skiers almost have the similar annual training, the sprint team appear to train slightly less than the distance skiers, but with more speed and strength training (Sandbakk & Tønnessen, 2012).

Anaerobic capacity and energy supply are correlated with performance and justify 26% of the total energy turnover (Losnegard, Myklebust, & Hallén, 2012). The contribution of anaerobic capacity will decrease with duration of the exercise and is therefor less important for long distance XC skiers (Gastin, 2001). Conversely, it is important for the XC skier to have the ability to frequently recover the anaerobic capacity (Karlsson, 2017).

"Since anaerobic capacity is highly related to the muscle mass involved in the exercise (Bangsbo et al., 1990; Bangsbo, Michalsik, & Petersen, 1993), differences in body mass may also occur between different types of athletes" (Losnegard & Hallén, 2014b, p. 25).

The majority of XCS competitions are mass-starts, which requires sprint abilities to determine the final result. In this competition, since it's a longer race distance (30 km and 50 km), the race format is interval-based, "with increased effort in uphill terrain and lower intensities downhill" (R. W. Norman, Ounpuu, Fraser, & Mitchell, 1989; Sandbakk, Ettema, Leirdal, Jakobsen, & Holmberg, 2011; Sandbakk & Holmberg, 2017; Solli et al., 2017, p. 2).

2.9 Rest and Recovery by Gjerset, Raastad, and Nilsson (2015)

Recovery is highly necessary to achieve results in training, and adequate rest is required for the organism to adapt to the load of training (Gjerset et al., 2015). How much and how long the rest is needed depends on the intensity and the duration of the given exercise. The athletes health both psychological and physiological, age, which muscle tissues has been affected, and what kind of recovery actions you plan to do (Gjerset et al., 2015). Methods of recovery after the exercise is done are for example; fluid, nutrition, replacement of important nutrients, new and dry clothes, cool down/easy jog or equivalent. This, depending on what time and what methods, will start the process of recovery faster and abbreviate it (Gjerset et al., 2015).

"The recovery time is needed is different for different cell constituents, cells, tissues, organs and other factors that are stresses when we exercise and compete in sports" (Gjerset et al., 2015, p. 40). Roughly speaking the factors can be divided into those who use short time, medium and long time to recover. Those factors considered relatively fast in recover are ATP, creatine phosphate (CrP), myoglobin stores of O_2 and lactate concentration in the blood. Repair of moderate to major damage to muscle structures, on the other hand, needs a fairly long recovery process (Gjerset et al., 2015).

The recovery process of endurance sport such as XC skiing, with relatively low intensity (I-zone 1, 70% of HR_{max}) is happening while the activity is going on, or will take up to a day and a half. This is possible because of the low intensity; muscles will get enough O_2 by the blood and nutrients to tolerate the training load (Gjerset et al., 2015).Right nutrition and fluid contribute to faster recovery, but it also supplies the athlete to achieve optimal performance, as written in the next section.

2.10 Athletic Performance and Nutrition

Dehydration of only “2 to 3% body mass decreases exercise performance; thus, adequate fluid intake before, during and after exercise is important for optimal performance” (Rodriguez, Dimarco, & Langley, 2009, p. 510), and especially in long distance competitions. The appropriate food and fluids and time of intake, especially protein and carbohydrate, is essential to maintain the right “body weight replenish glycogen stores, and provide adequate protein to build and repair tissue” (Rodriguez et al., 2009, p. 509).

> *”Adequate food and fluid should be consumed before, during and after exercise to help maintain blood glucose concentration during exercise, maximize exercise performance, and improve recovery time. Athletes should be well hydrated before exercise to balance fluid losses” (Rodriguez et al., 2009, p. 509).*

Endurance athletes usually have a diet with lots of carbohydrates, and the stores of glycogen should be filled up before a competition. Burke, Hawley, Stephen, Wong, and Jeukendrup (2011) in Frøyd, Gjerset, Nilsson, and Enoksen (2015) recommend 30-90 gram of carbohydrates per hours during an activity, for example sports drinks or nourishment food. “These nutrition guidelines are especially important for endurance events lasting longer than an our when an athlete has not consumed adequate food or fluid before exercise, or if an athlete is exercising in an extreme environment (eg, heat, cold, or high altitude)” (Rodriguez et al., 2009, p. 510).

After an activity 1-1,2 gram carbohydrates per kg body weight are consumed every hour, and 10-20 gram carbohydrates as soon as the activity is ended, especially for those athletes who train more than one session a day. This will also start the recovery process faster (Frøyd & Helge, 2015).

2.11 Psychological Factors in Cross-Country Skiing (XCS)

The performance of an athlete depends on theirs sports skills and their state of mind. There are several examples of big sports icons failing their competitions when they are under a lot of pressure. The term “choking” describes the phenomena decrease in performance in situations where it's high pressure to succeed (Baumeister, 1984), though Ferrari (2001) defines it as a weakness in the athlete's self-regulation.

Motivation is a key term when understanding humans choice and behaviour (A. M Pensgaard, 2015), and two approaches within Achievement Motivation, developed by John Nicholls, are

Self-regulation, a central part of a performance phase, should be used continuous for getting best equipped for what is to come (Sun & Wu, 2011).

Hanin (2003) chapter in "Psychological factors in cross-country skiing", mentions four significant aspects for the skier to achieve performance optimization:

> *"There are at least four main groups of factors that can either enhance or impair skiing performance. These include:*
>
> *1 group dynamics or social psychological factors;*
>
> *2 athlete's personality traits;*
>
> *3 self-regulation and coping skills; and*
>
> *4 situational performance related states in practices and races".*

A calm mental state, good preparatory phase training, exercise and low pressure is the major contribution factors to successful self-regulation. The self-regulation appears to be one of the most important factors in achieving the best possible condition in a sports competition. These characteristics of self-regulation may be the most important factors to achieve optimal performance (Sun & Wu, 2011).

For a XC skier, or any endurance athletes, it is important to have a self-empowering relationship towards physical pain and fatigue. This will help to develop the endurance. Such as "experience-based awareness, acceptance and action-orientated mind-set are the components of a skier's positive attitude towards fatigue and even physical pain" (Hanin, 2003, p. 176). With a self-empowering mind-set, telling you that fatigue is useful for me, the athlete will have beneficial outcomes like physical stress, persistence and goal-oriented (Hanin, 2003).

Having a negative relationship with fatigue and physical pain will have the opposite affect for the performance. “A negative attitude towards fatigue, anticipation and avoidance of pain could be a strong psychological barrier to the development of an athlete’s endurance and other physical and psychological qualities” (Hanin, 2003, p. 177).

The psychological part of a competition is so essential, that if the athlete fails and changes the mind-set from an unconditional to a conditional mind-set it can have a decrease on performance on 70%. This means going from telling yourself that “I can” to “I can do this *if*, I’ll try my best *if* the weather is good (Hanin, 2003).

Research on self-regulation and performance shows that self-regulation may have a positive effect on performance level. Studies indicate that elite athletes are more aware of their strengths and weaknesses and are better to follow up specific training. It also appears that elite athletes want to make a greater effort in training and competition than athlete on a lower level (Sun & Wu, 2011; Toering, Elferink-Gemser, Jordet, & Visscher, 2009).

2.12 Equipment

In the beginning of XCS competitions in the 1800-1900s, the Norwegians had better equipment than the Finns and Swedes. The ski bindings were tighter and the skis were shorter because of the Norwegian variation in the terrain. This way the skis had better steering in the snow. Likewise, the Norwegian XC skier’s technique was the best. They had to be tough and shouldn’t fear either uphill or downhill (Gotaas, 2013).

After three years of research, Swix ski was launched 28th November 1946. Made from synthetic compounds, new wax eliminated the use of wax with sebum, threshing or salt (NRK, 2009b).

World championship in Falun 1974, skis of artificial materials, fiberglass, were presented for the first time. The skis were lighter than before and the material made a greater speed into the sport. Today, equipment is lighter, tighter and more aerodynamic than before. With skis, poles, shoes made of carbon, it has contributed to decrease the competition time in XC-skiing, combined with more knowledge and research within ski wax (Sandbakk & Tønnessen, 2012).

With such big influence as the equipment has today, the right wax and pare of skis for the conditions may determine the outcome of the winner. An early interest and knowledge about ski wax and skis can contribute the athlete to chose the right skis in competitions, and be more comfortable with equipment (Sandbakk, Rise, & Nymoen, 2017)

2.13 Development of technique

Hallgeir Brenden was a technical pioneer in diagonal technique, both skiing uphill and at flat ground. He was probably the first “complete” XC skier in Norway, with his remarkable high-speed sprint, endurance an unbeatable record on 3000m hurdles (NRK, 2009b).

XCS is considerably unique, comparing to other endurance sports. This is because of its many sub techniques and changing in frequency during a race. The two main techniques in XCS is classical and free technique. In both classical and free technique, we have a variety of several sub techniques, which are called gears. In classical there are 4 of them, while in free technique there are 7 gears. XC skiers change between the gears up to 30 times in a sprint (1.5 km), which means they probably change sub technique several hundred times, during a distance race such as a 30 or 50 km competition (Andersson et al., 2010).

All the gears allow the skier to control their speed during the given course. Within each gear the skier will change cycle length and the frequency of the movement (Nilsson, Tveit, & Eikrehagen, 2004). “The competition terrain varies, but is mandated to include approximately one-third uphill, one-third flat, and one-third downhill. This forces skiers to alter their technique often” (Sandbakk & Holmberg, 2014, p. 118).

The demands of technique in XCS are constantly increasing. The best athletes have developed the technique over the years, especially in free technique, skating. To adapt the most efficient technique, the trainer should see every individual and their skills. Doing this, the technique will fall most naturally for the skier (Jørgensen & Andersen, 2004).

Today, most of the technique training will happen during low intensity training, either on roller-skis or XC skis. With low intensity they can concentrate on input and comments from trainer(s). Use of video is an advantageous tool that points out movements that can be solved in other or better ways. Video will also put light on the skier’s good skills (Jørgensen & Andersen, 2004).

2.13.1 Sub Techniques in Free Technique

Even though all XC skiers might have their own approaches, the basic principles for efficient XCS technique is the sum of forces that accelerates your body in the direction of speed (Sandbakk & Tønnessen, 2012). To create the most efficient skiing technique, the momentum of force has to be as big as possible, and be going towards speed direction. Several factors are affecting the skiing technique, and the skiing efficiency is depending on the relationship between force and movement (Sandbakk & Tønnessen, 2012). The gravity's target is the body's centre of gravity, usually just above navel/belly button. The gravitational forces can act both breaking or give momentum on whether it is uphill or downhill. The steeper uphill terrain, the more breaking forces, and the steeper downhill the more propulsive forces.

The requirement of aerobic capacity in XCS is remarkable, but if the skiers don't have a good enough technique, the skiing will not be efficient enough. A variety of different sub techniques, are essential to become a complete XC skier (Sandbakk et al., 2017).

Originally there was only one ski track. When the slopes later improved with more breadth and multiple ski tracks, it made it possible for the free technique to arrive, firstly as a one-leg skating sequence (Sandbakk & Tønnessen, 2012).

> *"After American Bill Koch won the cross-country skiing World Cup in 1982 using a skating technique, skiers quickly adopted ski skating. Since that time, there has been an exciting evolution of more advanced ski skating techniques, skiing equipment and trail preparation methods. As a result of these changes, races are completed in a 10-30% faster time than with the classical techniques" (Fredrick & Street, 1988; Hoffman & Clifford, 1992; Pinchak, Hagen, Hall, & Hancock, 1987).*

From 1986, XCS was divided into classical technique and free technique. Athletes who performed both techniques adapted the training accordingly to either classical or free technique (Sandbakk & Tønnessen, 2012).

"The skating, or free technique sequence, takes place by sliding vertical to the skis as they glide forward, with an angle to the direction of the tracks, while both poles is pushed backwards" (Sandbakk & Tønnessen, 2012, p. 161). While the skis are shorter than classical skis, the poles are longer. The different skating techniques are used in different terrain types, and can be compared to the gear system in a vehicle. The steeper terrain it is, the lower gear. The faster sub technique the more flat terrain.

In free technique there is five gears (Sandbakk & Tønnessen, 2012, p. 163):

1. Diagonal stride (V skate) rarely used is competition, except from long and steep uphill like the last competition in Tour de Ski.
2. Offset (V1 Skate) commonly used hill climbing. You hold the one pole higher than the other (called "hanging arm") while placing it in the snow and pushing the same side as the hanging arm. Legs gliding while the poles are moving forward.
3. Double pole technique (V2). Both poles are used in every thrust, which means that upper body and legs work at the same time. The technique is used in flat terrain and easy uphill.
4. Two Skate (V2 Alternate). The poles are used every other leg thrust, like in V1. This technique is used on flat terrain, and easy downhill.
5. Free skate (No Poles) or skating without poles, is leg pushes with active arms either commuting to the sides or assembled along the body.

Weight transfer in XCS is a central part of technique training, and is referred to as "moving the center of gravity to a position where you can create great force against the substrate" (Sandbakk & Tønnessen, 2012, p. 149).

In an interval start, the athlete can choose what kind of pace he will have, and decide different techniques depending on the terrain. With well-developed feeling of the right velocity and technique relative to exertion, this is an important skill to perform optimal. The angle between the skis is related to the velocity and terrain (Sandbakk & Tønnessen, 2012).

Figure 5 Shows sequence of double pole technique "V2" (velocity 2). Photo down to the right illustrate the ideal weight transfer with nose, knee and ankle in the same position. Photo 12.04.2019 from https://www.trening.no/utholdenhet/laer-deg-effektiv-skoyting/

Figure 6 Photo to the left: Finn Hågen Krogh skiing V1 Offset in uphill, photo 10.04.2019 from https://www.ski-tv.no/langrennsteknikk-ep-1-padling Photo to the left Eirik Brandsdal illustrating V1 photo 10.4.2019 from https://www.trening.no/utholdenhet/laer-deg-effektiv-skoyting/

2.13.1.1 Downhill and Turn Techniques

Two different strategies are used in downhill terrain: either the athlete wants to ski as fast as possible or to rest. Sandbakk and Tønnessen (2012) write how "the skier should have a low speed position with elbows ahead of the knees, hands against the face, poles close to the body and gaze forward. The body weight must be balanced on the entire foot – possibly with a slight weight at high speed. The skis must be flat against the snow to reduce friction" (Sandbakk & Tønnessen, 2012, p. 171). On the other hand, if you want to use the downhill's to rest, a higher position and straight legs has to be used.

Figure 7 Marit Bjørgen and Heidi Weng in lead skiing downhill WC Seefeld January 2018, photo from [*https://www.tronderbladet.no/sport/2018/01/30/Langrenn-er-TV-favoritten-foran-OL-15992150.ece*](https://www.tronderbladet.no/sport/2018/01/30/Langrenn-er-TV-favoritten-foran-OL-15992150.ece)

Figure 8 Downhill technique "hockey" with aerodynamic position. Photo 10.3.2019, from https://stellamagasinet.no/treningsvideoer/skiteknikk-pa-langrenn.

Skiing technique in turns can divide into two phases: the first phase when the skier is going into the turn, and the second, acceleration phase. The "input" phase is about adjusting the lines and the speed. The acceleration phase is about creating high speed so when skiing put of the turn, the speed is as high as possible. We vary between four turn techniques; ploughing, skidding, tramp turn, and skate turn (Sandbakk & Tønnessen, 2012).

2.14 Tactical Demands

> *"Although cross-country-skiing races can last from 12 minutes (4 races of 3 min in sprint skiing) to over 2 hours (in a 50-km race), 10 of the 12 Olympic competitions involve mass starts, where tactics are more important than previously and the outcome is often decided in the final sprint" (Sandbakk & Holmberg, 2014, pp. 117,118).*

Tactic is defined as "the pattern of action ones follows in different situations to achieve the best possible result" (Giske, 2015, p. 532; idrettsforbund, 1979). We differentiate between individual tactic and team strategies, where individual tactic is about what the athlete chooses to do and what kind of strategy he or her will use. Team strategies are what the group decide to do of tactical choices. The order of athlete in relay competition is a kind of team tactic (Giske, 2015).

Even though XC skiing is an individual sport, team strategies are used in mass start competitions (de Koning et al., 1999; Stickland, Jones, Haykowsky, & Petersen, 2004). This XC skiing competition was individual start, which exclude the team strategies and tactics. "The athlete fight against every chronometer and the pacing strategy during the competition plays an important role for the best performance" (de Koning et al., 1999; Formenti et al., 2015, p. 128; Stickland et al., 2004).

It can be different kind of tactical dispositions in individual start. For long races as 30 km and 50 km we sometime see that there are groups of two to 5 skiers going together for many km. Lying behind another skier is beneficial because the speed can be quite high, and you can save energy not being in front of a group.

Before the mass start competition arrived, tactic didn't have the same influence on a race as it has nowadays. Today, mass start competition can lead to rivalry between nations and teams (Sandbakk & Tønnessen, 2012). Visualization is one of the skills being devoted more and more attention to within the sport psychology, and is also a way of preparing yourself for the upcoming training or competition (Cumming & Ramsey, 2009; A. M Pensgaard, 2015). The mental training part may be as important as the physiological training. To master tactical and strategically choices, concentration and stress management are those skills which is strongly represented is mental training (A. M Pensgaard, 2015).

2.15 Modern Cross-Country Skiing (XCS): Individual Changes in The Skier

Development in the competition form XCS has grown comparable to the athletes who are performing in this sport. Skiers are now stronger than before, with better endurance (Stöggl et al., 2018). Today, more specific training, more strength training on upper body and core, as well as endurance training, seem to have an effect on performance through increased work economy and upper body power (Hoff, Helgerud, & Wisløff, 1999; Vandbakk et al., 2017; Welde, Evertsen, Von Heimburg, & Medo, 2003).

Over time, the lumberjack became a full-time XC skier, and the athletes started to receive bonus money, which made is possible to have full focus on the sport. Ultimately, the sport professionalized, resulting in money and prestige in an emerging industry and a profession. Several athletes were dependent on the occupational success of being an elite athlete in sports. The prosperity increased in Norway, which reflected into the sport (Gotaas, 2013; NRK, 2009a).

During the 19th century, a lot of senior age athletes have moved away from home to get closer to better snow conditions and more important competitions. The increased mobility, and several cross-country schools gave the chance to have competent coaches and stable snow conditions in junior age. Moreover, it led to several good training environments (Sandbakk & Tønnessen, 2012).

2.16 Specificity

For improving performance involves a considerable investment of time and training. As one of the ground principles to achieve development within your sport, specificity is a vital key to reach an expert level. Depending on the athlete's skill level and training experience, different methods are used to achieve specificity. To reach an expert level, training situations as similar to the competition is demanding for development (Hallén & Ronglan, 2013). This specificity can be trained either in intensity, pace or terrain, depending on the sport and its requirements (Frøyd, Madsen, Tønnessen, Wisnes, & Aasen, 2005)

Norwegian XC skiers from the 18th century were mostly hardworking loggers from the villages. Some of them would actually ski several km to the competition that was starting the day after (Gotaas, 2013). They trained about 40-50 hours a week, skiing to the timber forest, to get groceries and visiting neighbors (Sandbakk & Tønnessen, 2012).

The roller skis was developed in 1960 in Trusetal, in Germany (NRK, 2009a). Oddvar Brå says in the documentary that he experienced a distinction in 1970. At this point the roller skis got introduced to Norway, which attributed to a more specific training among the athletes. The elite skiers, both in Norway and Central Europe, began to go XCS during the summer and fall. The snowmobile came and drove tracks for skiing. This made the topography firmer and better, and required a more modern XCS technique (Sandbakk & Tønnessen, 2012)

Finland and Sweden had a different vision and regime of systematic training. The Norwegians were negative against this and didn't share the same culture. Berit Aunli remembers what her dad said about training during 1940's: "no one could see him training, because of his work and job. So he had to get up early every morning, before everybody else, and exercise where no one could see him" (NRK, 2009b).

Training was became more specific in the way to organize your training and distinguish from low and high intensity training. From the 1970's and later, elite athletes were training up to 150 hours a month. Myths about how an XC-skier should train were many and confusing. Some said you should train as hard as you can, others meant you should not feel fatigue during or after a workout (Sandbakk & Tønnessen, 2012). With the development in specificity, the concept of recovery also bloomed.

2.17 Pacing

"Pacing is defined as time per distance, usually minutes per kilometer or mile" (Edwards & Polman, 2012; Nikolaidis & Knechtle, 2017, p. 1)

In long distance XCS, the average speed for men is measured at 20-25 km/h in free technique; with variations in speed from 8 to 50 km/h. Women achieve about 10-15% poorer paces than men. These disciplines are prolonged endurance work in varied terrain. The athletes must master climbs and uphill, flat terrain, downhill slopes and turns. They must also alternate effectively between these terrains. The skiers use different techniques in different terrain and snow conditions, and these techniques make different demands on the use of legs and upper body (Sandbakk & Tønnessen, 2012).

The changes in speed during a race and competition show how pacing influence the performance (Carlsson, Assarsson, et al., 2016; Losnegard et al., 2017). In addition to pacing, biomechanical (Komi & Norman, 1987; R. Norman, Linnamo, & Komi, 2010) and physiological aspects seem to relate in XCS(Hebert-Loiser, Zinner, Platt, Stöggl, & Holmberg, 2017), though this study report to sprint skiing performance, not long distance XCS.

Formenti et al. (2015) simulated a 10 km long XCS race in free technique, with eleven skiers. With a laboratory test performed on a treadmill running, they verified the athlete's aerobic threshold, intensity zones and measured their VO_{2max}. With these results they could establish the reference to maximum heart rate (HR_{max}).

The trial course consisted of four identical laps of 2439 m long. The total length was 9756 m. They found skiers decreased their velocity in the second and third laps compared to the first lap; in the fourth lap they increased velocity slightly. The average of completed race was 25 min 47 sec. Using 1-way ANOVA they observed a progressive increase in intensity. The skiers adapted to a reverse J-shaped pacing strategy (Abbiss & Laursen, 2008; Formenti et al., 2015).

When comparing O_2-demand with pacing strategies in XCS, XC-skiers practise a variable pacing strategy in flat and uphill terrain (Karlsson, 2017). Concerning the athletes O_2 uptake, among other factors, this depends on the athlete's ability to create energy. Since this energy is limited, the athlete needs to realistically distribute their workload during the race (Carlsson, Assarsson, et al., 2016).

Several of the Olympic games are classified as "head-to-head" competitions, meaning that the other participants influence their pacing strategy; the individual time-trial is to "race against the clock" and the skiers ability to distribute their pacing strategy can have a significant impact on their performance (Abbiss & Laursen, 2008; Foster, Shrager, Snyder, & Thompson, 1994; Roelands, de Koning, Foster, F, & Meeusen, 2013; Tucker, Lambert, & Noakes, 2006).

Losnegard et al. (2017) “an analysis of the pacing strategies adopted by elite XC skiers shows that for the 40 top finishers both sexes demonstrate a positive pacing strategy, with a decline in velocity. The men in the non-elite group tended to have a quick start comparing their average velocity, and a greater decrease throughout the race.

2.17.1 Regulation of Pacing

When training its up to you to decide what kind of intensity the workload is at.

> *”During self-paced exercise, the exercise work rate is regulated by the brain base on the integration of numerous signals from various physiological systems. It has been proposed that the brain regulated the degree of muscle activation and thus exercise intensity specifically to prevent harmful physiological disturbances” (Tucker, 2009, p. 392).*

The rating of perceived exertion (RPE) describes how the pacing to the athlete is regulated. Tucker (2009) presented the model of “anticipatory feedback”, which includes factors for the athlete’s performance. The RPE involves feedback components, which firstly depends on the athlete’s expectation of the exercise duration. This gives a certain indicator of what pace and work rate that is reasonable to start witch, and increase the RPE. During the exercise our system receives physiological signs, which will give you a sub consciousness feeling of work output. The system is linked up against each other, which means that the pacing strategy can be adjusted to prevent catastrophic changes in the physiological variables like pace and velocity.

2.17.2 The Anticipatory Component

In competition, the main goal for any athlete is to achieve an optimal performance. Tucker (2009) uses the theoretical construction “template”. The template is how the physiological system rapidly gets information of the conscious RPE during exercise, to prevent early termination. So that the conscious RPE will not increase during exercise. Figure below is a schematic diagram modified by Karlsson (2017) inspired from Tucker (2009). The model for an anticipatory system that regulates the performance using the rating of RPE, perceives exertion.

> *"The anticipatory regulation of exercise performance during self-paced exercise. The conscious RPE is continuously matched to the template RPE in the context of the remaining exercise duration. Work rate and RPE may be adjusted in order to match the conscious and the anticipated RPE. The templet RPE and the initial work rate are determined based on previous experience and physiological and psychological status of the skier at the start of the exercise bout. Black arrows denote input to the brain, grey lines demote output from the brain and stapled arrows denote the anticipatory components" (Karlsson, 2017, p. 4; Tucker, 2009), (Figure 4).*

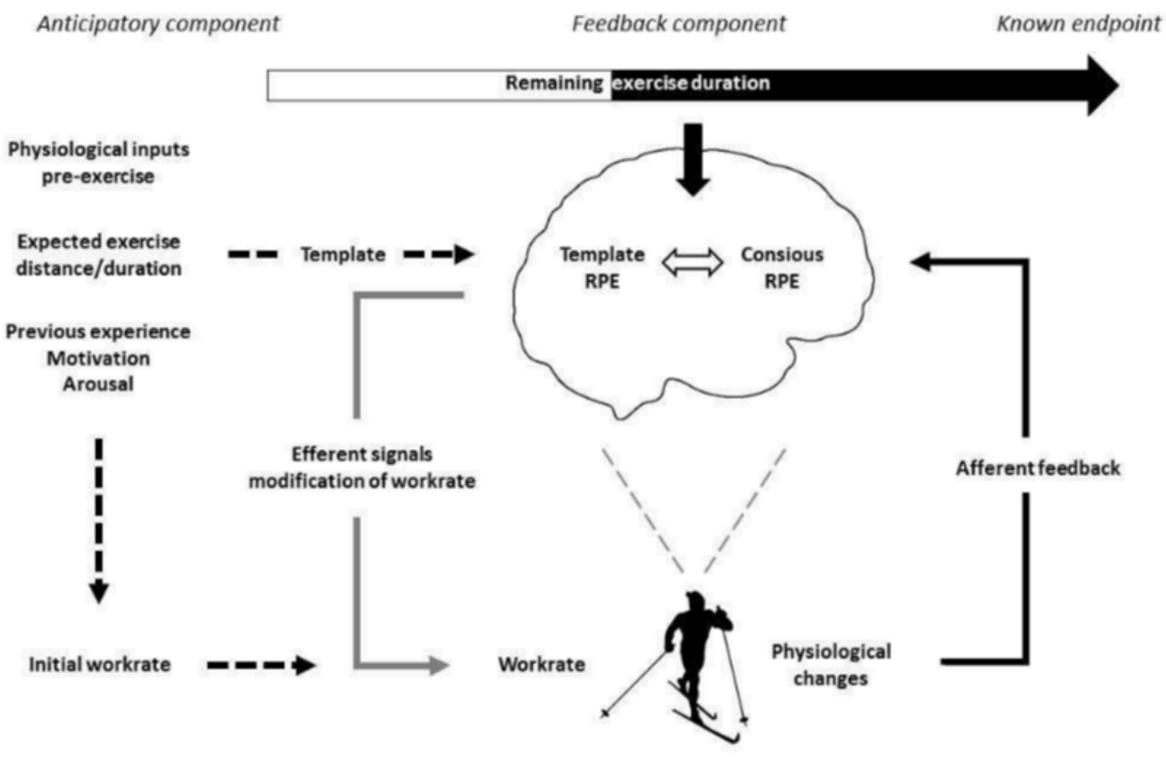

Figure 9 The anticipatory and feedback component

2.17.3 The Feedback and Regulation of Intensity

RPE, Rated Perceived Exertion, is the intensity in the workout. Throughout a workout or a race, the skier will have a conscious perception of the intensity. Our various physiological systems send out afferent information, for example body and skin temperature, metabolite storages levels, arterial oxygen saturation levels, respiratory rate, HR and mechanical afferents (Figure 1).

Mental and physiological factors strongly influence the conscious RPE when it comes to afferent feedback. Difference between the "template" RPE and "conscious" RPE, is that the "conscious" RPE can be affected by verbally use during exercise (Tucker, 2009).

During the workload the "conscious" RPE goes over to the "template" RPE. Which means that the physiological changes don't increase or decrease excessively, and causes premature exhaustion or poorer performance.

2.18 Pacing Strategy

Foster, de Koning, and Hettinga F (2004); Foster, Hoyos, Earnest, and Lucia (2005); GJ, JJ, and G (1992); Marino (2004); Tucker, Marl, and Lambert (2006), are all sports scientist who have attempt to understand how work of energy expenditure is distributed during an exercise task. This work of energy during an exercise has been termed "pacing" or "pacing strategy".

Abbiss and Laursen (2008) have suggested "that several factors can affect the optimal distribution of work: the duration and the importance of the race, the course geography, the environmental conditions, and the specific activity being performed" (Formenti et al., 2015, p. 127).

For long distance races, like 30 km and 50 km XCS race, no studies have found that a faster start would attribute to a faster finish time. In fact, a faster start for longer races could negatively affect your performance (A. Jones, 2007). Mattern, Kenefick, Kertzer, and Quinn (2001) study of a 20-km cycle trial, found that a fast start would accumulate blood lactate, and again affect the race performance. When it comes to shorter competitions and races, earlier investigations suggest an even pacing strategy or a fast start, to a faster finish time (Foster et al., 1994; Foster et al., 1993).

Abbiss and Laursen (2008) have acknowledged six fundamental pacing strategies: 1) negative pacing (increase in speed over time); 2) all-out pacing (maximal speed possible); 3) positive pacing (continuous slowing over time); 4) even pacing (same speed over time); 5) parabolic-shaped pacing (positive and negative pacing in different segments/terrain of the race); 6) and variable pacing (pacing with multiple fluctuations). Their definition of generally pacing strategy is to "regulate their velocity in order to reach the endpoint of the race in the fastest possible time", and has a considerable effect on performance in all kinds of endurance sports (Abbiss & Laursen, 2008; Joseph, Johnson, & Battista, 2008; St Clair Gibson, EJ, & TD, 2001, p. 2).

Positive pacing strategy is investigated in cross-country skiing by Andersson, Holmberg, Ortenblad, and Bjorklund (2016); Bolger et al. (2015); Formenti et al. (2015); Losnegard et al. (2017) presented in Table 2.

2.18.1 Pacing Strategy in Cross-Country Skiing

When it comes to pacing strategy in cross-country skiing, the master thesis of Karlsson (2017) has represented a table of applied pacing strategies. The table shows an overview of literature on pacing strategy in XC skiing.

Table 2 Literature overview of pacing strategy in XC skiing by Karlsson (2017).

Study	Subjects	Level	Distance	Method	Measure	Pacing strategy
Bilodeau et al. (1996)	34/27	National	30/50	LtL	avg. speed	POS
Larsson and Henriksson-Larsen (2005)	10	Elite Jr.	5.6 km	LtL	avg. speed	POS
Andersson et al. (2010)	9	Elite	1425 m	LtL	avg. speed	POS
Sundstrom et al. (2013)	-	-	1425 m	SIM	power	VAR
Bolger et al. (2015)	9	Elite	15/10 km	LtL	avg. speed	POS
Formenti et al. (2015)	11	National	10 km	LtL	avg. speed	POS/PAR
Andersson et al. (2016)	10	well-trained	1300 m	LtL,TM	time	POS
Losnegard et al. (2017)	22*	Elite	15 km	LtL	avg. speed	POS

*: number of races
LtL = lap-to-lap comparrison; **TM** = tread mill **SIM** = computer simulation; **POS** = positive; **VAR** = variable; **PAR** = parabolic

2.19 Sex Differences in Pacing Strategy

The physiological difference between male and female is generally accepted. And this can attribute to generate a variance in performance capability in endurance sports (Carlsson, Carlsson, et al., 2016). For example, Steffensen, Roepstorff, Madsen, and Kiens (2002) found that both untrained and endurance-trained women had a greater proportional area of the more fatigue resistance type 1 fibre. This may be advantageous for long-duration endurance performance such as a 30 km long competition.

Another difference between the sexes is that women who are exercising at different intensities have higher rates of fat oxidation, and a later shift to the use of carbohydrates as the dominant source of energy (Horton, Pagliassotti, Hobbs, & Hill, 1998; Roepstorff et al., 2006; Venables, Achten, & Jeukendrup, 2005). The reason why men have a higher maximal oxygen uptake (VO^2max) than women (Wernstedt et al., 2002), may be physiological influence of the males larger left ventricular mass and stroke volume (Hutchinson, Cureton, Outz, & Wilson, 1991; Wernstedt et al., 2002), and higher haemoglobin content (Morkeberg, Saltin, Belhage, & Damsgaard, 2009). Elite male skiers also have a higher lean mass and a lower fat mass than females (Carlsson, Carlsson, Hammarstöm, Malm, & Tonkonogi, 2014; Sandbakk, Ettema, Leirdal, & Holmberg, 2012). Sex difference in performance, where the men perform faster than women, have been observed (Bolger et al., 2015), which has been attributed mostly to the higher VO_2max and lower body fat in men compared to women (Nikolaidis & Knechtle, 2017; Sandbakk et al., 2012).

Studies on sex differences in endurance sports such as (long distance) XCS are various. There are several studies on marathon and long distance running (Hoffman, 2014; Knetchle et al., 2015; Lambert, Dugas, Kirkman, Mokone, & Waldeck, 2004). In long distance running (marathon) some evidence suggests that females have physiologic advantages over men in maintaining an even pace strategy. Specifically, women compared with equally trained men have a lower respiratory exchange ratio (RER) during endurance exercise, suggesting that women use proportionately more fat and less carbohydrate at a given relative intensity. Such a glycogen-sparing effect could delay the onset of glycogen (Spencer, Losnegard, Hallén, & Hopkins, 2014).

This can be relatable to a certain extent, since both sports are endurance sports. There’s also research on sex, nationality and pacing strategy:

Pantelis T Nikolaidis and Beat Knechtle (2018) present the effect of nationality on pacing strategies on XC skiers finished the Swedish race “Vasaloppet”, from 2004-2017. With a total of 183,919 finishers and 15 nationalities, women and men from Russia were the fastest, and women and men from Denmark were the slowest. They noticed that Russian XC skiers presented a more even pacing strategy compared to their slower counterparts. The nationalities with the fastest finishing time had a more even pacing strategy.

Losnegard et al. (2017) studied the most successful male and female XC skiers in World Cup, World Championship and Olympic events. Competing in 10 km and 15 km races classic and free technique, with interval start. The results shown that both sexes demonstrated a positive pacing strategy pattern. Where the velocity declined from the first to the last lap. No group differences in pacing strategy were found. For the men, slower skiers were characterized by a quick start relative to their average velocity, with a greater decrease during the race compared with the faster skiers (Losnegard et al., 2017).

Pacing strategy in long distance XCS, such as Engadin Ski Marathon (42 km) free technique, found sex differences in pacing. The result was showing that women had a less even pacing than men. Women under 20 years had a smaller decrease in velocity, than older women. They concluded with younger and male XC-skiers had a more even pacing than women and older XC-skiers (Pantelis T Nikolaidis & B Knechtle, 2018). When studying the influence of sex, age and finishing time in long distance running, like marathon, opposite findings are made from XCS. March et al. (2011) found that "older, women, and faster are better pacers than younger, men, and slower marathoners, respectively" (March et al., 2011, p. 386).

When investigating sex, age and race experience and its influence on pacing strategy, older subjects in age 40-59 years ski faster than young subjects 19-39 years old (Carlsson, Assarsson, et al., 2016). The male skiers had a faster sectional pacing in the second, third, fourth and from section one to four. Where as female skiers skied faster in section six, seven, eight, and from section five to section eight. The female skiers actually had a more even pacing strategy than male skiers. Experience also influence the pacing strategy positive (Carlsson, Assarsson, et al., 2016).

2.20 Research Questions

A study looking at female and male cross-country skiers at different performance level and how the track topography may influence their pacing strategy.

The aim of the present study was to investigate individual time trial based on average lap times and in different terrain in a long distance XC skiing competition. Further, we wanted to use these data to describe the pacing strategies adopted by female elite and non-elite group, and male elite and non-elite group.

2.21 Hypothesis

Based on former studies about pacing strategy, I have settled with four hypotheses.

Hypothesis 1 –Pacing strategy lap times

Overall, both groups of female and male XC skiers will have a positive pacing strategy throughout the race. Elite skiers will still have a positive split, but with a more even development than the non-elite skiers. Non-elite skiers will have a greater difference in average time comparing the laps

Hypothesis 2 Uphill Terrain

The laps in uphill terrain may tell us more about the athletes pacing strategy than lap times and downhill terrain. Both groups will most likely adapt positive pacing strategy in uphill terrain laps. Elite group will have a more even development in the race, compared to the non-elite group.

Hypothesis 3 Downhill Terrain

Both groups of male and female will perform a positive pacing strategy in downhill terrain. Though, because of their difference in their performance level, female and male elite skiers will have a less difference in average lap time.

Hypothesis 4 Sex Differences in Pacing Strategy Every 10 km lap

Both female and male elite and non-elite skiers, will adapt a positive pacing strategy. There will be a larger difference in the development of the race in male group compared with female group, because of the distance difference.

3 Method

The aim of this study is to investigate pacing strategy among Norwegian female and male XC skiers, at different levels (elite group and non-elite group). Hypothesized that lap times from every 10th km, split times from 200 m uphill terrain (% of height or how steep), and split times from 400 m downhill terrain (% of height or how steep), will influence their performance and pacing strategy.

3.1 Scientific Point of View – Epistemology

Generally, quantitative research is "*supported by the positivist or scientific paradigm, leads us to regard the world as made up of observable, measurable facts*" (Glesne & Peshkin, 1992, p. 6). With a positivistic approach, this study is based on natural science, which studies the physical things and phenomena (Jacobsen, 2016). Within an epistemology philosophy, a positivistic, deductive approach will be appropriate. With a deductive approach, there has already been created some expectations about how reality looks like. And then go out and collect empirical evidence to see if expectations match reality. These expectations basis on previous findings, studies, and theories (Jacobsen, 2016).

Furthermore quantitative measurements are performed to test hypothetical generalizations (Hoepfl, 1997). The hypothesis are based on previous studies, which leads hypothetical deductive method in this study (Kvarv, 2010). Quantitative studies also emphasize the measurement and analysis of casual relationship between variables (Denzin & Lincoln, 1998).

Its meaning of use (quantitative research) is to explain social problems, like (Bogdan & Biklen, 1998, p. 4) have written:

> *Charts and graphs illustrate the result of the research, and commentators employ words such as "variables", "population" and "result" as part of their daily vocabulary…even if we do not always know just what ass of the terms mean…(but) we know that this is part of the process of doing research. Research, then as it comes to be known publicly, is a synonym for quantitative research.*

The purpose/aim of this study was to generate four hypotheses to be tested. In this paradigm there are four steps. (1) The emphasis is on facts and causes of behaviour (Bogdan & Biklen, 1998; Golafshani, 2003), (2) the information is in the form of numbers that can be quantified and summarized, (3) the mathematical process is the norm for analysing the numeric data and (4) the final result is expressed in statistical terminologies (Charles, 1995).

3.1.1 Subjects

Table 3 shows division in men and female athlete level

Sex/group	National Team	Recruit Team	Regional Team	Local Team
Men EG	4	1	8	11
Men NON-E				25
Female EG	6	4	9	6
Female NON-E			1	24

50 female and 50 male XC skiers participated in the study. The skiers are picked out of the result list from the national championship in Alta. In this championship the women were skiing 30 km skate technique, while the men competed in 50 km skate. In both competitions, the skiers were doing the same lap of 10 km.

4 of the male and 6 of the female XC skiers are national team practitioners who are followed up by NSF (Norwegian XCS team). That means that they are professional and full-time XC-skiers. Other athletes belong to either national recruit teams (female 4, male 1), regional affiliation (8 male EG, female 9 EG and 1 NOE) (Team Veidekke Nord-Norge, Midt-Norge, Innlandet, Oslofjorden and Vest) which is more semi-professional performers (semi-pro) (Langrenn). The remaining athletes are in regional teams (RGT) (female EG 6, female NOE 24, male EG 11 and male NOE 25). The elite group in both male and female is assumed to have a total of 750 to 950 hours annual training (Sandbakk & Holmberg, 2017).

The majority of the regional team athletes are from Team Veidekke Midt-Norge, with a total of 5 XC skiers. This is the county of Nord-Trøndelag, Sør-Trøndelag and Møre og Romsdal. Seconds and third most athletes come from Team Veidekke Innlandet and Team Veidekke Oslofjord.

All the skiers are active athlete, either on national level/teams or regional teams in the season 2017/2018. Further, both women and male skiers were divided into two level groups. 50 male athletes are separated in two groups of 25 skiers, one in an “elite” group (MEG), and one in “non-elite” group (MNEG). The 50 female athletes are one “elite” group (FEG) consisting of 25 skiers and one “non-elite” group with same amount of athletes. The 25 in elite group for both female and male, are the 25 first on the result list, with around 10 min difference from nr.1 to nr.25. The same for the 25 in non-elite group

In order to define elite and non-elite group, the first 25 finishers in female and male class were picked out. In female class the next 25 were placed in non-elite, because of only 52 skiers in total. In men’s class, there were totally 133 competitors. The first 25 skiers were elite level skiers. While number 96-120 were picked out for the non-elite group. The non-elite group were picked out based on their final results. If they were less than 10 minutes after the elite level skiers they were within the criteria.

3.2 General Design

The study is based on two separate competitions at the same day. The female competition covering the distance of 30 km and the starting point was at 11:30 am. The male competition had the distance of 50 km and the starting point was 13:30 pm. Both female and male skiers used free technique, XCS. Competition one and two both performed in the same 10 km long trial. The skiers performed either 3 or 5 identical laps of 10 km. Individual time trial from every 10 km were used to estimate their pacing strategy during their race (from 1-6 at Figure 10). Individual time trial from 2 to 3 going uphill and time trial from 4 to 5 skiing downhill were used to estimate their pacing strategy (see Figure 10).

The study was done April 7th 2018, which considered as one of the last races-phase of the XC season 2017/2018. To investigate their pacing strategy, average time used on every 10th km lap, uphill and downhill are analysed and measured. Performance level group are compared in both female and male. Since there is a difference in race distance female and male, no analysis are done to measure difference between sexes.

3.3 Time Trial

The competition was carried out in Alta, Norway, on the same day. The 30 km free technique for women started 11:30 am. 50 km free technique for men started 13:30 pm. The competition was interval start, which will say that the first skiers started every 30 seconds. The course profile is stated after FIS declaration with one-third flat, one third uphill and one-third downhill.

3.3.1 Track Topography

The start of the race takes place at the stadium, 58 meters above sea level (MASL). Figure 10 shows the 10 km course profile and altitude changes. Female skiers completed 3 identical laps (10 km) with a total length of 30 km. Male skiers completed 5 identical laps (10 km) with a total length of 50 km. Prior to the time trial the skiers may have performed individual warm up, most likely, but this is not taken into consideration and measured.

Lap times from passing every 10th km are measured for both male and females. For female skiers, 3 identical laps of 10 km are registered every time passing the stadium. For male skiers 5 identical laps of 10 km are measured. From 0-10 km, 10-20 km, 20-30 km, 30-40 km, and 40-50 km are measured. The course fulfills FIS requirements of a track consisting of one-third flat, one-third uphill and one-third downhill. This is confirmed by the leader and responsible for the track and course, Per Erik Bjørnstad.

Table 4 shows clipart of the certificate of FIS homologated XC course from the FIS XC committee showing course length, height difference, maximum climb, total climb, lowest and highest point. Given in metres

Course length:	10,145m	Height difference (HD):	106m	Lowest point:	37m
Course category:		Maximum climb (MC):	73m	Highest point:	143m
		Total climb (TC):	340m		

Figure 10 shows the topography of the trial, from 0m - 10 000m. Both female and male complete the trial 3 or 5 times. Numbers from 1-6 identify the distance of lap times, uphill and downhill. The X-axis is distance in meters, and Y-axis is elevation MASL. Number 1-6 (0m – 10 000m, and a total elevation of 340 m, is the distance used of measuring lap times. From number 2(110 MASL) to 3(120 MASL) (7000m-7200m) is distance in uphill terrain. From point 4(140 MASL) to point 5(60 MASL) (7550m-9100m) is distance of measured downhill terrain.

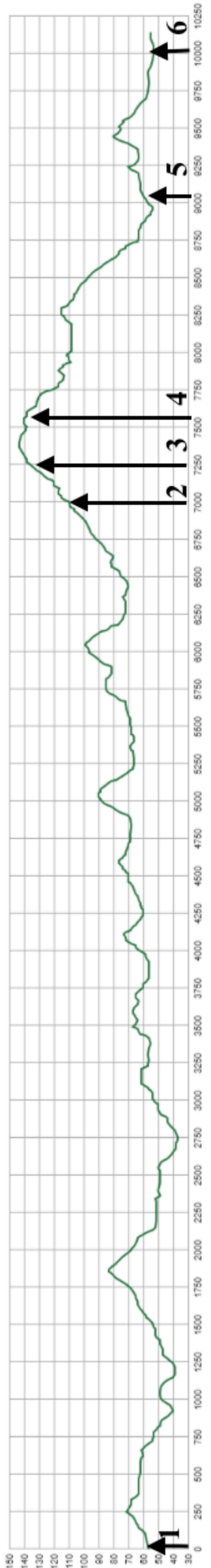

Figure 10 Shows the topography of the trail from 0-10 km.

From 7.690 km (138 meters above sea level) to 9.150km (61 meters above sea level), with a total decline of 77 meters, section time was measured every lap completed, to correspond changes in pacing strategy in skiing downhill. The downhill distance is marked from number 4 to number 5 in figure 10. The decline of elevation makes parts of the course steep downhill, as well as it has a significant turn at the end. Skiing downhill will include using different techniques and adjustment of speed, accelerating and turns (Sandbakk & Tønnessen, 2012).

Figure 6, marked from 2-3 is the distance of uphill skiing. From 7.00 km (around 110 meters above sea level) to 7.20 km (around 140 meters above sea level) section times was taken every lap completed, to correspond changes in pacing strategy skiing in uphill terrain, a total elevation of 30 metres. This measurement is done almost halfway of the total length of the uphill course (going from 6500m-7300m).

3.4 Equipment

aQ-timing was the responsible provider for timing system during the national championship (EQTIMING). They use a split time station called Emit Time Station ETS1, which replace the traditional clock and record the time when the emiTag pieces pass the eLine loop (s), internal or external. The chip ID and time are sent from the pieces back to ETS1 via the internal radio antenna. The data is stored locally before being forwarded to a computer/PC via USB, RS-232 or RS-485.

This system can be used in several sports, both in training and competition. Today ETS1 is actively used in sports like XCS, biathlon, cycling (on road, off-road, tempo, track), and triathlon, orienteering and cross-country orienteering (Emit).

Figure 11 Photo of Emit Time Station ETS1 and ETS1 in use in the right photo

3.5 Data Sampling and Statistical Analysis

Data was collected from the official race website https://www.eqtiming.no. Initially 185 finishers considered. I excluded the cases (n=85) with skiers having more than 10 minutes split from the best skier in their group (elite or non-elite), which resulted in the final inclusion of 100 finishers (50 women and 50 men). Data were first registered in EQ timing, https://www.eqtiming.no/quick/index.php?page=eqtevent&eventuid=42353&search=30+NM+alta&sport=2-138-277-258-267-377&focusuid=. All the data were later transferred into Microsoft Office Excel for Mac 2011. Times excluding from lap times, uphill and downhill was eliminated. All times were then calculated to one unit, seconds.

Firstly there's done a descriptive analysis. "The descriptive statistics include simple analyzes that gives us basic information about the variables that are studied" (Tjønndal, 2018, p. 49). The table contains average and standard deviation of every lap from each level group.

Data are presented as mean ± standard deviation (SD), unless otherwise was stated. Independent t-test (two tailed) was used to determine whether there was statistically significant difference between average time on 10km lap and laps of uphill and downhill terrain during the competitions between two groups. Significant difference at 1% and p-value $p < 0.01$, which is more strict than $p < 0.05$

The statistical analyses were performed in SPSS Statistics (IBM Corporation, Amonk, USA). STATA (version 15.1) was used to analyze d (known as Cohen's d). This is a common measurement for effect size and the difference is divided by an interpolated standard deviation. Cohen's vary between 0 and 1 and the values of d for small, medium, and large effects, respectively, are 0.2, 0.5, and 0.8 (Cohen, 1988; Rice & Harris, 2005).

3.6 Missing data

There has been an error in the system at the fourth lap of downhill terrain in male group elite and non-elite skiers. No data were registered from 4 to 5 (figure 10). The fourth time passing from 7.690km to 9.150km, passing time is executed.

3.7 Reliability and validity

“Reliability and validity are tools of an essentially positivist epistemology” (Winter, 2000, p. 7). The reliability is embodied with the idea of replicable and/or repeatability of results or observations. Kirk and Miller (1986, pp. 41-42) have identified three different types of reliability when using quantitative research, which relate to (1) the degree to which a measurement, given repeatedly, remains the same (2) the stability of a measurement over time; and (3) the similarity of measurement within a given time period.

“A survey should be a method for collecting empirical data. No matter what kind of empirical data it is, it should satisfy two requirements: empiric must be golden and relevant (valid) and empiric must be reliable and credible (reliable)” (Jacobsen, 2016, p. 16).

How “truthful” the research actually is, is depending on the quality of the study, and how reliability and validity is assessed in it (I. Jones & Gratton, 2015).

3.8 The validity in this study

The concept of validity involves the right method to measure what the researcher wants to measure, a relationship between conclusion and empiric, that again will lead to a valid conclusion (I. Jones & Gratton, 2015). Because of previous research on pacing strategy and XC skiing, I use a similar research problem and methodologies as the ones before me. This way the measurements are a valid way to collect the research (I. Jones & Gratton, 2015).

Benefit with using data from a Norwegian national championship is that there will be competing athletes at both elite level and a lower level (non-elite). Even though, this race was at the end of the competition season and not all of the elite skiers was prioritizing this competition. I also want to know how much the total training amount would have an impact on the skiers pacing strategy and performance.

Systematic measurement errors may create validity problems, and is difficult to avoid. Though, since all data in this study is measured and not answered by questionnaire, the risk of errors is smaller than if the study was qualitative. Then I would have to take social desirability into considerations (Ringdal, 2018)

3.9 The reliability in this study

In this study, data have been measured by digital equipment, not manually or by several individuals/a researcher teams. This will strengthen the reliability in forms of "inter-observer reliability", which ensure that the study doesn't have to take human observations or assigns into consideration (I. Jones & Gratton, 2015). Because of the different performance level, with elite group athletes that have a higher annual training than non-elite athletes, it is most likely to believe that the result would have been the same, if implementing a "test-retest reliability" (I. Jones & Gratton, 2015)..

Because of the split time station Emit Time Station ETS1 (which replace the traditional clock and record the time when the emiTag pieces pass the eLine loop (s) internal or external) it is highly believed that the internal consistency of reliability is measuring the same phenomena (I. Jones & Gratton, 2015).

Because of the circumstances, a national championship, the threats of reliability concerning subject- error and bias are minimal. Other possible errors that can affect the reliability in this thesis are related to the athlete. The athletes' daily condition, energy intake, psychological and physiological factors are some of the errors that has to be taken into consideration.

Research error may occur. For example when manually plotting measurement in Excel, or the stability of measured glide-test (snow conditions). For testing weather- and snow conditions, only one researcher was responsible for the tests. This is to minimize the risk of researcher error, and more vital to believe the same procedure was followed (I. Jones & Gratton, 2015).

3.9.1 Weather conditions and changes in snow condition

During the race day, speed measurement downhill was taken before, at start, midways, and after the race. This makes the study even more valid, seeing the results from the tests and the minimal changes in weather and snow conditions.

Brower Timing System was set up with two sensors in a downhill to measure speed. The sensors had 25 m between them. Start downhill after 5.2 km. Start from 0 m/s, down in hockey. Runs 20 m before the first sensor. Sits stable in hockey from 1st sensor to the 2nd sensor, length of 25 meters, and angles with distances are shown in figure below.

Equipment used: skate skis Rossignol. The test was 2 run and 6 tests downhill, and no use of the skis between the tests.

Lubrication: Glider- Start: FHF 4. Used groove: 0.75V and 1.0H, 2 times. Used 2mm straight groove, from the center to the back of the ski. Speed tests done by Tor Oskar Thomassen.

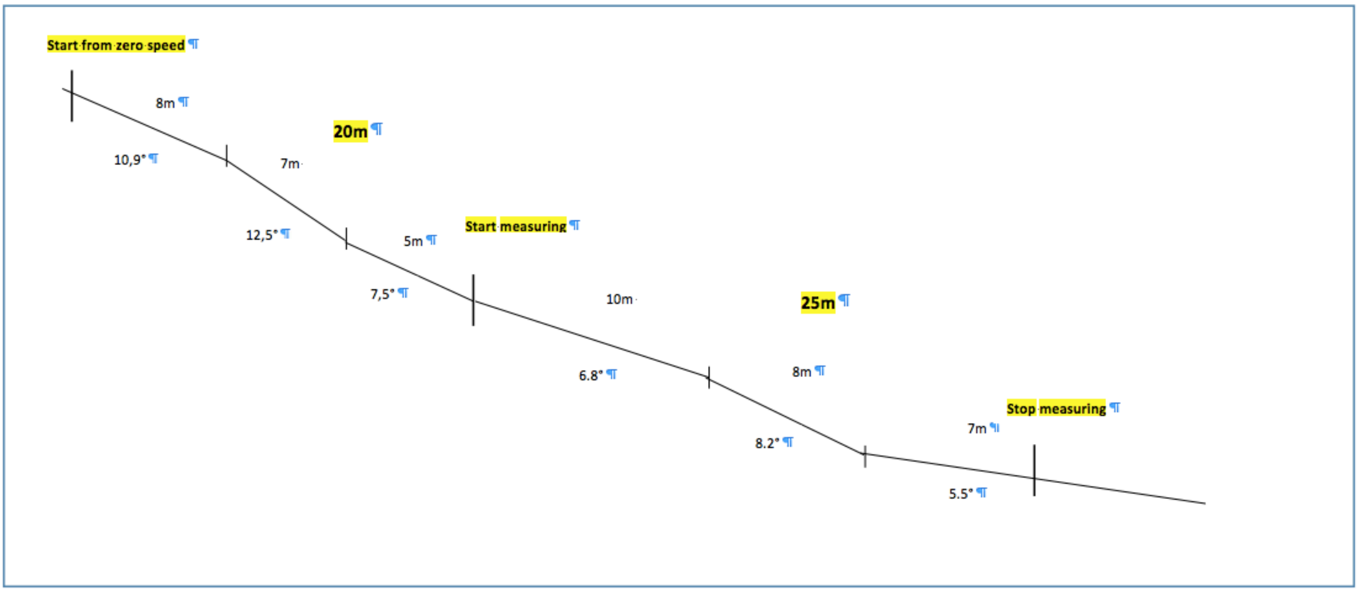

Figure 12 shows sequence of speed measurement and terrain. Degrees of height start and stop point and meters before and between sensors

Air temperature varied between 0 to minus 2 degrees. Weather was partly cloudy and light breeze.

Table 5 shows what time of the day they were measured, average of test 1 and 2, temperature in snow. F = female, M = male

Time	1. Test	2. Test	Average 2 tests	Temperature snow
Time 11.00 – Before F start	2,88	2,85	2,87	Not measured
Time 11.30 – Start F	2,83	2,85	2,84	-3,8
Time 12.50 – Midways F	2,85	2,83	2,84	-3,5
Time 13.30 – After F/before M	2,83	2,84	2,84	-3,2
Time 15.00 – Midway M	2,82	2,84	2,83	-2,8
Time 1700 – After M	2,84	2,84	2,84	-3,0

The athletes are going the same lap 3 or 5 times, which makes it relevant

3.10 Strength and Weaknesses of The Study

Although the points listed above regarding validity and reliability, it is important to discuss both the strengths and weaknesses of this master's thesis.

Strength:

The thesis is based on measured times in different terrain in a Norwegian national championship in XCS. By using performance from a real national championship to investigate something, may bring strengthens into the study. It could get the athlete to find it easier to motivate them selves, when they know it's not a test-race, but a real competition.

The participants are many, which leads to a group of total 100 XC skiers (50 female, 50 male).

A positive and valid strengthens of the study was the stabile weather conditions and snow temperature through the day. With measured air-, and snow temperature test before, during and after 30 km and 50 km race, brings validity in.

Also the well-prepared track was an important factor for the stability in the snow conditions. Even though sunny weather occurred during the competitions, snow and weather conditions stayed stable, look figure 9.

Weaknesses:

Permission was not accepted to use heart rate monitors on some of the athletes during the race. There was only a few volunteers, and only in the non-elite group. With observing the cardiovascular demands by monitoring the heart rate, the thesis could say something about the workload or the intensity the skiers had during the race.

A weakness of the study is that all the skiers have different XC skis, most likely not the same glider and other type of equipment. Even though they're different level skiers, the equipment can differentiate a lot looking at the big picture.

3.11 Ethics

As a researcher it is important, among other things, to reflect and being able to explain how your own values and attitudes can influence the theme, data samples and interpretations. This include respect and duty of care for the subjects, as to ensure professional freedom and the independence of the research (Ringdal, 2018). All information regarding the subjects involved in this study is anonymous and participants have been coded. As well as results from the competition are stored according to the directions required by NSD.

Because of the circumstances in this thesis, where data are measured from a national championship, consent from subjects is not necessary. And because it is a larger group of subjects (Ringdal, 2018).

All subjects have received information and written consent before testing. All participants received written and detailed information about the aim of the study and how the data would be processed. Because the subjects live geographically spread, information wasn't given oral. Furthermore, the study was registered and approved by NSD (Norsk Senter for Forskningsdata, Bergen, Norway).

4 Results

In this part of the thesis, the results of the illustrated research question will be presented. In the first part, individual and graph t-test samples overview for both sexes are presented. In every figure showing graphs (Figure 13, 14, 15, 16, 17, 18) seconds are calculated into minutes and second to easier understand. For example: 1424 seconds = 23:44 min. The 2.tailed independent t-test shows significant difference at 0.0000 for all the tests. This means that all laps and performance level shows consequential results with significant difference, and the p-value is at $p<0.01$, which is strongly in sport studies, where 0.005 is the most common (I. Jones & Gratton, 2015).

4.1 Graph and Independent T-test Female Lap times 30 km

The mean time trial on laps of 10 km for female EG is 1728 seconds (28:05 minutes), and NEG 1931 seconds (32:11) (Table 10). Average lap time elite was 1696 ± 50,4 s, 1738 ± 53,9 s and 1749 ± 63,8. Non-elite skiers 1874 ± 84,4 s, 1944 ± 101,8 s and 1976 ± 129,46 s (Figure 13). There was significant interaction between average lap times x performance level with t-value on -9,07, -8,99 and -7,88 (Table 10, p<0.01). Both groups increase in average lap times and adapt a positive pacing strategy. EG have a more even development in the race than NEG.

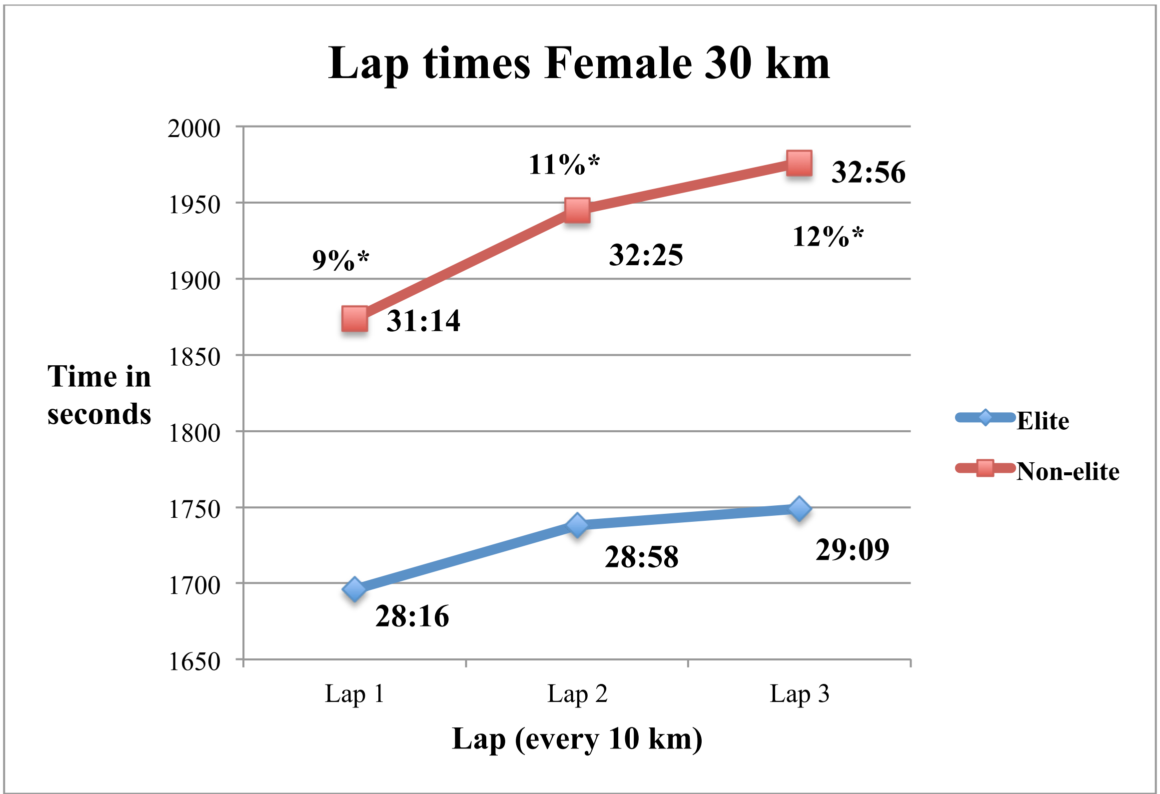

*Figure 13 pacing strategy profiles for elite and non-elite in each lap (mean time). Statistical significance: *p<0.01.*

Table 6 Independent t-test with mean difference ± SD, t-value, degrees of freedom, p>0.01 and Cohen's d

	Elite	Non-elite	Mean Difference	t	df	p	Cohen's d
Lap 1	1696 +/- 50,4	1874,28 +/- 84,4	-178,32	-9,07	48	0,01	-2,56
Lap 2	1738 +/- 53,9	1944,52 +/- 101,8	-207,00	-8,99	48	0,01	-2,54
Lap 3	1749 +/- 63,87	1976,12 +/- 129,46	-227,52	-7,88	48	0,01	- 2,23

4.2 Graph and Independent T-test Female Uphill 30 km

The average time skiing uphill for female EG was 50 seconds and NEG 58 seconds (Table 11) (Figure 14). Average lap times for elite group in uphill terrain were 51 ± 3,07 s, 50 ± 2,38 s and 50 ± 3,02 s. For NEG the average was 57 ± 3,91 s, 58 ± 4,28 and 59 ± 6,0 s. NEG have an even increase in average lap times, and elite skiers decreases in average time from second lap. There is significant difference between lap times in uphill terrain and performance level groups, with t-value on -5,80, -7,81, -6,88 (Table 11) ($p<0.01$). EG stabilizes after second lap and ski 1-second faster second and third lap. Non-elite increases in average time during the race.

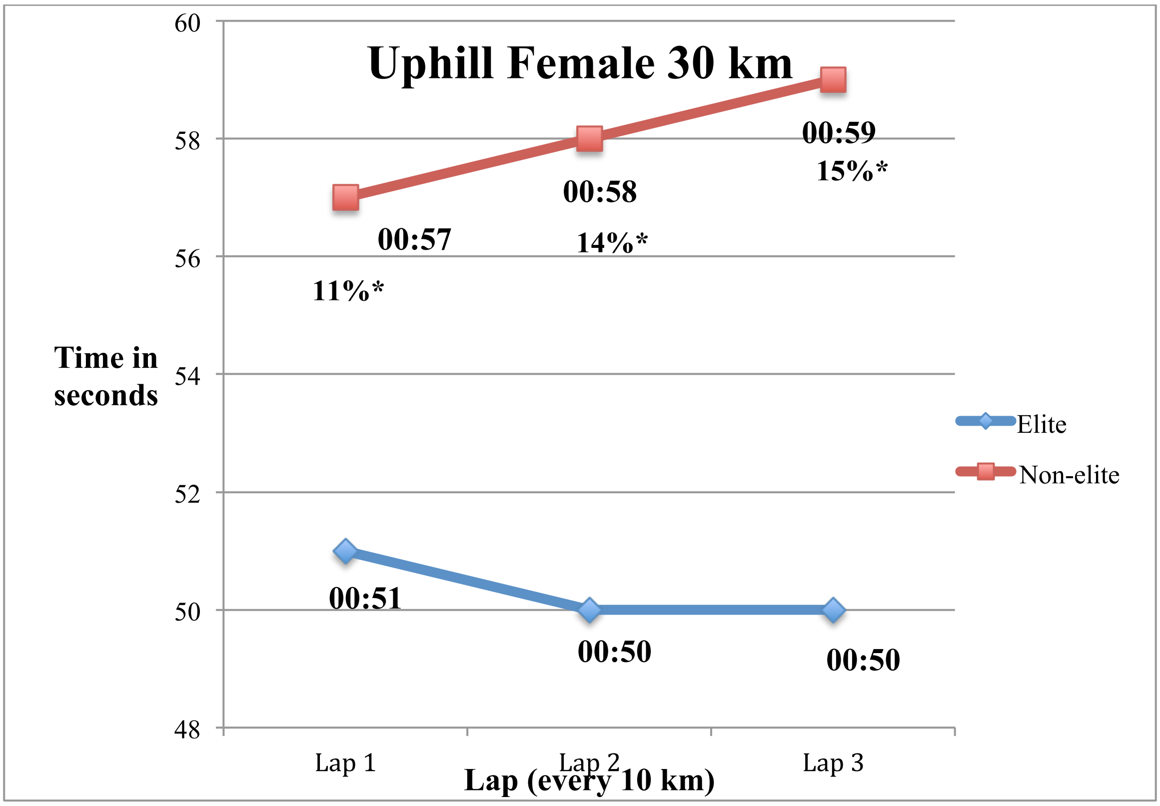

*Figure 14: pacing strategy profiles for elite and non-elite in uphill (mean time). Statistical significance: *p<0.01.*

Table 7 Independent t-test with mean difference ± SD, t-value, degrees of freedom, p>0.01 and Cohen's d

	Elite	Non-elite	Mean Difference	t	df	p	Cohen's d
Lap 1	51 +/- 3,07	57,00 +/- 3,91	-5,76	-5,80	48	0,01	-1,64
Lap 2	50 +/- 2,38	58,28 +/- 4,28	-7,64	-7,81	48	0,01	-2,21
Lap 3	50 +/- 3,02	59,56 +/- 6,0	-9,24	-6,88	48	0,01	-1,94

4.3 Graph and Independent T-test Female Downhill 30 km

The average time skiing downhill for female EG was 156 seconds (02:36 min) and NEG 169 seconds (02:49 min) (Table 12) (Figure 15). Average lap times for EG downhill terrain were 157 ± 4,7 s, 157 ± 5,4 s and 156 ± 4,7 s. For NEG the average was 167 ± 7,1 s, 170 ± 7,8 s and 169 ± 8,5 s. Average time for NEG increased from lap 1 to lap 2, while EG remained at the exact same average time. EG manage to reduce average time in the last lap with one second, while non-elite group increases with one second. This means there's a significant difference between lap times in downhill terrain and performance level groups ($p<0.01$), with t-values of -6,91, -6,73 and -7,2 (Table12). Both groups manage to decrease in average time at the last lap of downhill with one second

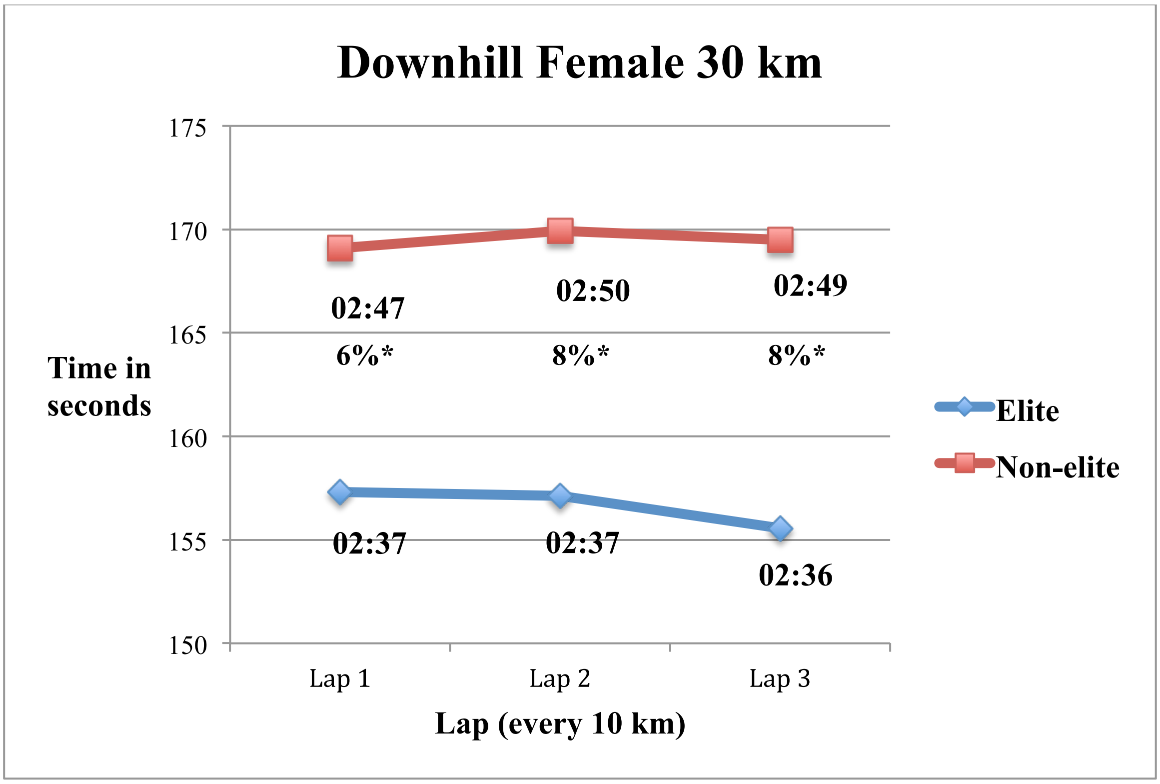

*Figure 15 pacing strategy profiles for elite and non-elite in each lap (mean time). Statistical significance: *p<0.01.*

Table 8 Independent t-test with mean difference ± SD, t-value, degrees of freedom, p>0.01 and Cohen's d

	Elite	Non-elite	Mean Difference	t	df	p	Cohen's d
Lap 1	157 +/- 4,7	167 +/- 7,1	-11,8	-6,91	48	0,01	-2,104
Lap 2	157 +/- 5,4	170 +/- 7,8	-12,8	-6,73	48	0,01	-1,90
Lap 3	156 +/- 4,7	169 +/- 8,5	-13,9	-7,2	48	0,01	-2,04

4.4 Graph and Independent T-test Male Lap times 50 km

The mean time trial on laps of 10 km for male EG is 1570 seconds (26:10 min), and NEG 1814 seconds (30:14 min) (Table 13) (Figure 16). Average lap time in EG was 1506 ± 42,2 s, 1545 ± 30,5 s, 1571 ± 34,4 s, 1596 ± 30,2 s and 1633 ± 41,8 s. NEG 1650 ± 52,1 s, 1687 ± 56,2 s, 1742 ± 54,6 s, 1910 ± 76,4 s and 2088 ± 105,2 s. Percentage difference show a significant decrease in average pacing strategy based on lap times for non-elite males, from a 9% difference at the first lap to 22% difference in the last lap. Comparing average lap times, NEG use 27:30 min on the first lap, while EG still goes 17 seconds faster (27:13) on their last lap. T-values are at -10,7, -11,1, -13,3, -19,1 and -19,9 ($p>0.01$) (table 13), which indicate strong significant difference.

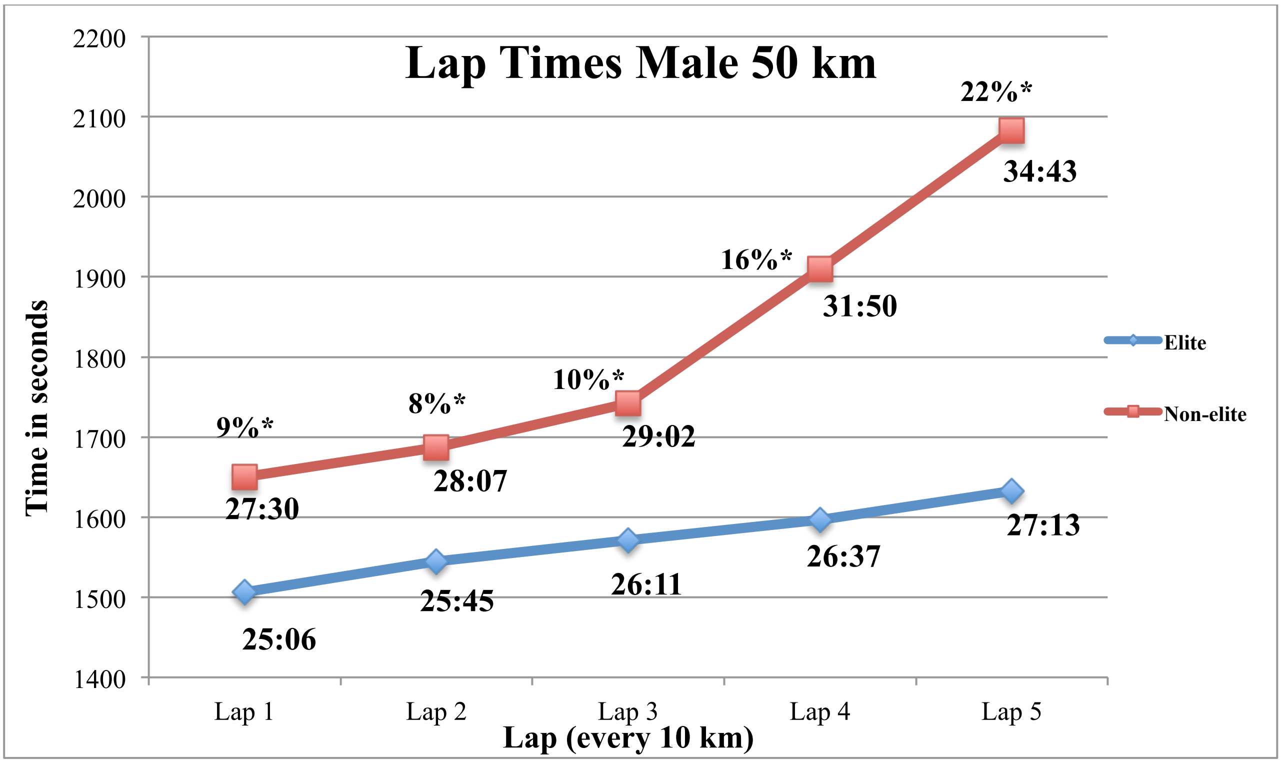

*Figure 16 pacing strategy profiles for elite and non-elite in each lap (mean time). Statistical significance: *p<0.01.*

Table 9 Independent t-test with mean difference ± SD, t-value, degrees of freedom, p>0.01 and Cohen's d.

	Elite	Non-elite	Mean Difference	t	df	p	Cohen's d
Lap 1	1506 +/- 42,2	1650 +/- 52,1	-143,9	-10,7	48	0,01	-3,04
Lap 2	1545 +/- 30,5	1687 +/- 56,2	-142,1	-11,1	48	0,01	-3,14
Lap 3	1571 +/- 34,4	1742+/- 54,6	-170,9	-13,3	48	0,01	-3,75
Lap 4	1596 +/- 30,2	1910 +/- 76,4	-314,0	-19,1	48	0,01	-5,40
Lap 5	1633 +/- 41,8	2083 +/- 105,2	-450,2	-19,9	48	0,01	-5,63

4.5 Graph and Independent T-test Male Uphill 50 km

The mean time trial in uphill terrain for male EG skiers (Figure 17) is 44 seconds, while NEG skiers have an average of 53 seconds (table 14). Average lap time for EG was 42 ± 2,1 s, 43 ± 2,15, 43 ± 1,99, 45 ± 1,8 s and 46 ± 3,6 s. NEG have average of 47 ± 2,6 s, 48 ± 2,19 s, 50 ± 2,38 s, 58 ± 5,5 s and 64 ± 4,3 s. Both groups have an increase in average time, but no difference in average lap time was observed between second and third lap for elite skiers. There is significant interaction between lap in average time and performance level, and t-value is at -7,6, -7,9, -11,2, -11,64 and -15,78 ($p<0.01$) (Table 14).

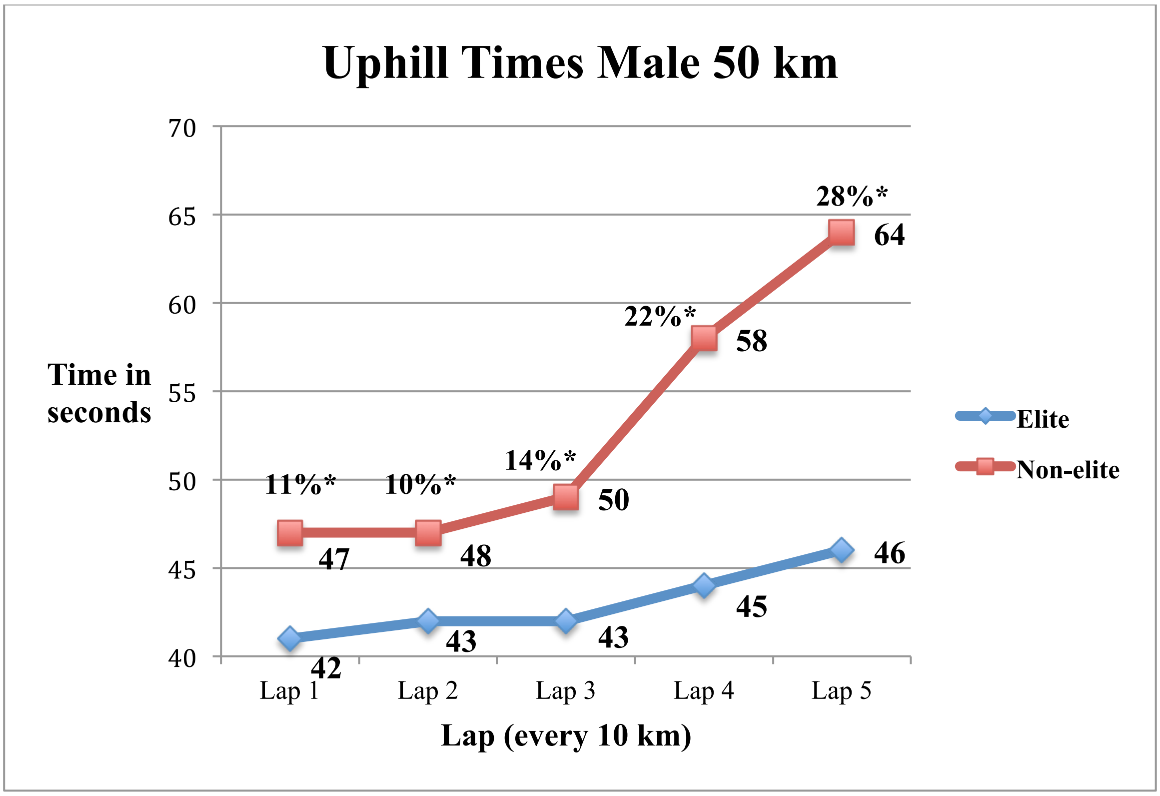

*Figure 17 pacing strategy profiles for elite and non-elite in uphill (mean time). Statistical significance: *p<0.01.*

Table 10 Independent t-test with mean difference ± SD, t-value, degrees of freedom, p>0.01 and Cohen's d.

	Elite	Non-elite	Mean Difference	t	df	p	Cohen's d
Lap 1	42 +/- 2,1	47 +/- 2,6	-5,08	-7,6	48	0,01	-2,15
Lap 2	43 +/- 2,15	48 +/- 2,19	-4,88	-7,9	48	0,01	-2,25
Lap 3	43 +/- 1,99	50 +/- 2,38	-6,96	-11,2	48	0,01	-3,17
Lap 4	45 +/- 1,8	58 +/- 5,5	-13,56	-11,64	47	0,01	-3,33
Lap 5	46 +/- 3,6	64 +/- 4,3	-17,76	-15,78	48	0,01	-4,47

4.6 Graph and Independent T-test Male Downhill 50 km

The mean time trial in downhill terrain for male EG (Figure 18) is 143 seconds (02:23min) and 155 sec (02:35 min) for NEG (table 15). Average lap time for EG was 140 ± 2,97 s, 142 ± 2,58 s, 144 ± 2,5 s and 147 ± 4,1 s. NEG have average of 149 ± 3,9 s, 148 ± 5,6 s, 152 ± 4,2 s and 171 ± 7,0 s. Overall both groups have an increase in average time. NEG reduce average time on the second lap with one second before increasing for the third and last lap. EG have an even increase in average time of all four laps. There is significant interaction between lap in average time and performance level, and t-value is at -9,09, -5,59, -7,72 and -13,5 (p<0.01) (Table 15).

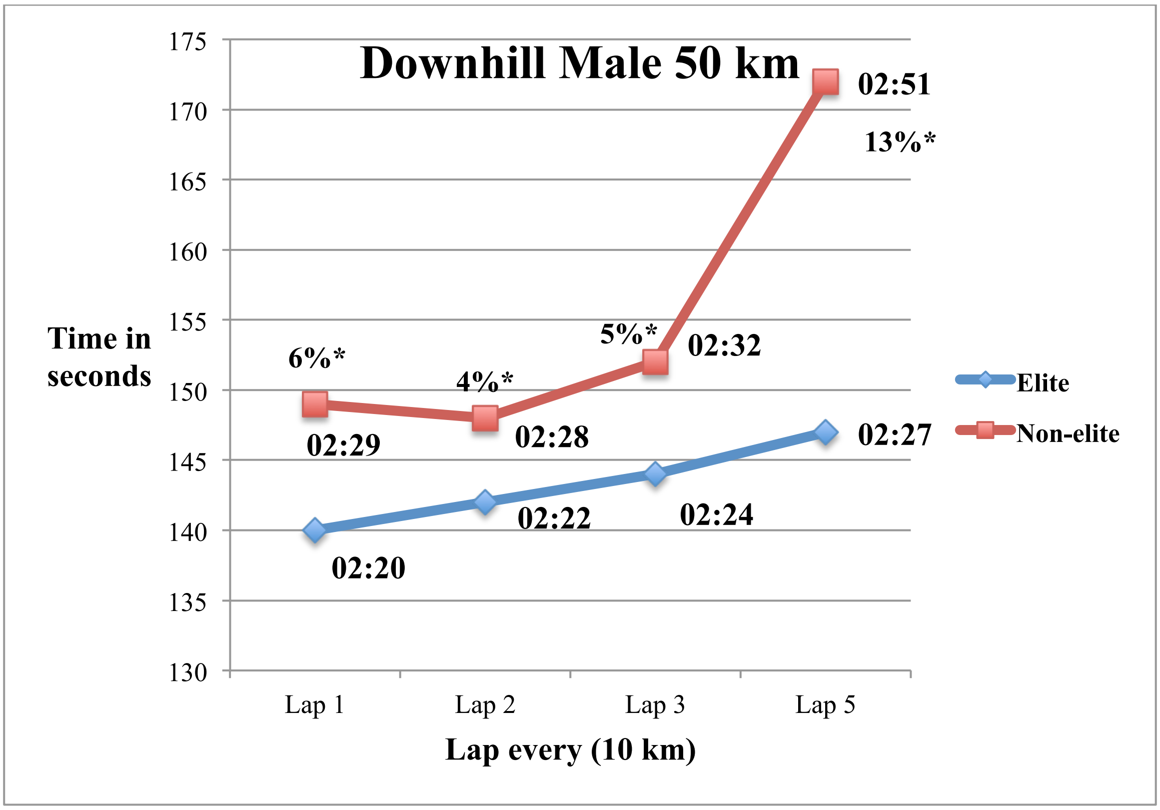

*Figure 18 pacing strategy profiles for elite and non-elite in downhill (mean time). Statistical significance: *p<0.01, 1%.*

Table 11 Independent t-test with mean difference ± SD, t-value, degrees of freedom, p>0.01 and Cohen's d

	Elite	Non-elite	Mean Difference	t	df	p	Cohen's d
Lap 1	140 +/- 2,97	149 +/- 3,9	-8,96	-9,09	48	0,01	-2,57
Lap 2	142 +/- 2,58	148 +/- 5,6	-6,88	-5,59	48	0,01	-1,58
Lap 3	144 +/- 2,5	152 +/- 4,2	-7,52	-7,72	48	0,01	-2,18
Lap 5	147 +/- 4,1	169 +/- 7,0	-23,34	-13,5	46	0,01	-3,91

4.7 Comparing Lap Times and Uphill Terrain in Females and Males

Figure 19 is a compounded comparable with graphs only of figure 13 and 14, 16 and 17. To the left: lap times and uphill terrain 50 km for males, to the right: lap times and uphill terrain 30 km for females. Blue graph = elite group, red graph = non-elite group. This illustrates the similar characteristics of pacing strategy used on 10 km rounds as in uphill terrain. Male non-elite skiers seem to have the exact same development in the race in lap rounds and uphill terrain. They have a fairly even average time the first three laps, which progressively increases. At the fourth and last lap the average time increases remarkable and the EG and NEG difference is at 16% and 20% in lap rounds, and 22% and 28% in uphill terrain (Figure 16, Figure 17). The EG also increase their average time overall, but there's a more markedly increase in uphill terrain from the third lap compared with lap times.

Female EG and NEG difference is at 11% and 12% in lap rounds, and 14% and 15% in uphill terrain (Figure 13, Figure 14). Figure 19 shows that NEG almost have the same pacing strategy on lap times as in uphill terrain. EG reduce average time used on la times, but have the opposite pacing strategy in uphill terrain. They decrease in average time and stabilize from the second to the last lap.

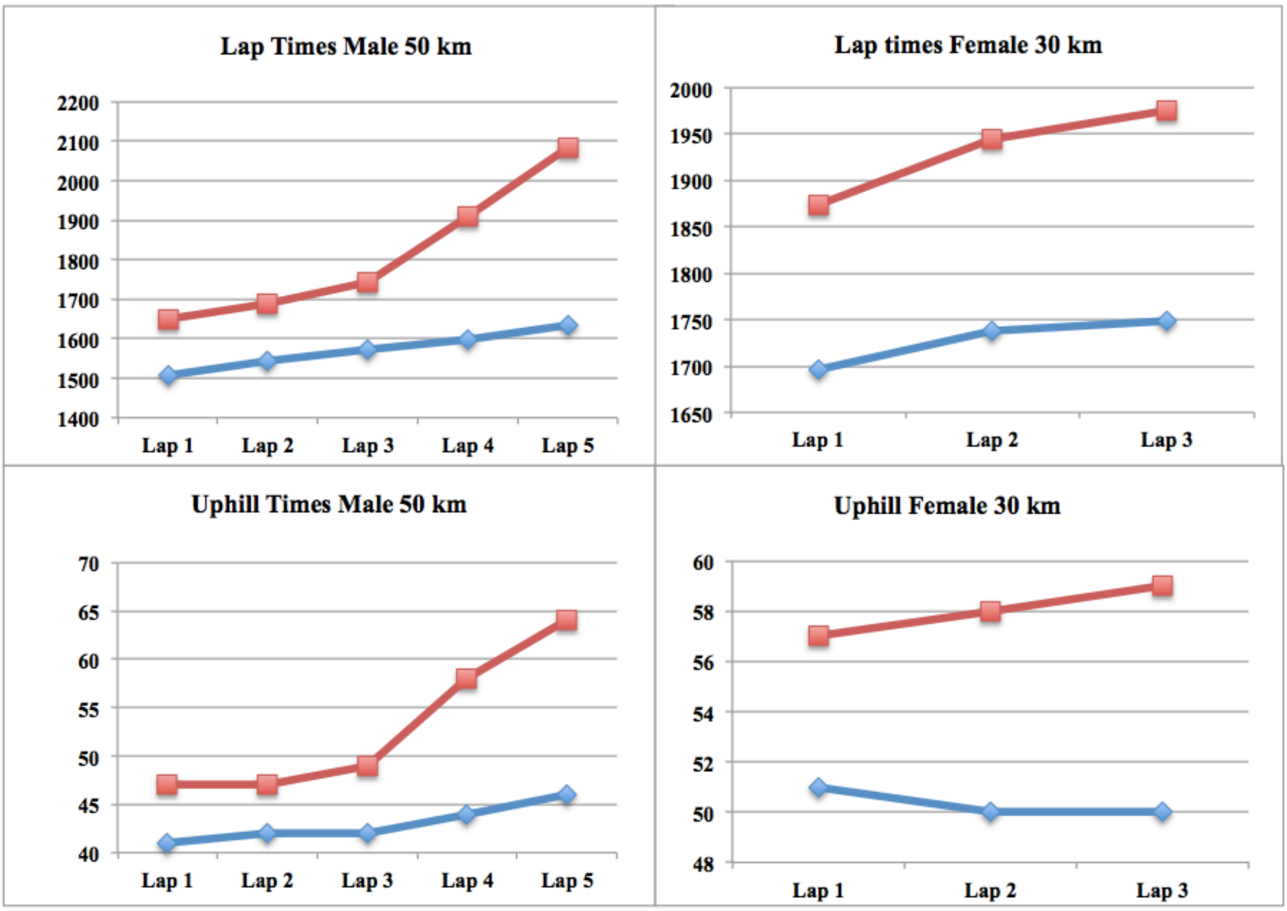

Figure 19 lap times female 30km and male 50km female uphill 30 km and male uphill 50 km.

5 Discussion

XC skiing history have developed significantly trough the decades. From being a competitions form for men only, women was finally included to the sport in from the Olympics in Oslo, in 1952. This was 68 years after men started to race (Nordberg, 1984). Improvement of equipment, topography and grooming of tracks (Sandbakk & Tønnessen, 2012), specificity in training (Hallén & Ronglan, 2013), development of technique (Andersson et al., 2010), tactic (Anne Marte Pensgaard & Hollingen, 2006) and more detailed performance factors and demands (Gjerset et al., 2012; Olympiatoppen, 2007) are some of the elements that have enhanced within XC skiing. Because of all of these developments in the sport, the velocity has increased significant from 1976 to 2012. When measuring average speed of male winners in Olympic 15 km competitions (Sandbakk & Holmberg, 2014). Knowledge about success factors, aerobic and anaerobic capacity makes it easier to facilitate proper amount of training and what intensity level that is required to achieve progress (Seiler, 2010; Wilmore & Costill, 1994).

This master thesis is a describing investigation of two long distance XC skiing-competitions during a Norwegian national championship, for female and male XC skiers at different performance level. The method was to investigate the skiers pacing strategy (average time) in three different ways; one based on lap times passing every 10 km, the second in uphill terrain and the third in measuring skiing downhill terrain. Athletes are divided into elite group (EG) and non-elite group (ENG), and within the two groups they are in different teams; national team (NT), recruit team (RCT), regional team (RGT), and local team (LT).

The main findings of the current study were (I) XC skiers employ a general positive pacing on a lap-to-lap basis, independent from terrain, sex and performance level. (II) Non-elite skiers tend to have a fast start with difficulty to optimize even pacing strategy and significant fall in performance. (III) Pacing strategy in uphill terrain reflects overall pacing strategy of the performance.

In this chapter the hypothesis will be discussed according to the different measurement of pacing strategies. The hypothesis will be repeated and used as headings for discussion.

5.1 Hypothesis 1 –Pacing strategy on Average Lap Times

"Overall, both groups of female and male XC skiers will have a positive pacing strategy throughout the race. Elite skiers will still have a positive split, but with a more even development than the non-elite skiers. Non-elite skiers will have a greater difference in average time comparing the laps"

The world's first 50 km competition was in 1888 with the winning time of 4:26:30 (Gotaas, 2013). Now, 130 years later the best XC skier wins with 2:06:23. This massive decrease in time is a great example of what XC skiing has gone through and its development.

Comparing the average laps time, shows that skiers adopt a general positive pacing strategy, conferring to athletic performance and competition of pacing strategy (Abbiss & Laursen, 2008). This is in accordance with earlier investigations on pacing strategy in XC skiing when observing individual time trials (Bolger et al., 2015; Formenti et al., 2015; Karlsson, 2017; Losnegard et al., 2017). Abbiss and Laursen (2008) have suggested the best pacing strategy for endurance sport competitions, lasting <2min, is an even pacing strategy, which don't compliance to this thesis. During the day of the race day, speed measurement downhill was taken to ensure snow and weather conditions. As measured, weather and snow conditions held stable during both competitions with small changes in temperature. Even though conditions were stable, we don't know what kind of skis or ski wax the athletes used. If we disregard the wax, glide friction between the skis and the snow seem to increase during a race (Kuzmin & Tinnsten, 2006). This influence the XC skiers 60-90% of max VO_2 –cost, and may be another reason for reduction in average time (positive pacing) (Karlsson, 2017; Rusko et al., 1980).

There is a significant difference between male NEG and EG XC observing pacing strategy when comparing laps of 10 km. NE average time for lap 1 of 5 is 27:30 min, while E average time is 25:06. The last lap for average time, EG use 27:13, which means that E skiers use less time on the last lap of the race, compared to NEG skiers who is already skiing 9% slower at the first 10 km. There is 22% difference in average time on the last lap between NE and E male XC skiers. From the first (9%) to the last (22%) there is an increase of 13%.

5.2 Hypothesis 2 Uphill Terrain

"The laps in uphill terrain may tell us more about the athletes pacing strategy than lap times and downhill terrain. Both groups will most likely adapt positive pacing strategy in uphill terrain laps. Elite group will have a more even development in the race, compared to the non-elite group".

Using sub techniques (Figure 2, Figure 4) and changing in frequency during a race is what makes XC skiing special. During this long distance race, the athletes probably change sub technique gears several hundred times (Andersson et al., 2010). The uphill terrain "…forces the skier to alter their technique often" (Sandbakk & Holmberg, 2014, p. 118). This course with a total elevation of 340m (Table 4) is a relatively tough course, but satisfy the Fédération Internationale de Ski (FIS).

All groups, except the female EG, accomplishes a positive pacing strategy in uphill terrain, with an increase in average time. The female EG (Figure 14) actually manage to decrease average lap time with one second from the first to the second lap, and stabilize at the same average time to the last lap. Comparing the sexes (Figure 19), female XC skiers have a relatively even pacing strategy in uphill terrain in relation to the male XC skiers. But there's still a significant gap between the EG and NEG for females.

The influence of technique in uphill terrain and the skiers pacing strategy is highly stimulated of the athlete's skiing efficiency. The EG have developed their skating technique over years to adapt the most effective technique (Jørgensen & Andersen, 2004), this will give them an advantage in uphill terrain and overall in the race. With this comparison based on average lap times in uphill terrain, we can predict male EG, male NEG and female NEG adapt a positive pacing strategy for the race. Female EG stabilize from the second to the last lap. Figure 19 indicate a remarkable equality comparing uphill and laps.

5.3 Hypothesis 3 Downhill Terrain

"Both groups of male and female will perform a positive pacing strategy in downhill terrain. Though, because of their difference in their performance level, female and male elite skiers will have a less difference in average lap time".

Measured downhill lap, distance 1550m, goes from point 4 (140 MASL) to point 5 (60 MASL) (Figure 10). This hypothesis led to interesting results, maybe most noticeable in the males group, comparing the pacing strategy between the sexes. Starting with the female EG: They managed to stabilize at the first two rounds, while they decreased in average time with one second the last round. The NEG group adopted a reverse J-shaped pacing strategy (Abbiss & Laursen, 2008; Formenti et al., 2015), with an increase in average time. Their second lap was slower than the first one, and the third was faster than the second one, but not faster than the first lap of downhill terrain.

Compared to the male group, female XC skiers have a more even average time and pacing strategy in downhill terrain. When looking at the male group, EG only ski 7 seconds slower from the first to the last lap, while NEG increases with 22 seconds. Female EG in downhill terrain is the only measured lap with 1) negative split (increase in speed over time), or in this case; decrease in average time (Abbiss & Laursen, 2008)

This downhill is relatively long with its 1550 m. There are two strategies used in downhill terrain: either ski as fast as possible, or to rest. This will also depend on a higher or lower body position (Sandbakk & Tønnessen, 2012). It may seem like male NEG used the resting strategy downhill from the third to last lap. A lower body position will be more demanding trough the race and the athletes may be more exhausted. Also, this large increase in average time, may be influenced by glide friction, which again affects the athletes VO_2max-cost (Kuzmin & Tinnsten, 2006; Rusko et al., 1980). If so, this is only regarding the male XC skiers. The distance is too short for the female to notice a significant difference in glide friction. The snow and weather conditions were stabile through the day (Figure 12). Technique and downhill skiing skills seem to affect the performance for male NEG on their last lap.

5.4 Hypothesis 4 Sex differences in Pacing Strategy Every 10 km lap

"Both female and male elite and non-elite skiers, will adapt a positive pacing strategy. There will be a larger difference in the development of the race in male group compared with female group, because of the distance difference".

From being a male-dominated sport, XC skiing has developed excessively the last decades. Women were finally allowed to compete in XC skiing from 1952 (Nordberg, 1984), though the distances were not longer than 10 km. Men were already competing in 15 km, 30 km, 50 km (Sandbakk & Tønnessen, 2012). Still, in national, international and Olympic championships, women do not compete longer than 30 km distances. We may ask why they don't compete in the same distances as the men's today. This would have resulted in different findings in the female group, and would be easier to compare the sexes and their pacing strategy. At the time, the distance doesn't seem to be long enough for the females to have the same development and influence in the race, such as the male group.

As we know, women have a greater proportion of resistance type 1 fibre, which may influence them in advantage for long-duration endurance performance (Steffensen et al., 2002). It is also suggested that females have physiologic advantages over men in maintaining an even pacing strategy (Spencer et al., 2014).

Measurement of weather and snow conditions during the race day reduces the risk of speculations in conditions. Figure 12 and table 3 explains speed measurement and terrain. Temperature in weather and snow was carried out before each competition and after each competition. This means that weather and snow condition had minimal impact to the performance. On the other hand, little is know about what kind of wax there was used.

Both female and male skiers performed the first lap at the lowest average time. This shows that the athletes chose a fast start strategy. The fast start may be due to why the skiers couldn't maintain a constant and more even pacing strategy throughout the duration, and that they opened too fast (Abbiss & Laursen, 2008). None of the groups achieved to increase their speed the last lap, which could turn into a reverse J-shaped pacing strategy if they managed (Formenti et al., 2015). Comparisons of the differences between the sexes in pacing strategy, have not been investigated in this thesis. This is because of the difference between 30 km and 50 km. With such a major difference in distance, the male skiers may have another pacing strategy or tactic when competing 20 km longer than female skiers. Anyway, it would be interesting to see, if the women were soon allowed to compete as long as the male XC skiers, if they achieve a more even or better pacing strategy.

Dehydration of only 2-3% will decrease the performance in a race (Rodriguez et al., 2009). This small percentage is enough to influence the performance significant, if not the skier have an adequate fluid intake before and during the competition. The glycogen stores should be filled up before competition (Burke et al., 2011), and it's unknown how much or what the athlete have eaten or drank before this competition.

The female XC skiers (Figure 13) compete for about one hour and a half, which is less time than the male XC skiers. With a shorter time of competition time, the female skiers are not so dependent on fuelling up during the race, as the male skiers are. For the female skiers, the glycogen stores have possibly not been emptied yet. Females also have a higher rate of fat oxidant, which influence a later shift in use of carbohydrates as the dominant energy source (Horton et al., 1998; Roepstorff et al., 2006; Venables et al., 2005). The male NEG, because of their fast start, have possibly emptied their glycogen stores around 30 km (about one hour 15 minutes) and is too dehydrated to maintain the same speed.

Looking at Olympiatoppen's 8-split intensity scale (Table 1), it might seem like the NEG skiers have started out in intensity zone (i) 3 (total duration 50-90min) transitioning to 4 (total duration 30-50 min), which they have to suffer during fourth and last lap. I3 and i4 is also intensity at anaerobic capacity and the intensity is higher. Because of the higher intensity, the body needs more glycogen than fat (McArdle WD, FI, & VL, 1991).

5.4.1 Causes of Results

Overall, all the XC skiers, in both female and male group, have a progressive increase in average time during the race. It may be speculated in that the skiers did not maintain an even pacing strategy throughout the competition because of such as a fast start strategy (Abbiss & Laursen, 2008). Abbiss and Laursen (2008) have suggested several environmental factors that can influence the distribution of work, for instance the duration and importance of the race and the course geography.

The duration is varying from 1-2,5 hours, depending on female and male competitions. The race is categorized as a long distance-competition, which means 30 km and 50 km (Sandbakk & Holmberg, 2017). This race is a Norwegian national championship, and may be more important for a lot of the XC skiers, than if it "only" was a regional or local competition. The course profile (Figure 10) is a relatively demanding topography, with lots of elevation. Even though it's within the FIS requirements for a competitions course (Federation, 2015).

Regardless, both sexes show strong effects and large differences. For all the kinds of laps, uphill and downhill, there is a statistical significant difference with 1%. Also Cohen's d are all above -1.0, which means the effect size is strong, when large effect is at 0.8 (Cohen, 1988). To perform the best pacing strategy in a long distance race, such as these once, an even pacing strategy is optimal to cover the distance in the shortest possible time (Abbiss & Laursen, 2008). With the results of male skiers on lap times, it is obvious that the NEG group don't manage well enough to maintain an even pacing strategy and has a significant decrease in performance. The EG XC skiers also have a decrease in performance based on average time, but their development in pacing strategy is more even than the non-elite group. They manage to stabilize after the second lap.

There is a larger difference between the two groups of performance in males 50 km, than in the female 30 km competition. This may be influenced by several factors, but most likely the difference in distance.

The causes of these results can be many. To start with, individual differences like age and sex may influence the performance (Pantelis T Nikolaidis & B Knechtle, 2018). It shows that men and young (<20 years) XCS had a more even pacing strategy than women and older XCS. This study had a larger spectre of age groups, which is not so relevant to this thesis (age up to 80-89 years). Respectively, study of March et al. (2011) concluded with opposite results, where older individuals, women and faster athletes showed a more even pacing strategy than younger, men and slower athletes. Though this can be related to XC skiing because both is endurance sport, the study is done at marathon by running.

Age can also influence the annual training of the athletes, where the EG is considered to train a total of 750 to 950 hours yearly (Sandbakk & Holmberg, 2017). NEG maintain non-professional skiers (male regional teams 8, local teams 36, female regional teams 10 and local teams 30) that may have a lower amount of training hours due to lifestyle. As age may influence less annual training, younger athletes might not be used to the subjective feeling according to intensity (RPE, rated perceived exertion) as much as the elite-group is (Tucker, 2009).

The physiological aspects that affect the performance may also be influence by age. For example a positive relationship towards physical pain and fatigue might help the athlete to develop better endurance. The right mindset with an experience-based awareness, acceptance and action orientated phycology, will have beneficial outcomes to the athlete (Hanin, 2003). The development of male non-elite skiers may indicate that also the psychological aspect have influenced their performance. If the athlete is getting a hard time following up on the same pacing strategy for every round, it may be difficult to accept the fact that it is going slower and negatively influences you psychological.

Rest, recovery and nutrition are highly necessary to achieve results in competitions, especially in long distance races like this one. The organism needs to bee recovered to be able to perform optimal in endurance competitions (Gjerset et al., 2015; Rodriguez et al., 2009). Most likely the skiers haven't exercised for moderate to major damage to muscle structures ahead of the competition, which needs a fairly long recovery process (Gjerset et al., 2015).

For high intensity/long duration competitions like this one, adequate consumption of nutrition is important to avoid increased rick of fatigue, illness and dehydration (Frøyd & Helge, 2015; Rodriguez et al., 2009). In the male non-elite group, the significant decrease in performance in fourth and last lap may be caused or influenced by too little nutrition and fluids during the race. This, and a combination of a fast start pacing strategy in the first 10-30 km (Abbiss & Laursen, 2008).

Figure 19 is a comparison of graphs from Figure 13 and 14 for females, and Figure 16 and 17 for males. The development in pacing strategy is relatively similar for both sexes. This is showing that the pacing strategy in uphill terrain may be reflected in the pacing strategy and overall performance.

I wish to generalise the results of the study. The study does not involve any new research in pacing strategy.With a representative sample of 100 XC skiers at different performance level, it is safe to say that elite XC skiers are better trained and more professional of predisposing their race with a more even pacing strategy. EG manage to maintain the average time even, compared with NEG (especially male).

5.5 Perspectives and The Significance of The Findings

The findings in this study support previous researches Formenti et al. (2015), Karlsson (2017), Losnegard et al. (2017), Carlsson, Assarsson, et al. (2016) Abbiss and Laursen (2008), regarding positive pacing strategy in XC skiing.

It seems appropriate to suggest that athletes and coaches should focus on pacing and pacing strategy when training, and to create specific training programmes for this to each athlete.

Further, there is still much left to investigate in pacing strategy, which not only will benefit the single athlete, but also coaches and teams. It would be interesting to investigate further championships, using the same method, but with some adjustments, like a mixed-method thesis. The athletes would receive a questionnaire ahead of the race, regarding their tactics and pacing strategy. The study would not only investigate describing data but also the psychological issues the athlete experiences before, during and after the races.

A more detailed study with more specific information for example: body (age, height, weight)- and muscle mass measurement (which is highly related to the exercise and its performance (Bangsbo et al., 1990; Bangsbo et al., 1993; Losnegard & Hallén, 2014b)), lactate- and VO_2max tests to know the intensity zones and AT-value of the athlete and HR-curve to observe cardiovascular demands, like Formenti et al. (2015) did. It would also be interesting to use GPS on the athlete, to measure technique, and transition between techniques. With these data we would know more about skiing efficiency and biochemical aspects. With a combination of the GPS and HR-intensity, it would show a more detailed aspect of what kind of technique would be the most efficient in different terrain, merged with measured time used in different terrain.

Reading through the historical theory about cross-country skiing, a lot have changed and developed the last decades. Though, there is still one aspect that seems a bit “old days”. Women in 2019 are still not able to compete in longer Olympic distances than 30 km. Why is there a difference in distance for male and female? Shouldn’t they compete both in 50 km races?

Comparing the female’s 30 km pacing strategy (Figure 13) with the males 50 km pacing strategy (Figure 16) both sexes has an even pacing strategy for the first 30 km. It would be interesting to see if the female skiers would adapt a more even pacing strategy through a 50 km than male skiers. But first, the Fédération Internationale de Ski (SKI) should arrange a new congress to include and challenge women to the long distance competition of 50 km.

6 Conclusion

The main findings of the current study were (I) XC skiers employ a general positive pacing on a lap-to-lap basis, independent on terrain, sex and performance level. (II) Non-elite skiers tend to have a fast start with difficulty to optimize even pacing strategy and significant fall in performance. (III) Pacing strategy in uphill terrain reflects overall pacing strategy of the performance.

7 References

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8 Appendix

Boye Welde
Follumsvei 31
9510 ALTA

Vår dato: 26.02.2018 | Vår ref: 58595 / 3 / HJT | Deres dato: | Deres ref:

Tilrådning fra NSD Personvernombudet for forskning § 7-27

Personvernombudet for forskning viser til meldeskjema mottatt 22.01.2018 for prosjektet:

58595	*Kartlegging av motivasjon, løpsdisponering og teknikkvalg i ulike terrengpartier hos kvinnelige og mannlige langrennsløpere under NM i Alta 2018*
Behandlingsansvarlig	*UiT Norges arktiske universitet, ved institusjonens øverste leder*
Daglig ansvarlig	*Boye Welde*

Vurdering

Etter gjennomgang av opplysningene i meldeskjemaet og øvrig dokumentasjon finner vi at prosjektet er unntatt konsesjonsplikt og at personopplysningene som blir samlet inn i dette prosjektet er regulert av § 7-27 i personopplysningsforskriften. På den neste siden er vår vurdering av prosjektopplegget slik det er meldt til oss. Du kan nå gå i gang med å behandle personopplysninger.

Vilkår for vår anbefaling

Vår anbefaling forutsetter at du gjennomfører prosjektet i tråd med:

- opplysningene gitt i meldeskjemaet og øvrig dokumentasjon
- vår prosjektvurdering, se side 2
- eventuell korrespondanse med oss

Meld fra hvis du gjør vesentlige endringer i prosjektet

Dersom prosjektet endrer seg, kan det være nødvendig å sende inn endringsmelding. På våre nettsider finner du svar på hvilke endringer du må melde, samt endringsskjema.

Opplysninger om prosjektet blir lagt ut på våre nettsider og i Meldingsarkivet

Vi har lagt ut opplysninger om prosjektet på nettsidene våre. Alle våre institusjoner har også tilgang til egne prosjekter i Meldingsarkivet.

Vi tar kontakt om status for behandling av personopplysninger ved prosjektslutt

Ved prosjektslutt 31.12.2019 vil vi ta kontakt for å avklare status for behandlingen av personopplysninger.

Se våre nettsider eller ta kontakt dersom du har spørsmål. Vi ønsker lykke til med prosjektet!

Dokumentet er elektronisk produsert og godkjent ved NSDs rutiner for elektronisk godkjenning.

NSD – Norsk senter for forskningsdata AS | Harald Hårfagres gate 29 | Tel: +47-55 58 21 17 | nsd@nsd.no | Org.nr. 985 321 884
NSD – Norwegian Centre for Research Data | NO-5007 Bergen, NORWAY | Faks: +47-55 58 96 50 | www.nsd.no

Vennlig hilsen

Dag Kiberg

Håkon Jørgen Tranvåg

Kontaktperson: Håkon Jørgen Tranvåg tlf: 55 58 20 43 / Hakon.Tranvag@nsd.no
Vedlegg: Prosjektvurdering

Personvernombudet for forskning

Prosjektvurdering - Kommentar

Prosjektnr: 58595

SAMARBEIDSPROSJEKT

Personvernombudet forstår det slik at prosjektet er et samarbeid mellom UiT, universitetet i Salzburg og universitetet i Ljubljana, med førstnevnte som behandlingsansvarlig institusjon. Ombudet forutsetter at ansvarsforhold, sikring og evt. eierskap av data er avklart, og at det meldes til personvernombudet@nsd.no dersom det skal utveksles personopplysninger mellom institusjonene.

FORMÅL

Formålet er å kartlegge motivasjonsstrukturer hos idrettsutøvere på høyt nivå, og å kartlegge løpsdisponering under konkurranse og hvilke teknikker løperne velger i ulike terrengtyper.

INFORMASJON OG SAMTYKKE

Du har opplyst i meldeskjema at utvalget vil motta skriftlig og muntlig informasjon om prosjektet, og samtykke skriftlig til å delta. Vår vurdering er at informasjonsskrivet til utvalget er godt utformet.

SENSITIVE PERSONOPPLYSNINGER

Saksbehandler har endret meldeskjema slik at det fremgår at det skal behandles sensitive opplysninger om helseforhold, da det skal samles inn pulsdata, høyde og vekt for utvalget.

INFORMASJONSSIKKERHET

Personvernombudet forutsetter at du behandler alle data i tråd med UiT Norges arktiske universitet sine retningslinjer for datahåndtering og informasjonssikkerhet. Vi legger til grunn at bruk av privat pc er i samsvar med institusjonens retningslinjer.

PROSJEKTSLUTT OG ANONYMISERING

Prosjektslutt er oppgitt til 31.12.2019. Det fremgår av meldeskjema/informasjonsskriv at du vil anonymisere datamaterialet ved prosjektslutt.

Anonymisering innebærer vanligvis å:

- slette direkte identifiserbare opplysninger som navn, fødselsnummer, koblingsnøkkel
- slette eller omskrive/gruppere indirekte identifiserbare opplysninger som bosted/arbeidssted, alder, kjønn
- slette eller sladde bilde- og videoopptak

For en utdypende beskrivelse av anonymisering av personopplysninger, se Datatilsynets veileder:
https://www.datatilsynet.no/globalassets/global/regelverk-skjema/veiledere/anonymisering-veileder-041115.pdf