NORWEGIAN SCHOOL
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Competitive cross-country skiers have a longer time to exhaustion and a larger accumulation of oxygen deficit than recreational cross-country skiers during an intermittent interval protocol standardized for maximal aerobic power

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Abstract

Purpose: To compare a competitive and a recreational group of cross-country (XC) skiers in time to exhaustion (TTE) and accumulation of oxygen deficit (${O_2}^{def}$) in an intermittent interval protocol standardized for maximal aerobic power (MAP).

Methods: Twenty-two male XC skiers were recruited for the study and assigned into a competitive ($n = 12$) and a recreational ($n = 10$) group of similar age, weight, and height. All protocols were performed using the V2 ski skating sub-technique with roller skis on a treadmill. First, they performed two baseline protocols (sub-maximal loads and 1000-meter time-trial (TT)), to quantify MAP and maximal accumulation of oxygen deficit ($MAOD$). After a 60-minute break, they performed an intermittent interval protocol individually tailored to each subject's MAP. The test consisted of two phases repeating in cycles; a recovery phase lasting 20 seconds at 60% MAP, followed by a work phase at 120% MAP lasting 40 seconds, resulting in each cycle averaging an intensity of 100% MAP. TTE was measured along with oxygen consumption ($\dot{V}O_2$) and $\sum {O_2}^{def}$.

Results: The competitive group was faster during the 1000-meter TT and had a higher maximal rate of oxygen consumption ($\dot{V}O_{2max}$), gross efficiency (GE) and MAP than the recreational group. $MAOD$ was, however, similar for both groups. During the interval protocol, the competitive group had a 34 [3, 65] % longer TTE (473 ± 141 vs. 353 ± 94 s, p = 0.032), and accumulated a 45 [22, 68] % larger ${O_2}^{def}$ (112 ± 18 vs. 77 ± 20 %$MAOD$, p = 0.001) than the recreational group.

Conclusion: The competitive group had a longer TTE and a larger $\sum {O_2}^{def}$ than the recreational group during an intermittent interval protocol standardized for MAP. This implies that TTE could be related to the ability to repeatedly accumulate smaller bulks of ${O_2}^{def}$ amounting to a large total.

Preface

While growing up, I was lucky enough to have a mom and dad, both very loving and wise, teaching me important lessons about life. Perhaps the most important lesson is the fact that there are almost eight billion people on planet Earth, and every single one of us is different from one another. During my time in the field of physiology, I have learned from brilliant professors and fellow students alike that this incredible diversity of people is due to the phenomenon known as “gene expression”. Combined with the environment, this phenomenon shapes all aspects of each and every one of us. Disappointingly, my genes never really seemed to grasp the appeal of big strong muscles, or explosive power for rapid acceleration and agile change of direction. Instead, it appears that my body’s idea of fun is moving in a straight line at moderate pace for hours on end, and has thus prioritized a slender, rather lanky, figure. This has made me naturally gravitate towards sports such as distance running, biking and cross-country (XC) skiing. While attending a lecture on XC skiing, hosted by my current supervisor Thomas Losnegard, I was fascinated by the complex physiological requirements for performance in the sport and other similar sports combining classical endurance and intermittent exercise. I believe this was the spark that further inspired me to center my master’s thesis around this topic. It has undoubtedly been the most difficult academic work of my (relatively short) academic career, perhaps even more so due to the current circumstances of the pandemic that is challenging people all around the world. As such, a huge thank you is in order to family, friends, professors, and not least to all participating subjects who helped this thesis become a reality. A special thank you to my main supervisor, Thomas Losnegard, for the tremendous amount of patience shown and guidance provided in every aspect of this study, helping me stay grounded and regain focus whenever needed. A true inspiration. Secondly, to co-supervisor, Øyvind Gløersen, for great technical assistance, both inside and outside the laboratory, and helping me collect and manage an overwhelming amount of data. Thirdly, to fellow master’s student, Ånung Viken, with whom I have collaborated a great deal in the planning and execution of this study. Fourthly, to Magne Lund Hansen, for helping recruit subjects to participate in this study, and for pilot testing the included protocols. Last, but certainly not least, to all the other people who participated and gave their all, either as pilot testers or subjects, in the very physically demanding protocols in this study.

Eivind Holsbrekken

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Abbreviations

XC: cross-country

TT: time-trial

TTE: time to exhaustion

MAP: maximal aerobic power

$\dot{V}O_2$: rate of oxygen consumption

$\dot{V}O_{2_{sm}}$: rate of oxygen consumption during sub-maximal loads protocol

$\dot{V}O_{2max}$: maximal rate of oxygen consumption

GE: gross mechanical efficiency

${O_2}^{def}$: oxygen deficit

$\sum {O_2}^{def}$: accumulated oxygen deficit

${O_2}^{dem}$: oxygen demand

Eco: efficiency

Eco_{ski}: skiing efficiency

HR: heart rate

HR_{peak}: highest measured heart rate

RPE: rate of perceived exertion

$[La^-]$: blood lactate concentration

$[La^-]_{peak}$: highest measured blood lactate concentration

P_{prop}: propulsive power

$P_{prop_{sm}}$: propulsive power measured during sub-maximal loads protocol

$P_{prop_{recovery}}$: propulsive power during recovery phases of the interval protocol

$P_{prop_{work}}$: propulsive power during work phases of the interval protocol

$v_{recovery}$: velocity during recovery phases of the interval protocol

v_{work}: velocity during work phases of the interval protocol

v: velocity

g: acceleration due to the force of gravity

m_{BW+E}: mass of bodyweight and equipment

θ: the angle of the treadmill incline

SD: standard deviation

CI: confidence interval

*: statistical significance $p < 0.05$

**: statistical significance $p < 0.01$

C_{rr}: coefficient of rolling resistance

n: number of subjects

mmol: millimole

bpm: beats per minute

COM: competitive group

REC: recreational group

R: rest phase

W: work phase

PO_2: partial pressure of oxygen

PCO_2: partial pressure of carbon dioxide

RER: respiratory exchange ratio

1. Introduction

Performance in endurance sports is analogous to moving through a defined racecourse in a shorter period of time than the competitors. From a physiological perspective, this translates to sustaining a high metabolic energy turnover rate, while efficiently converting the metabolic energy into a greater mechanical power output, and by extension a higher velocity, thus completing the racecourse more quickly. There is, however, an upper threshold to sustainable turnover rates, and the conversion efficiency (Eco), of metabolic energy. Endurance sports are therefore often performed at a steady-state sub-maximal intensity equivalent to "performance $\dot{V}O_2$", which is the highest fraction of the maximal rate of oxygen consumption ($\dot{V}O_{2max}$) that can be sustained for the duration of the competition. The relationship between performance $\dot{V}O_2$ and competition duration is inversely related, meaning that a longer duration results in a lower performance $\dot{V}O_2$. Eco further determines the velocity that performance $\dot{V}O_2$ translates to (Joyner & Coyle, 2008). Performance $\dot{V}O_2$ and Eco are therefore considered two of the main determinants of performance in many endurance sports.

Some endurance sports, like cross-country (XC) skiing, distinguish themselves with characteristics of intermittent exercise. Performance $\dot{V}O_2$ and Eco are still considered important performance determinants (Saltin & Åstrand, 1967; Mahood, Kenefick, Kertzer, & Quinn, 2001; Losnegard, 2019). However, descending segments, in combination with the gliding properties of the skis and the gravitational acceleration, provide opportunities for recovery, which allows for shorter bursts of non-sustainable efforts, typically occurring in ascending segments. Thus, athletes frequently transition between sub- and supra-maximal efforts, which effectively results in phases of recovery and high-intensity work during a race. The recovery phases typically have an oxygen demand (${O_2}^{dem}$) of 40-60% of $\dot{V}O_{2max}$ (Sandbakk & Holmberg, 2017), while the ${O_2}^{dem}$ of the most intense supra-maximal efforts can be as high as 160% peak aerobic power (Karlsson, Gilgien, Gløersen, Rud, & Losnegard, 2018). Ascending segments account for approximately 50% of the race duration, and they have proved to be the most differentiating segments with regards to performance (Sandbakk, et al., 2016; Sollie, Gløersen, Gilgien, & Losnegard, 2021). Additionally, XC skiers of an inferior skill level typically show a stronger positive pacing (velocity decreasing throughout the race), and performance can therefore be defined as the ability to repeatedly perform supra-maximal efforts while minimizing the reduction in pace throughout the race (Losnegard, 2019).

The duration a single bout of supra-maximal effort can be maintained is related to the maximal capacity to accumulate oxygen deficit ($MAOD$) (Medbø & Tabata, 1989). Losnegard et al. (2013) examined the predictability of $\dot{V}O_{2max}$, Eco, and $MAOD$ on FIS skiing distance race points, and the variables accounted for approximately 70% of the variation between skiers. Although this might be considered a high degree of predictability, it is apparent that there are additional determinants of XC skiing performance. One possible additional performance determinant is the ability to repeatedly accumulate smaller bulks of oxygen deficit (${O_2}^{def}$) amounting to a large total. Gløersen et al. (2020) reported ${O_2}^{def}$ to be accumulated in bulks of < 20% $MAOD$ on average and no more than 50% $MAOD$ during a simulated XC skiing distance race. The total $\sum {O_2}^{def}$ was, however, approximately 4 times the magnitude of $MAOD$. Therefore, it appears that it is not simply $MAOD$ that matters, but rather the ability to accumulate a total that, by far, exceeds $MAOD$ through repeated accumulation of much smaller bulks of ${O_2}^{def}$. This is an aspect of XC skiing that is not sufficiently investigated, as the majority of previous literature has focused on $\dot{V}O_{2max}$ and Eco in roller ski protocols with a constant intensity profile.

The purpose of the current study was to compare a competitive and a recreational group of cross-country skiers in time to exhaustion (TTE) and $\sum {O_2}^{def}$ in an intermittent interval protocol standardized for maximal aerobic power (MAP). The hypothesis was that the competitive group would have (1) a longer TTE and (2) a larger $\sum {O_2}^{def}$ than the recreational group due to a greater ability to repeatedly accumulate ${O_2}^{def}$.

2. Theory

2.1 Endurance sports

Many different sports share certain common characteristics labeling them as endurance sports. In such sports, a relatively high energy cost must be tolerated for a certain amount of time. Depending on the sport, the duration can vary from only a few minutes to several hours. Considering the vast range of duration, it is no surprise that the determinants of performance can differ from one endurance sport to another. However, essential to them all is the interplay of muscular, cardiovascular, and neurological factors, and their cooperation in producing power from aerobically and anaerobically derived energy (Joyner & Coyle, 2008). A variety of different systems interact with each other to maintain a state of inner balance, physiologically known as homeostasis. Homeostasis may be influenced by external factors, such as physical exercise, and could potentially be lost. If homeostasis is lost, the body can eventually no longer continue its current endeavor (Burnley & Jones, 2018). This is a key principle within the context of endurance sports.

2.2 The power-duration relationship

Homeostasis is related to the power-duration relationship. The fundamentals of the power-duration relationship were first systematically analyzed in the early 1900s by the British physiologist and Nobel Prize winner A.V. Hill (1925). Hill studied velocity’s (the end product of power) relation to duration, by comparing the average velocity sustained during world record performances in different sports over a variety of distances. He described the velocity-duration relationship to be hyperbolical. For shorter durations, very high velocities can be maintained, but the drop-off is substantial as duration increases. For longer durations, only lower velocities can be maintained, but the drop-off is not very large as duration is further increased. For durations longer than twelve minutes, Hill concluded the velocity to be practically constant despite a further increase in duration. This was true for all the sports he analyzed, which led him to believe that there must be a common set of underlying physiological factors determining the velocity-duration relationship in all forms of physical exercise.

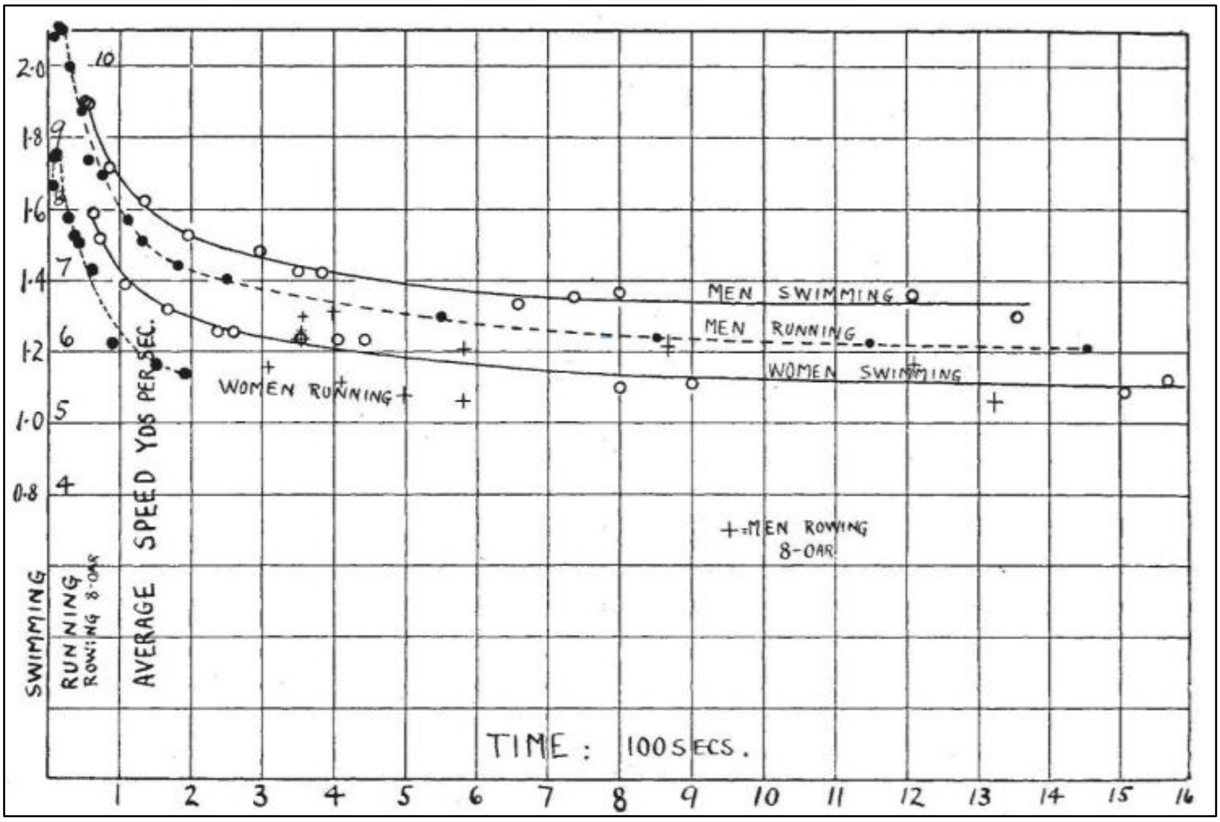


Figure 2.1: *Hill's systematic analysis of world records over a variety of distances in running and swimming. Adopted from Hill (1925).*

The power-duration relationship has a similar hyperbolic nature to the velocity-duration relationship reported by Hill. The maximal power output can only be maintained for a few seconds, while lower power outputs can be maintained for a very long duration. The maximal sustainable power output is no more than 35 % of the maximal attainable power output (Vanhatalo, Doust, & Burnley, 2007). This equates to ~70 % of the power output at the maximal rate of oxygen consumption ($\dot{V}O_{2max}$) (Burnley & Jones, 2018).

2.3 Intensity domains

The range of attainable power outputs generate different physiological responses related to exercise tolerance, and intensity domains have been defined based on these responses. Power outputs are thus classified into a moderate, heavy and severe intensity domain based on the response of the rate of oxygen consumption ($\dot{V}O_2$) and blood lactate concentration ($[La^-]$), to describe their effect on exercise tolerance (Burnley & Jones, 2007). Note that each of these three domains may cover a different range of power outputs between individuals and may also change within a single individual over time in response to training. Intensity domains are thus individually determined and highly plastic.

2.3.1 The moderate intensity domain

The moderate intensity domain is any intensity at or below the lactate threshold (LT), sometimes referred to as the aerobic threshold. LT is hereby understood as the highest power output where lactate production does not exceed lactate clearance and is usually measured by analyzing $[La^{-}]$. In contrast, the $\dot{V}O_2$ will increase linearly (but with a slight delay) in correspondence with the power output and stabilize within just a few minutes. Within this domain, physical exercise can be sustained for well above four hours (Burnley & Jones, 2007).

2.3.2 The heavy intensity domain

The heavy intensity domain is any intensity in between the LT and maximal lactate steady state (MLSS), also sometimes referred to as the anaerobic threshold. MLSS is hereby defined as the highest power output where $[La^{-}]$ is able to stabilize. $[La^{-}]$ will rise in response to an increasing power output but stabilize at the elevated level once the power output is maintained constant. A $\dot{V}O_2$ slow component eventually emerges, typically 90-180 seconds after the onset of exercise. The $\dot{V}O_2$ slow component drives $\dot{V}O_2$ past the steady-state value expected from the initial linear relation between $\dot{V}O_2$ and power output before it stabilizes after 10-20 minutes of exercise. Within this domain, physical exercise can be maintained for up to two hours before limited glycogen stores becomes a limiting factor. However, with dietary enhancement strategies exercise may be sustained for 3-4 hours (Burnley & Jones, 2007).

2.3.3 The severe intensity domain

The severe intensity domain represents intensity levels exceeding MLSS. Within this domain, $[La^{-}]$ and $\dot{V}O_2$ are no longer able to stabilize. This is per definition the breaking point of homeostasis, as the balance of the body's physiological environment is lost. MLSS is therefore a metaphorical event horizon, and the severe intensity domain a black hole, pulling $[La^{-}]$ and $\dot{V}O_2$ so far beyond baseline values that the body is eventually no longer able to maintain the current intensity. Within this domain, physical exercise can be maintained for no longer than 45 minutes (Burnley & Jones, 2007). Muscle power output is compromised, likely by the depletion of anaerobic energy stores and the accumulation of fatigue related metabolites, such as inorganic phosphate (P_i) and hydrogen ions (H^+) (Glaister, 2005), which limits the synaptic input to motoneurons and disrupts the excitation-contraction coupling. As muscle power output is compromised, additional motor units must be recruited to maintain the power output, which reduces efficiency, as reflected by the developing $\dot{V}O_2$ slow component. When $\dot{V}O_2$ reaches $\dot{V}O_{2max}$, the muscles must depend on the limited quanta of anaerobic energy sources to maintain the power output as efficiency is further reduced (Burnley & Jones, 2018).

2.4 Performance power

Joyner & Coyle (2008) give a detailed review of endurance exercise performance, and how it can be explained through performance power. In practical terms, performance power is the highest sustainable mechanical power output for any given duration.

2.4.1 Aerobic components

The fundamental aerobic components of performance power are the muscle capillary density, stroke volume of the heart and the maximal heart rate, hemoglobin content in the blood plasma, the aerobic enzyme activity, and the distribution of power output between muscle cells, also called muscle fibers (Joyner & Coyle, 2008).

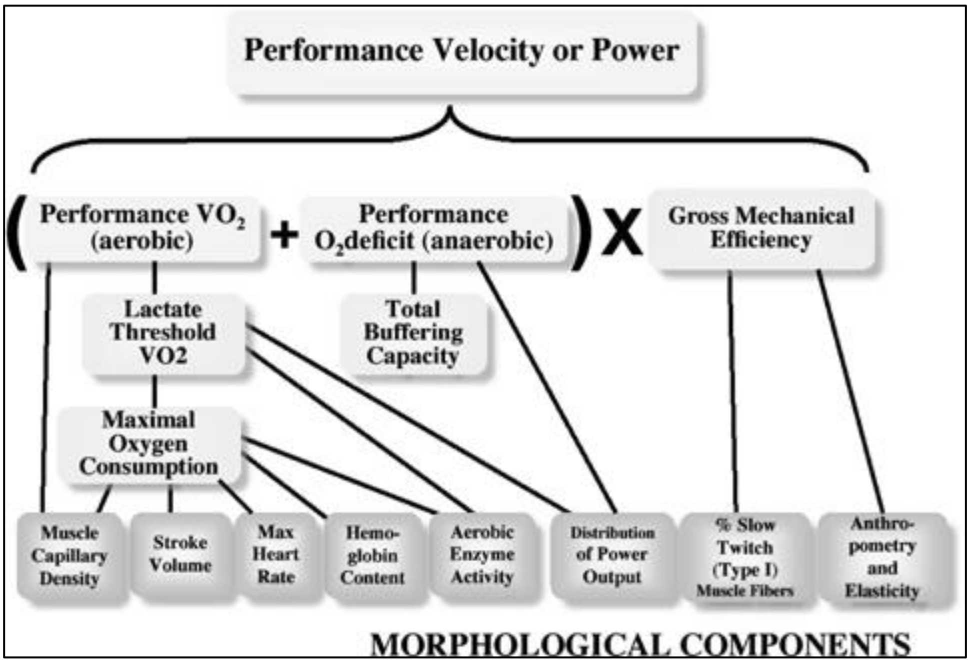


Figure 2.2: *A model illustrating the components of performance power. Adopted from Joyner & Coyle (2008).*

Muscle capillary density is the ratio of capillary surface area to skeletal muscle fiber volume. Capillaries are the smallest form of blood vessels, connecting the arterial vessels leading oxygenated blood from the heart to different tissue, and venous blood vessels leading deoxygenated blood from tissue back to the heart. The capillary network is the place where exchange of gasses, along with substrates and waste metabolites, take place between the blood plasma and the muscle tissue. The density of capillaries is therefore instrumental to the rate of which crucial metabolites and gasses can be exchanged to and from the muscles to maintain optimal conditions for muscle work, thus directly responsible for the rate of which oxygen can be delivered to, and consumed by, the muscles (Joyner & Coyle, 2008).

Stroke volume is the blood volume the heart is able to empty in a single pump. Together with the maximal heart rate, which is the highest frequency the heart is capable of pumping, it determines the minute volume, which is the largest blood volume the heart can pump in one minute (Joyner & Coyle, 2008).

Hemoglobin content is the amount of hemoglobin present in the blood plasma. Hemoglobin is an iron-containing protein with a high affinity for oxygen, and is present in the erythrocytes, also known as red blood cells. Hemoglobin therefore enables erythrocytes to carry oxygen diffusing into the blood plasma from the lungs, thus determining the amount of oxygen that can be carried by the cardiovascular system (Joyner & Coyle, 2008).

Aerobic enzymes are enzymatic proteins present in the cell organ mitochondria, which is commonly known as the powerhouse of the cell, and they contribute to the oxidative processes of synthesizing adenosine triphosphate (ATP), which is the main energy substrate in the human body. The total aerobic enzyme activity is therefore dependent on mitochondrial density. Enzymes are fitted to a certain environment, and aerobic enzyme activity may therefore also be affected by environmental factors, such as temperature, pH, and the regulatory influence by other enzymes (Joyner & Coyle, 2008).

The distribution of power output affects how the power output is distributed between muscle fibers within a muscle. If able to rotate power production between a larger number of fibers, the total glycolytic stress is distributed across more fibers, thus reduced per fiber. This could delay the activation of type II fibers, which are less efficient than type I fibers (Joyner & Coyle, 2008).

Together, these six components determine $\dot{V}O_{2max}$. Because $\dot{V}O_{2max}$ is the maximal rate of which humans are able to consume oxygen, it is by extension the highest turnover rate of metabolic energy that can be achieved through oxidative processes. This involves transporting pyruvate (derived from fat and carbohydrates) into the mitochondria, where it is metabolized in the Krebs cycle, which supplies metabolites essential to synthesizing ATP by oxidative phosphorylation in the electron transport chain. If the oxidative capacity is exceeded, pyruvate can no longer be transported into the mitochondria, and is instead converted into lactate with

H^+ as a byproduct. Champion endurance athletes have a $\dot{V}O_{2max}$ potentially twice the size of normally active and healthy young adults, mainly due to their increased blood volume, increased capillary density, mitochondrial density, and especially increased cardiac stroke volume. Women usually have a 10 % lower $\dot{V}O_{2max}$ than men due to lower hemoglobin concentrations and more body fat. Elite $\dot{V}O_{2max}$ therefore range from 70 to 85 ml/kg/min (Joyner & Coyle, 2008).

As the highest sustainable power output is limited to the equivalent of ~70 % $\dot{V}O_{2max}$ by the power-duration relationship, duration determines the highest $\dot{V}O_2$ that can be maintained when intensity level exceeds sustainable power outputs. The highest maintainable $\dot{V}O_2$ for any given duration is known as performance $\dot{V}O_2$ (Joyner & Coyle, 2008).

2.4.2 Anaerobic components

Performance power also has an anaerobic component, the anaerobic capacity. It is determined by the magnitude of the anaerobic energy stores and the buffering capacity of H^+, but also the distribution of power output, as it effects the utilization of local anaerobic energy substrates (Joyner & Coyle, 2008).

2.4.3 Gross mechanical efficiency

The final component to performance power is gross mechanical efficiency, which is determined by the ratio of different muscle fiber types, as well as the anthropometry and elasticity of the components forming the human body, such as knuckles, skeletal muscles, tendons, and ligaments. The degree to which these factors are optimized determines how efficiently metabolic energy is translated into mechanical work, providing power and velocity. A higher gross mechanical efficiency therefore results in a lower oxygen demand (${O_2}^{dem}$) for any given power output. The ${O_2}^{dem}$ of running at a certain velocity can vary from 30 to 40 % between individuals, while cycling have less variation, from 20 to 30 %. This suggests a larger variation in gross mechanical efficiency in movement of biomechanical complexity (Joyner & Coyle, 2008).

2.5 $\dot{V}O_2$ kinetics

Burnley and Jones (2007) emphasize that the components in the model presented by Joyner and Coyle (2008) only indirectly determine endurance exercise performance, as $\dot{V}O_2$ kinetics serve as the conduit in between the two. The components regulate the $\dot{V}O_2$ response in different ways, and the $\dot{V}O_2$ kinetics directly determine exercise tolerance by affecting the rate and mixture of aerobic and anaerobic energy substrate utilization, and the rate of which heat is stored, and waste metabolites accumulated.

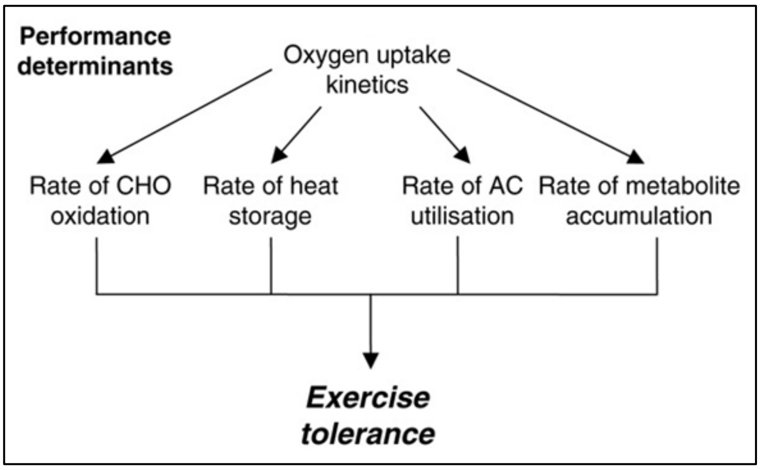


Figure 2.3: *A model illustrating how $\dot{V}O_2$ kinetics affect exercise tolerance. Adopted from Burnley & Jones (2007).*

2.5.1 Phases of $\dot{V}O_2$ kinetics

$\dot{V}O_2$ kinetics are dependent on the rate of blood arriving at the pulmonary capillary network, and to which degree the blood is deoxygenated. There is, however, a 10-20 second delay for deoxygenated blood to reach the pulmonary capillaries, and pulmonary $\dot{V}O_2$ does therefore initially not reflect muscle oxygen consumption directly. $\dot{V}O_2$ still increases during this delay, due to an elevated cardiac output. This is phase I of the $\dot{V}O_2$ kinetics, and it is called the cardio-dynamic phase. During the cardio-dynamic phase, venous partial pressure of oxygen (PO_2) and carbon dioxide (PCO_2), and the respiratory exchange rate (RER), are not yet affected. Phase II $\dot{V}O_2$ kinetics are signaled by an abrupt change in these variables, in addition to an exponential increase in $\dot{V}O_2$. At this point, pulmonary $\dot{V}O_2$ reflects the kinetics of muscle oxygen consumption, especially at higher power outputs, because more of the cardiac output is directed to the exercising muscles and signal-to-noise ratio is higher. The third and final phase of $\dot{V}O_2$ kinetics is signaled by $\dot{V}O_2$ moving towards a steady state, unless power outputs exceed the heavy intensity domain, in which case the $\dot{V}O_2$ slow component drives $\dot{V}O_2$ towards $\dot{V}O_{2max}$ (Burnley & Jones, 2007).

2.5.2 The $\dot{V}O_2$ fast component

The $\dot{V}O_2$ response within phase II is close to mono-exponential and known as the fast (or the primary) component of the $\dot{V}O_2$ kinetics. The speed of the $\dot{V}O_2$ fast component is dependent on the responsiveness of the $\dot{V}O_2$, which can be highly individual, but it is usually completed within a few minutes. Due to the limited responsiveness of $\dot{V}O_2$, ${O_2}^{dem}$ will initially exceed

$\dot{V}O_2$, even if it is within an attainable range of $\dot{V}O_2$. Faster phase II $\dot{V}O_2$ kinetics therefore reduce oxygen deficit (${O_2}^{def}$) and the requirement for anaerobic energy supply, while blunting fatigue related metabolites (Burnley & Jones, 2007).

2.5.3 The $\dot{V}O_2$ slow component

The $\dot{V}O_2$ slow component emerges due to reduced efficiency when exercising within, or above, the heavy intensity domain, resulting in a greater energy expenditure, draining the body's fuel stores more rapidly. Therefore, if an athlete wishes to preserve the endogenous fuel supplies, the exercise intensity must be maintained within the moderate intensity domain. The more the LT (the upper limit of the moderate intensity domain) is exceeded, the greater the $\dot{V}O_2$ slow component develops, and the faster the endogenous fuel stores are drained. The slow component also leads to a greater rate of heat accumulation and potentially an earlier attainment of hyperthermia and dehydration. Because $\dot{V}O_{2max}$ is the maximal attainable rate of oxygen consumption, $\dot{V}O_{2max}$ determines the extent to which the $\dot{V}O_2$ slow component can develop. When the $\dot{V}O_2$ slow component drives the $\dot{V}O_2$ to $\dot{V}O_{2max}$, exhaustion is imminent (Burnley & Jones, 2007).

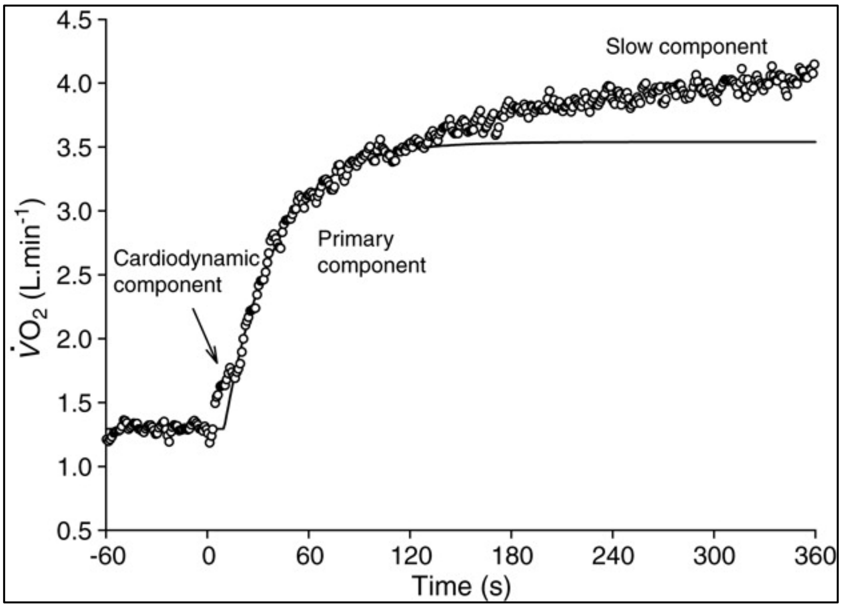


Figure 2.4: *An illustration of $\dot{V}O_2$ kinetics, including the three phases with the cardio-dynamic, the fast (primary) and the slow $\dot{V}O_2$ component. Adopted from Burnley & Jones (2007).*

2.5.4 Manipulating the $\dot{V}O_2$ kinetics for enhanced endurance exercise performance

Endurance exercise performance can be enhanced by improving exercise tolerance through faster $\dot{V}O_2$ kinetics. $\dot{V}O_2$ kinetics can be altered by a change in LT, MLSS or $\dot{V}O_{2max}$ through training, and phase II $\dot{V}O_2$ kinetics can be sped up by 50% in 4-6 weeks, which has a significant effect on the initial accumulation of ${O_2}^{def}$. $\dot{V}O_2$ kinetics can also be acutely affected through preceding exercise. Prior exercise can affect $\dot{V}O_2$ kinetics in subsequent exercise by speeding phase II $\dot{V}O_2$ kinetics and reducing the magnitude of phase III $\dot{V}O_2$ kinetics. It has been suggested that this is related to altered motor unit recruitment. Another way to acutely affect $\dot{V}O_2$ kinetics is through pacing strategies. A fast pace start with positive pacing can speed $\dot{V}O_2$ kinetics at the start of the exercise and improve time to exhaustion (TTE) when comparing with slow start with negative pacing and normal start with constant pacing of the same average power output (Burnley & Jones, 2007).

In summary, endurance exercise performance is related to $\dot{V}O_2$ kinetics that are determined by the aerobic and anaerobic capacity's ability to provide metabolic energy, and the efficiency of which it is converted into power and velocity.

2.6 Endurance in intermittent exercise

Some endurance sports distinguish themselves with characteristics of intermittent exercise, consisting of recurring work bouts of high and low intensity. During the high-intensity work bouts, ${O_2}^{dem}$ may exceed $\dot{V}O_2$, leading to accumulation of ${O_2}^{def}$ and depletion of anaerobic energy stores, which results in accumulation of fatigue related metabolites. This negatively affects the power output a muscle is able to produce. The ability to recover is therefore critical to complete the subsequent work bouts. The recovery of muscle power output correlates greatly with PCr resynthesis. PCr depletion is therefore likely a major factor in the development of fatigue during intermittent exercise (Glaister, 2005). Recovery of PCr is an oxidative process, and so $\dot{V}O_2$ remains elevated when ${O_2}^{dem}$ is reduced during the low-intensity work bouts, to provide excess oxygen for PCr resynthesis. The recovery is biphasic, with 70 % of the phosphagens restored within 30 seconds and 100% restored within 3 to 5 minutes. If recovery durations are too short, PCr is only partially recovered, and subsequent capacity for high-intensity work is reduced. Aerobic fitness will therefore contribute to greater performance by reducing the PCr depletion due to greater aerobic power, while also restoring PCr quicker due to speedier $\dot{V}O_2$ kinetics. Additionally, endurance trained have been reported to have enhanced PCr stores, potentially delaying fatigue (Tomlin & Wenger, 2012).

2.7 Cross-country skiing

XC skiing is a sport combining traditional endurance elements with intermittent exercise. The sport is divided into two separate technical styles called classic and skate. Competitions range from sprint (< 1.8 km) to distance (≥ 10 km for women and ≥ 15 km for men). The sport has a similar aerobic proportion of total energy expended during competitions compared to other sports with similar race durations. However, the topography of the racecourse is frequently shifting, typically altering every 10-35 seconds. Ascending, descending, and flat segments are evenly distributed, but due to the combination of a frequently shifting topography, the gliding properties of the skis, and the gravitational acceleration, large variations in race velocity occur. Therefore, approximately 50% of the race duration is spent in ascending segments, while 35% is spent in flat segments, and 15% is spent in descending segments. The downhill segments provide opportunities for recovery. This allows for high-intensity non-sustainable efforts to be exerted during other parts of the race. The high-intensity efforts are usually performed in ascending segments because of the increased resistance and lower velocity imposed by the ascending terrain, which allows for a longer ground contact time and larger force-impulse. This increases the muscle mass activated and the amount of ${O_2}^{def}$ that can be accumulated. Additionally, the effort required to overcome the air drag is reduced at lower velocities. Because the terrain is constantly shifting, XC skiers frequently transition between the sub- and supra-maximal efforts, giving the race an intermittent characteristic, which effectively results in phases of recovery and high-intensity work during a race (Losnegard, 2019). The recovery phases typically have an ${O_2}^{dem}$ of 40-60% of $\dot{V}O_{2max}$ (Sandbakk & Holmberg, 2017), while the ${O_2}^{dem}$ of the most intense supra-maximal efforts can be as high as 160% peak aerobic power, requiring a significant anaerobic contribution (Karlsson, Gilgien, Gløersen, Rud, & Losnegard, 2018). The ascending segments have proved to be the most differentiating segments with regards to performance (Sandbakk, et al., 2016), suggesting the ability to repeat supra-maximal efforts throughout the race is an important determinant for performance in XC skiing.

The large variation in race velocity requires effective gearing by the usage of different sub-techniques, involving complex movement of both lower and upper limbs. The classic style consists of five sub-techniques, while the skate style consists of six sub-techniques, and XC skiers typically transition 25 times between sub-techniques per kilometer. XC skiing is therefore a biomechanically complex sport where technical abilities are crucial for moving efficiently. The variety in velocity also results in a strategical challenge with regards to pacing, rewarding XC skiers for optimizing their pacing strategy. A positive pacing is usually observed during XC skiing races, which might have a positive effect on $\dot{V}O_2$ kinetics, speeding up the fast component and reducing the initial accumulation of ${O_2}^{def}$, while also reducing the $\dot{V}O_2$ slow component (Losnegard, 2019).

The high-intensity efforts performed in XC skiing results in significant accumulation of ${O_2}^{def}$. Gløersen et al. (2020) reported ${O_2}^{def}$ to be accumulated in bulks of < 20% $MAOD$ on average and no more than 50% $MAOD$ during a simulated XC skiing distance race. However, the total $\sum {O_2}^{def}$ amounted to nearly 4 times $MAOD$. XC skiing performance therefore seems to be limited by the ability to repeatedly accumulate smaller bulks of ${O_2}^{def}$ amounting to a large total, rather than the maximal capacity to accumulate ${O_2}^{def}$ during a single high-intensity work bout.

3. Methods

3.1 Subjects

Twenty-two male cross-country (XC) skiers were recruited for the study and assigned into a competitive ($n = 12$) and a recreational ($n = 10$) group. All subjects signed a written consent, and the study was approved by both the ethics committee of the Norwegian School of Sport Sciences and the Norwegian Center for Research Data. The research was conducted according to the Declaration of Helsinki.

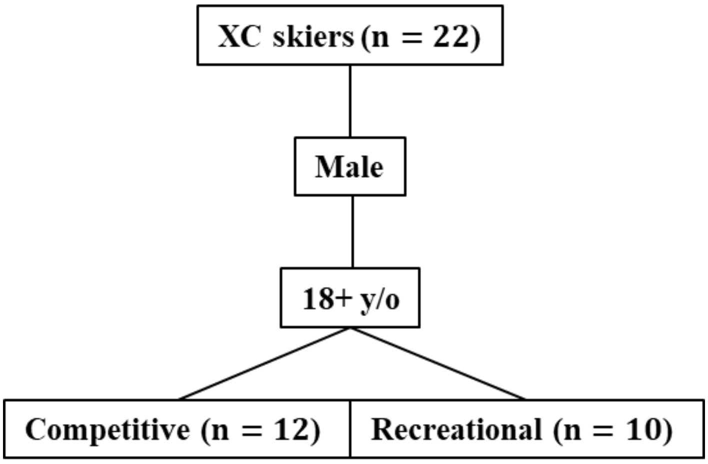


Figure 3.1: *Distribution of competitive and recreational XC skiers, separated into two different groups representing their skill level.*

There was no difference between the two groups regarding age, height, or bodyweight. The competitive group did, however, have a lower body mass index (BMI). An overview of the two groups is provided in table 3.1.

Table 3.1: *Group-average age and anthropometrics of subjects, including height, bodyweight, and body mass index (BMI).*

	Competitive (n = 12)	**Recreational (n = 10)**	**Difference (%) [95% CI]**
Age (y/o)	24 ± 5	26 ± 3	−7 [−21, 7]
Height (cm)	183 ± 7	181 ± 6	1 [−2, 4]
Bodyweight (kg)	76.2 ± 4.5	79.1 ± 6.9	−4 [−10, 3]
BMI (kg·m^2)	22.8 ± 0.7	24.1 ± 1.9	−5 [−11, −0.2] *

Note: *BMI = body mass index, CI = confidence interval, asterisk = significant group difference (*$* = p < 0.05$, $** = p < 0.01$*).*

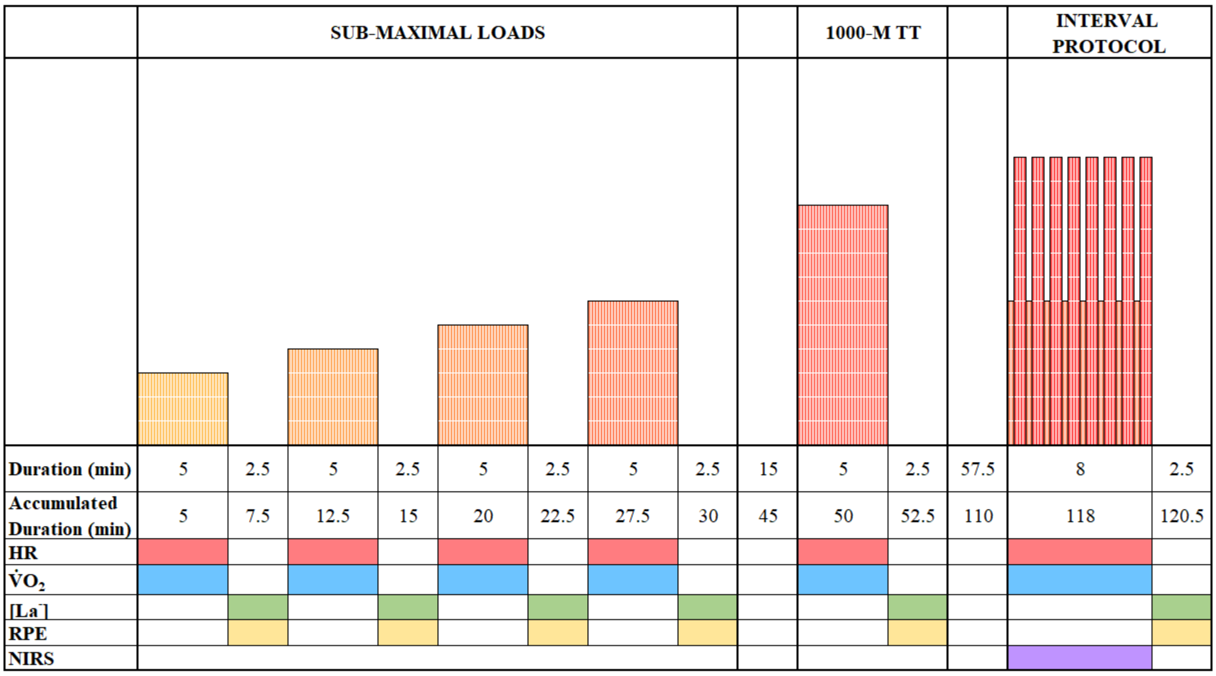
3.2 Overview of experimental procedures

The experiment consisted of three different protocols conducted on a roller ski treadmill, all completed within a single session lasting 2.5 hours. All three protocols were performed using the V2 ski skating technique, which is a technique utilized at moderate to high velocities, involving a double pole plant for each ski push-off. The first two protocols were functionally baseline protocols, determining the individualized intensity applied to the third and main protocol. Subjects were shown a timeline of the session and received relevant instructions verbally ahead of each protocol.

The first protocol was intended to quantify skiing economy (Eco_{ski}) and consisted of several five-minute long sub-maximal loads. It was preceded by a ten-minute warm-up consisting of easy skiing.

Approximately fifteen minutes after the final sub-maximal load was completed, the second protocol was performed. During the fifteen-minute break, subjects were allowed easy skiing concluded by a short burst of high intensity before resting in a stand-still position for two minutes. The second protocol was designed as a 1000-meter time-trial (TT) (Losnegard, Myklebust, Spencer, & Hallén, 2013), with the purpose of quantifying $\dot{V}O_{2max}$ and $MAOD$. The subjects started from a stand-still position and were counted down to start. They completed the first one hundred meters at a set velocity, which was increased by 0.25 $m \cdot s^{-1}$ for the next one hundred meters. After completing the first two hundred meters, the subjects could adjust the velocity as they wished in increments of 0.25 $m \cdot s^{-1}$.

After the 1000-meter TT, subjects had a one-hour break, free to eat, drink and go to the bathroom. During the final quarter of the break, the subjects performed easy skiing concluded by a short high intensity burst before resting for two minutes ahead of the main protocol. The main protocol was designed as an interval protocol consisting of recovery- and work phases repeating in cycles and was intended to quantify TTE at a similar relative intensity. It was therefore individually tailored to each subject's maximal aerobic power (MAP) by standardizing for $\dot{V}O_{2max}$ and Eco_{ski}. Each cycle of the protocol averaged an intensity of 100% MAP. The subjects started from a stand-still position, were counted down to start, and continued until exhaustion.



	SUB-MAXIMAL LOADS									1000-M TT			INTERVAL PROTOCOL	
Duration (min)	5	2.5	5	2.5	5	2.5	5	2.5	15	5	2.5	57.5	8	2.5
Accumulated Duration (min)	5	7.5	12.5	15	20	22.5	27.5	30	45	50	52.5	110	118	120.5
HR	🟥		🟥		🟥		🟥			🟥			🟥	
$\dot{V}O_2$	🟦		🟦		🟦		🟦			🟦			🟦	
$[La^-]$		🟩		🟩		🟩		🟩			🟩			🟩
RPE		🟨		🟨		🟨		🟨			🟨			🟨
NIRS													🟪	

Figure 3.2: *A simplified overview of the experimental procedure, including protocol intensity, duration and measurements taken. Explanation for the measurements follows:* HR *= heart rate,* $\dot{V}O_2$ *= rate of oxygen consumption,* $[La^-]$ *= blood plasma lactate concentration,* RPE *= subjective rate of perceived exertion, NIRS = near-infrared spectroscopy.*

3.3 Baseline protocols

3.3.1 Sub-maximal protocol

The subjects completed three to four loads, each increasingly more intense than the last and separated from the next by a 2.5-minute break. The intensity was increased by adjusting the incline (range 2.5-7.0 °), usually in increments of 0.5 °, while keeping the velocity constant at 3 $m \cdot s^{-1}$. The subjects started each load from a stand-still position on the treadmill, which was adjusted to the incline of the upcoming load, and they were counted down to start. The protocol was aborted after the third load if RPE (Borg, 1982) exceeded 14 or blood lactate concentrations $[La^-]$ dramatically increased. This was assessed during the breaks, immediately after a load was completed. A graphical RPE scale was provided to assist subjects evaluate their perceived exertion, which they communicated verbally. $\dot{V}O_2$ was measured and propulsive power (P_{prop}) was calculated for each load, and Eco_{ski} was determined from the assumed linear relationship between these two variables (Noordhof, de Koning, & Foster, 2010). The subjects had the option to start each load without the ventilation hose inserted into their mouth. When approximately three minutes remained of any ongoing load, the subjects inserted the ventilation hose by themselves, while the treadmill remained in motion. They held on to a railing in front of them with one hand while inserting the ventilation hose into the mouth with the other. After successfully inserting the ventilation hose, the subjects let go of the railing and continued skiing for the rest of the load. The nose clip was, however, worn throughout the entirety of each load, due to the difficulty of attaching it mid-protocol, as both arms were needed for the task. The instant heart rate (HR) was registered when thirty seconds remained of each load, and it was monitored together with RPE and $[La^-]$ to evaluate each subject's effort. During the breaks, subjects were allowed to drink, and they were informed about the $[La^-]$, $\dot{V}O_2$ and HR measured during the preceding load, as well as the velocity and incline for the subsequent load.

3.3.2 1000-meter time-trial

The subjects started the protocol from a stand-still position and were counted down to start. The subjects completed the first one hundred meters at a set velocity, which was increased by 0.25 m·s^{-1} for the next one hundred meters. After completing the first two hundred meters, the subjects could adjust the velocity as they pleased in increments of 0.25 m·s^{-1} by crossing either of two laser beams (BDL120, Black and Decker, Towson, Maryland, USA) with the front wheels of their roller skis; a laser beam in front to increase velocity and another one behind to decrease velocity. The velocity was adjusted manually by the test leader. If the subjects were clearly struggling to keep up with the treadmill, the velocity would be decreased with two or more increments, until they were able to get back into position. The incline was set to 6 ° for all subjects, and starting velocity was 3.25 m·s^{-1}, unless the subject's physical capacity required it to be reduced. The subjects were repeatedly informed verbally of the completed distance, and they were also able to see the completed distance visually on a screen in front of them. Subjects were, however, not verbally, or in any other way, intentionally encouraged or motivated to endure during the protocol by testing personnel. $\dot{V}O_2$ was measured during the entire protocol. HR, RPE and $[La^-]$ were monitored to evaluate each subject's effort.

3.4 Main protocol

3.4.1 Interval protocol

The interval protocol consisted of two phases repeating in cycles; a recovery phase lasting twenty seconds at 60% MAP, followed by a work phase at 120% MAP lasting forty seconds, resulting in an average intensity of 100% MAP. The intensity was fitted to each subject's MAP by adjusting the incline (range 2.6-5.1 °) while keeping the velocity of each of the two phases at 2.75 and 5.50 m·s^{-1}. Velocity was kept within this range so that it would be suited for the V2 ski skating technique. Apart from starting and stopping, the protocol was completely automated by adjusting parameters in the treadmill software ahead of start. The subjects continued until exhaustion, determined by crossing a laser line placed behind the defined protocol area on the treadmill, or by actively aborting the protocol. They were repeatedly informed verbally how much time remained of the current phase, usually after having completed ½ and ¾ of the phase. Additionally, the final three seconds of the phase were counted out loud. The subjects were also able to see the remaining time on a screen in front of them. Subjects were, however, not verbally, or in any other way, intentionally encouraged or motivated to endure during the protocol by testing personnel. $\dot{V}O_2$ was measured during the entire protocol. HR, RPE and $[La^-]$ were monitored to evaluate each subject's effort. Additionally, measurements of muscular blood oxygen saturation were attempted with a near-infrared spectroscopy (NIRS) sensor attached laterally on the subjects' thigh to quantify local oxygenation in the m. vastus lateralis. The attempt was, however, unsuccessful due to an excessive amount of noise distorting the data.

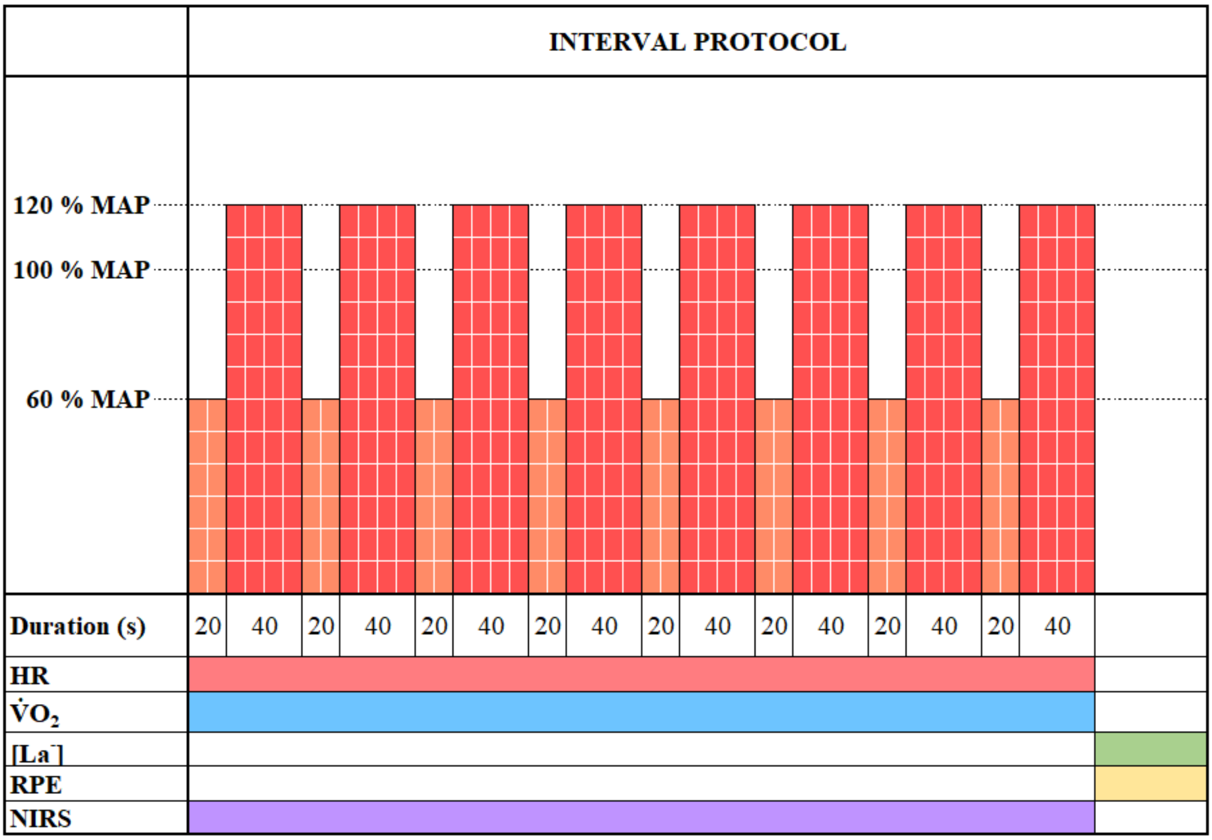


Figure 3.3: *A simplified overview of the experimental procedure, including protocol intensity, duration and measurements taken. Explanation for the measurements follows:* HR *= heart rate,* $\dot{V}O_2$ *= rate of oxygen consumption,* $[La^-]$ *= blood plasma lactate concentration,* RPE *= subjective rate of perceived exertion, NIRS = near-infrared spectroscopy.*

3.5 Instruments and materials

All subjects wore the same pair of Swenor Skate Long (Sarpsborg, Norway) roller skis. The use of roller skis in a laboratory environment sacrifices external validity to some degree in trade of higher internal validity and more reliable test data. All protocols were performed with the same wheel type for the sake of consistency and internal validity, and wheel type 1 (coefficient of rolling resistance $(C_{rr}) = 0.014$) was chosen, as it is the standard for the 1000-meter TT that is regularly performed in the particular lab. Wheel type 2 is, however, more similar to snow ski gliding resistance. However, because the rolling resistance was accounted for when calculating the protocol intensity, the choice of wheel type 1 should not be an issue to the external validity. The roller skis were equipped with ski binding type NNN from Rottefella (Klokkarstua, Norway). The subjects selected their preferred pair of Swix Triac 3.0 (Swix Sport, Lillehammer, Norway) from the assortment available in the lab. In the rare instances where no suitable pole length of Triac 3.0 was available, a pair of Swix Triac 2.5 was used instead. The poles were equipped with custom ferrules specifically designed for treadmill roller skiing. After selecting a pair of poles, the subjects stayed with it for all three protocols, but the ferrules were substituted if they got worn out. The subjects wore their personal ski boots and HR monitor, unless they requested to borrow a monitor from the lab. For safety reasons, subjects wore a harness which was strapped to a rope connected to an automatic emergency brake system during the 1000-meter TT and the interval protocol, preventing the subjects from hitting the ground if they were to lose their balance or get thrown off the treadmill due to exhaustion or some other reason. The total weight of the equipment worn by the subjects was approximately 3.5 kg. The treadmill was a model custom made by Rodby (Rodby Innovation AB, Hagby, Vänge, Sweden), dimensioned 300 cm wide and 450 cm long. Pulmonary gas exchange was measured with the mixing chamber method, using an automatic ergo spirometry system (Oxycon Pro; Jaeger GmbH, Höchberg, Germany) previously validated by Foss & Hallén (2005). $[La^{-}]$ was measured using capillary fingertip samples of blood (Biosen C-line, EKF diagnostic GmbH, Magdeburg, Germany). Both systems were calibrated according to the manufacturers' specifications. The NIRS sensor model was PortaMon (Artinis Medical Systems, Zetten, the Netherlands). Body mass and mass including equipment were measured using an electronic body-mass scale (Seca model nr: 877; Seca GmbH & Co., Hamburg, Germany).

3.6 Data analysis

MAP was defined as P_{prop} yielding $\dot{V}O_{2max}$, based on the assumption of a constant $\dot{V}O_2$ to P_{prop} ratio (Noordhof, de Koning, & Foster, 2010) determined during the sub-maximal loads and termed skiing efficiency (Eco_{ski}). MAP was calculated by the following relation:

$$MAP = \frac{\dot{V}O_{2max} \cdot P_{prop_{sm}}}{\dot{V}O_{2_{sm}}} \tag{1}$$

where $\dot{V}O_{2max}$ is the highest 60 second average measured during the 1000-meter TT. $P_{prop_{sm}}$ is the average P_{prop} required during the sub-maximal loads. $\dot{V}O_{2_{sm}}$ is the average $\dot{V}O_2$ measured during the final two minutes of each sub-maximal load.

P_{prop} was defined as the mechanical energy needed to overcome the forces of gravity and friction. Air resistance was neglected, due to the protocols being conducted on a treadmill, meaning subjects were standing still relative to their surroundings. P_{prop} was calculated by the following relation:

$$P_{prop} = m_{BW+E} \cdot g \cdot v \cdot (sin(\theta) + C_{rr} \cdot cos(\theta)) \tag{2}$$

where m_{BW+E} is the combined mass of the subject and equipment worn, $g = 9.81 \text{ m} \cdot \text{s}^{-1}$ is the acceleration due to the force of gravity, v is the velocity of the treadmill, $C_{rr} = 0.014$ is the coefficient of rolling resistance, and θ is the angle of the treadmill incline in degrees.

By applying the 1. order Taylor approximation, it can be assumed that $sin(\theta)$ is equal to θ, and $cos(\theta)$ is equal to 1, when θ is small and measured in radians. Equation 1 can thus be reworked into the following variations:

$$P_{prop} = m_{BW+E} \cdot g \cdot v \cdot (\theta + C_{rr}) \tag{3}$$

$$\theta = \frac{P_{prop}}{m_{BW+E} \cdot g \cdot v} - C_{rr} \tag{4}$$

Equation 4 was utilized to calculate the individualized interval protocol intensity for each subject. Because the velocity was already pre-determined for both phases to accommodate the V2 ski skating technique, the protocol intensity had to be fitted by adjusting the incline of the treadmill. The appropriate angle was then calculated by setting P_{prop} equal to the intended power output for the respective interval protocol phase ($P_{prop_{recovery}} = 0.6 \cdot MAP, P_{prop_{work}} = 1.2 \cdot MAP$) and v equal to the velocity of the treadmill during the respective interval protocol phase ($v_{recovery} = 2.75 \text{ m} \cdot \text{s}^{-1}, v_{work} = 5.50 \text{ m} \cdot \text{s}^{-1}$).

Gross efficiency (GE) was determined as the percentage of metabolic energy converted into P_{prop}, and calculated by the following relation:

$$GE = \frac{P_{prop}}{P_{met}} \times 100 \tag{5}$$

where P_{met} is the metabolic energy turnover rate calculated by the following relation (Garby & Astrup, 1987):

$$P_{met} = \frac{(4.94 \times RER + 16.04) \times VO_2}{60} \tag{6}$$

The maximal accumulated oxygen deficit ($MAOD$) was determined by subtracting the ${O_2}^{dem}$ from the average $\dot{V}O_2$ measured during the 1000-meter TT. ${O_2}^{dem}$ was calculated from the average P_{prop}.

$\dot{V}O_{2peak}$ was defined as the highest 30 second average $\dot{V}O_2$ that was measured during the interval protocol.

3.7 Statistics

Normality of data distribution was investigated using a Shapiro-Wilk Test. For normally distributed data, mean differences were analyzed performing an independent-samples t-test, while skewed data were analyzed with a non-parametric Mann-Whitney test using SPSS version 24.0.0.2 (IBM Corp., Armonk, NY). Mean averages are reported along with their adjoining standard deviation (SD). Mean differences are reported along with their adjoining 95% confidence interval (CI) as percentages. The threshold for statistical significance was defined as $p < 0.05$. Figures are constructed using GraphPad Prism 9 (GraphPad Software, San Diego, CA). In tables and figures, $p < 0.05$ is indicated by a single asterisk, while $p < 0.01$ is indicated by a double asterisk.

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5. Article

Title: Competitive cross-country skiers have a longer time to exhaustion and a larger accumulation of oxygen deficit than recreational cross-country skiers during an intermittent interval protocol standardized for MAP.

Abstract

Purpose: To compare a competitive and a recreational group of cross-country (XC) skiers in time to exhaustion (TTE) and accumulation of oxygen deficit (${O_2}^{def}$) in an intermittent interval protocol standardized for maximal aerobic power (MAP).

Methods: Twenty-two male XC skiers were recruited for the study and assigned into a competitive ($n = 12$) and a recreational ($n = 10$) group of similar age, weight, and height. All protocols were performed using the V2 ski skating sub-technique with roller skis on a treadmill. First, they performed two baseline protocols (sub-maximal loads and 1000-meter time-trial (TT)), to quantify MAP and maximal accumulation of oxygen deficit ($MAOD$). After a 60-minute break, they performed an intermittent interval protocol individually tailored to each subject's MAP. The test consisted of two phases repeating in cycles; a recovery phase lasting 20 seconds at 60% MAP, followed by a work phase at 120% MAP lasting 40 seconds, resulting in each cycle averaging an intensity of 100% MAP. TTE was measured along with oxygen consumption ($\dot{V}O_2$) and $\sum {O_2}^{def}$.

Results: The competitive group was faster during the 1000-meter TT and had a higher maximal rate of oxygen consumption ($\dot{V}O_{2max}$), gross efficiency (GE) and MAP than the recreational group. $MAOD$ was, however, similar for both groups. During the interval protocol, the competitive group had a 34 [3, 65] % longer TTE (473 ± 141 vs. 353 ± 94 s, p = 0.032), and accumulated a 45 [22, 68] % larger ${O_2}^{def}$ (112 ± 18 vs. 77 ± 20 %$MAOD$, p = 0.001) than the recreational group.

Conclusion: The competitive group had a longer TTE and a larger $\sum {O_2}^{def}$ than the recreational group during an intermittent interval protocol standardized for MAP. This implies that TTE could be related to the ability to repeatedly accumulate smaller bulks of ${O_2}^{def}$ amounting to a large total.

Introduction

Performance in endurance sports is analogous to moving through a defined racecourse in a shorter period of time than the competitors. From a physiological perspective, this translates to sustaining a high metabolic energy turnover rate, while efficiently converting the metabolic energy into a greater mechanical power output, and by extension a higher velocity, thus completing the racecourse more quickly. There is, however, an upper threshold to sustainable turnover rates, and the conversion efficiency (Eco), of metabolic energy. Endurance sports are therefore often performed at a steady-state sub-maximal intensity called "performance $\dot{V}O_2$", which is the highest fraction of the maximal rate of oxygen consumption ($\dot{V}O_{2max}$) that can be sustained for the duration of the competition. The relationship between performance $\dot{V}O_2$ and competition duration is inversely related, meaning that a longer duration results in a lower performance $\dot{V}O_2$. Eco further determines the velocity that performance $\dot{V}O_2$ translates to (Joyner & Coyle, 2008). Performance $\dot{V}O_2$ and Eco are therefore considered two of the main determinants of performance in many endurance sports.

Some endurance sports, like cross-country (XC) skiing, distinguish themselves with characteristics of intermittent exercise. Performance $\dot{V}O_2$ and Eco are still considered important performance determinants (Saltin & Åstrand, 1967; Mahood, Kenefick, Kertzer, & Quinn, 2001; Losnegard, 2019). However, descending segments, in combination with the gliding properties of the skis and the gravitational acceleration, provide opportunities for recovery, which allows for shorter bursts of non-sustainable efforts, typically occurring in ascending segments. Thus, athletes frequently transition between sub- and supra-maximal efforts, which effectively results in phases of recovery and work during a race. The recovery phases typically have an oxygen demand (${O_2}^{dem}$) of 40-60% $\dot{V}O_{2max}$ (Sandbakk & Holmberg, 2017), while the ${O_2}^{dem}$ of the most intense supra-maximal efforts can be as high as 160% peak aerobic power (Karlsson, Gilgien, Gløersen, Rud, & Losnegard, 2018). Ascending segments account for approximately 50% of the race duration, and they have proved to be the most differentiating segments with regards to performance (Sandbakk, et al., 2016; Sollie, Gløersen, Gilgien, & Losnegard, 2021). Additionally, XC skiers of an inferior skill level typically show a stronger positive pacing (velocity decreasing throughout the race), and performance can therefore be defined as the ability to repeatedly perform supra-maximal efforts while minimizing the reduction in pace throughout the race (Losnegard, 2019).

The duration a single bout of supra-maximal effort can be maintained is related to the maximal capacity to accumulate oxygen deficit ($MAOD$) (Medbø & Tabata, 1989). Losnegard et al. (2013) examined the predictability of $\dot{V}O_{2max}$, Eco, and $MAOD$ on FIS skiing distance race points, and the variables accounted for approximately 70% of the variation between skiers. Although this might be considered a high degree of predictability, it is apparent that there are additional determinants of XC skiing performance. One possible additional performance determinant is the ability to repeatedly accumulate smaller bulks of oxygen deficit (${O_2}^{def}$) amounting to a large total. Gløersen et al. (2020) reported ${O_2}^{def}$ to be accumulated in bulks of < 20% $MAOD$ on average and no more than 50% $MAOD$ during a simulated XC skiing distance race. The total $\sum {O_2}^{def}$ was, however, approximately 4 times the magnitude of $MAOD$. Therefore, it appears that it is not simply $MAOD$ that matters, but rather the ability to accumulate a total that, by far, exceeds $MAOD$ through repeated accumulation of much smaller bulks of ${O_2}^{def}$. This is an aspect of XC skiing that is not sufficiently investigated, as the majority of previous literature has focused on $\dot{V}O_{2max}$ and Eco in roller ski protocols with a constant intensity profile.

The purpose of the current study was to compare a competitive and a recreational group of cross-country skiers in time to exhaustion (TTE) and $\sum {O_2}^{def}$ in an intermittent interval protocol standardized for maximal aerobic power (MAP). The hypothesis was that the competitive group would have (1) a longer TTE and (2) a larger $\sum {O_2}^{def}$ than the recreational group due to a greater ability to repeatedly accumulate ${O_2}^{def}$.

Methods

Subjects

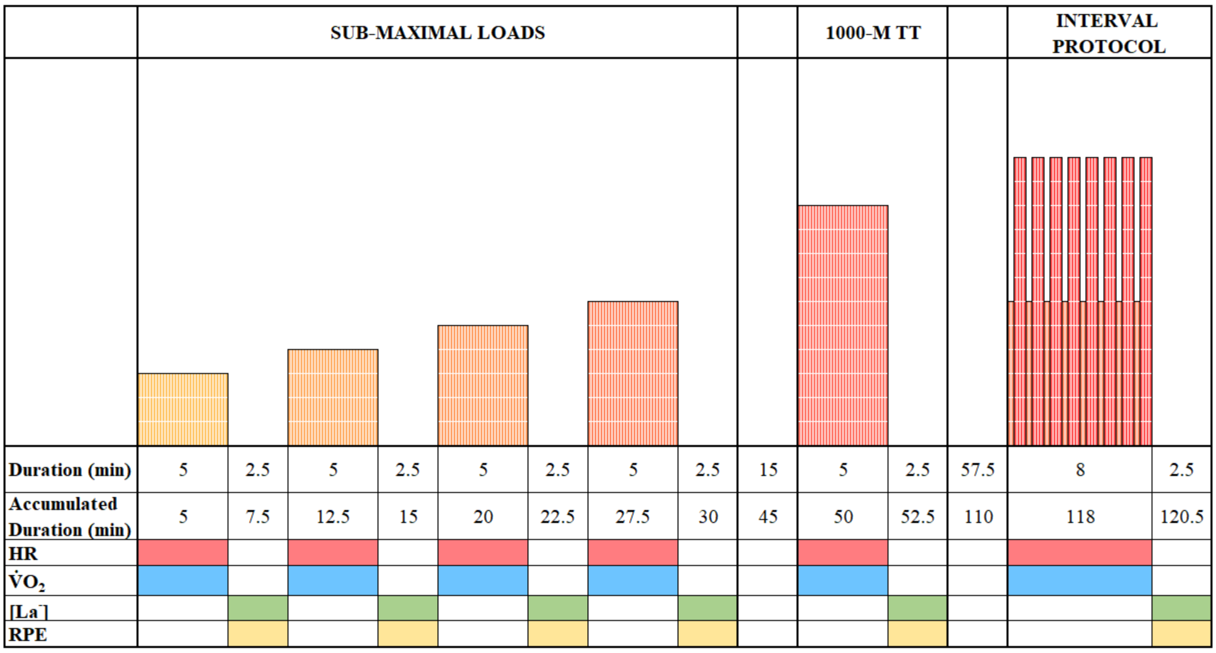
For the study, a group of competitive ($n = 12$) and recreational ($n = 10$) XC skiers were recruited. There was no difference between the two groups regarding age (24 ± 5 vs. 26 ± 3 y/o, p = 0.322), height (183 ± 7 vs. 181 ± 6 cm, p = 0.552), or bodyweight (76.2 ± 4.5 vs. 79.1 ± 6.9 kg, p = 0.258). All subjects signed a written consent, and the study was approved by both the ethics committee of the Norwegian School of Sport Sciences and the Norwegian Center for Research Data. The research was conducted according to the Declaration of Helsinki.

Overview of experimental procedures

The experiment consisted of three different protocols conducted on a roller ski treadmill, all completed within a single session lasting 2.5 hours. All three protocols were performed with the V2 ski skating technique, which is a technique utilized at moderate to high velocities, involving a double pole plant for each ski push-off. The first two protocols were functionally baseline protocols, determining the individualized intensity applied to the third and main protocol. Subjects were shown a timeline of the session and received relevant instructions verbally ahead of each protocol.

A detailed description of the first part is presented in Losnegard et al. (2013), while only briefly summarized here. After a ten-minute warm-up consisting of easy skiing, subjects completed three to four sub-maximal loads in order for skiing efficiency (Eco_{ski}) to be quantified. Each load was increasingly more intense than the last and separated from the next by a 2.5-minute break. The intensity was increased by adjusting the incline (range 2.5-7.0 °), usually in increments of 0.5 °, while keeping the velocity constant at 3 m·s^{-1}. The test was followed by approximately 15 minutes of easy skiing, concluded by a short burst of high intensity before resting in a stand-still position for two minutes. Subsequently, skiers performed a 1000-meter time trial (TT) with the purpose of quantifying $\dot{V}O_{2max}$ and $MAOD$. The subjects started from a stand-still position and were counted down to start. They completed the first one hundred meters at a set velocity, which was increased by 0.25 m·s^{-1} for the next one hundred meters. After completing the first two hundred meters, the subjects could adjust the velocity as they wished in increments of 0.25 m·s^{-1}.

After the 1000-meter TT, subjects had a one-hour break, free to eat, drink and go to the bathroom. During the final quarter of the break, the subjects performed easy skiing concluded by a short high intensity burst before resting for two minutes ahead of the main protocol. The main protocol was designed as an interval protocol consisting of recovery- and work phases repeating in cycles and was intended to quantify TTE at a similar relative intensity. It was therefore individually tailored to each subject's maximal aerobic power (MAP) by standardizing for $\dot{V}O_{2max}$ and Eco_{ski}. Each cycle of the protocol averaged an intensity of 100% MAP. The subjects started from a stand-still position, were counted down to start, and continued until exhaustion.



	SUB-MAXIMAL LOADS									1000-M TT			INTERVAL PROTOCOL	
Duration (min)	5	2.5	5	2.5	5	2.5	5	2.5	15	5	2.5	57.5	8	2.5
Accumulated Duration (min)	5	7.5	12.5	15	20	22.5	27.5	30	45	50	52.5	110	118	120.5
HR	🟥		🟥		🟥		🟥			🟥			🟥	
$\dot{V}O_2$	🟦		🟦		🟦		🟦			🟦			🟦	
[La⁻]		🟩		🟩		🟩		🟩			🟩			🟩
RPE		🟨		🟨		🟨		🟨			🟨			🟨

Figure 1: *A simplified overview of the experimental procedure, including protocol intensity, duration and measurements taken. Explanation for the measurements follows: HR = heart rate,* $\dot{V}O_2$ *= rate of oxygen consumption,* $[La^-]$ *= blood plasma lactate concentration, RPE = subjective rate of perceived exertion.*

Interval protocol

The interval protocol consisted of two phases repeating in cycles; a recovery phase lasting twenty seconds at 60% MAP, followed by a work phase at 120% MAP lasting forty seconds, resulting in an average intensity of 100% MAP. The intensity was fitted to each subject's MAP by adjusting the incline (range 2.6-5.1 °) while keeping the velocity of each of the two phases at 2.75 and 5.50 $m \cdot s^{-1}$. Velocity was kept within this range so that it would be suited for the V2 ski skating technique. The subjects continued until exhaustion, determined by crossing a laser line placed behind the defined protocol area on the treadmill, or by actively aborting the protocol. They were repeatedly informed verbally how much time remained of the current phase, usually after having completed ½ and ¾ of the phase. Additionally, the final three seconds of the phase were counted out loud. The subjects were also able to see the remaining time on a screen in front of them. Subjects were, however, not verbally, or in any other way, intentionally encouraged or motivated to endure during the protocol by testing personnel. $\dot{V}O_2$ was measured during the entire protocol. HR, RPE and $[La^-]$ were monitored to evaluate each subject's effort.

Instruments and materials

All subjects wore the same pair of Swenor Skate Long (Sarpsborg, Norway) roller skis with wheel type 1 (coefficient of rolling resistance $(C_{rr}) = 0.014$) and ski binding type NNN from Rottefella (Klokkarstua, Norway) during all three protocols. The subjects selected their preferred pair of Swix Triac 3.0 (Swix Sport, Lillehammer, Norway) from the assortment available in the lab. The poles were equipped with custom ferrules specifically designed for treadmill roller skiing. The subjects wore their personal ski boots and HR monitor. For safety reasons, subjects wore a harness which was strapped to a rope connected to an automatic emergency brake system during the 1000-meter TT and the interval protocol. The total weight of the equipment worn by the subjects was approximately 3.5 kg. The treadmill was a model custom made by Rodby (Rodby Innovation AB, Hagby, Vänge, Sweden), dimensioned 300 cm wide and 450 cm long. Pulmonary gas exchange was measured with the mixing chamber method, using an automatic ergo spirometry system (Oxycon Pro; Jaeger GmbH, Höchberg, Germany) previously validated by Foss & Hallén (2005). $[La^-]$ was measured using capillary fingertip samples of blood (Biosen C-line, EKF diagnostic GmbH, Magdeburg, Germany). Both systems were calibrated according to the manufacturers' specifications. Body mass was measured using an electronic body-mass scale (Seca model nr: 877; Seca GmbH & Co., Hamburg, Germany).

Data analysis

MAP was defined as P_{prop} yielding $\dot{V}O_{2max}$, based on the assumption of a constant $\dot{V}O_2$ to P_{prop} ratio (Noordhof, de Koning, & Foster, 2010) determined during the sub-maximal loads and termed skiing efficiency (Eco_{ski}). MAP was calculated by the following relation:

$$MAP = \frac{\dot{V}O_{2max} \cdot P_{prop_{sm}}}{\dot{V}O_{2_{sm}}} \tag{1}$$

where $\dot{V}O_{2max}$ is the highest 60 second average measured during the 1000-meter TT. $P_{prop_{sm}}$ is the average P_{prop} required during the sub-maximal loads. $\dot{V}O_{2_{sm}}$ is the average $\dot{V}O_2$ measured during the final two minutes of each sub-maximal load.

P_{prop} was defined as the mechanical energy needed to overcome the forces of gravity and friction. Air resistance was neglected, due to the protocols being conducted on a treadmill, meaning subjects were standing still relative to their surroundings. P_{prop} was calculated by the following relation:

$$P_{prop} = m_{BW+E} \cdot g \cdot v \cdot (sin(\theta) + C_{rr} \cdot cos(\theta)) \tag{2}$$

where m_{BW+E} is the combined mass of the subject and equipment, $g = 9.81 \text{ m} \cdot \text{s}^{-1}$ is the acceleration due to the force of gravity, v is the velocity of the treadmill, $C_{rr} = 0.014$ is the coefficient of rolling resistance, and θ is the angle of the treadmill incline in degrees.

By applying the 1. order Taylor approximation, it can be assumed that $sin(\theta)$ is equal to θ, and $cos(\theta)$ is equal to 1, when θ is small and measured in radians. Equation 1 can thus be reworked into the following variations:

$$P_{prop} = m_{BW+E} \cdot g \cdot v \cdot (\theta + C_{rr}) \tag{3}$$

$$\theta = \frac{P_{prop}}{m_{BW+E} \cdot g \cdot v} - C_{rr} \tag{4}$$

Equation 4 was utilized to calculate the individualized interval protocol intensity for each subject. Because the velocity was already pre-determined for both phases to accommodate the V2 ski skating technique, the protocol intensity had to be fitted by adjusting the incline of the treadmill. This appropriate angle was then calculated by setting P_{prop} equal to the intended power output for the respective interval protocol phase ($P_{prop_{recovery}} = 0.6 \cdot MAP, P_{prop_{work}} = 1.2 \cdot MAP$) and v equal to the velocity of the treadmill during the respective interval protocol phase ($v_{recovery} = 2.75 \text{ m} \cdot \text{s}^{-1}, v_{work} = 5.50 \text{ m} \cdot \text{s}^{-1}$).

Gross efficiency (GE) was determined as the percentage of metabolic energy converted into P_{prop}. Metabolic energy was calculated in accordance with the procedure of Garby & Astrup (1987).

The maximal accumulated oxygen deficit ($MAOD$) was determined by subtracting the ${O_2}^{dem}$ from the average $\dot{V}O_2$ measured during the 1000-meter TT. ${O_2}^{dem}$ was calculated from the average P_{prop}.

$\dot{V}O_{2peak}$ was defined as the highest 30 second average $\dot{V}O_2$ that was measured during the interval protocol.

Statistics

Normality of data distribution was checked using a Shapiro-Wilk Test. For normally distributed data, differences were analyzed performing an independent-samples t-test, while skewed data were analyzed with a non-parametric Mann-Whitney test using SPSS version 24.0.0.2 (IBM Corp., Armonk, NY). Averages are reported along with their adjoining standard deviation (SD). Differences are reported along with their adjoining 95% confidence interval (CI) as percentages. The threshold for statistical significance was defined as $p < 0.05$. Figures are constructed using GraphPad Prism 9 (GraphPad Software, San Diego, CA). In tables and figures, $p < 0.05$ is indicated by a single asterisk, while $p < 0.01$ is indicated by a double asterisk.

Results

Baseline protocols

The competitive group was faster during the 1000-meter TT and had a higher $\dot{V}O_{2max}$, GE and MAP than the recreational group. $MAOD$ was, however, similar for both groups (Table 1). Additionally, the competitive group reported a lower end RPE after the 1000-meter TT (18.1 ± 1.0 vs. 19.1 ± 1.0, p = 0.027), while HR_{peak} (189 ± 9 vs. 192 ± 12 bpm, p = 0.476) and $[La^{-}]_{peak}$ (11.6 ± 1.7 vs. 12.9 ± 3.2 mmol·L^{-1}, p = 0.232) were similar for both groups.

Table 1: *Average results for, and difference between, the competitive and recreational group during the two baseline protocols (sub-maximal loads and 1000-meter TT).*

	Competitive (n = 12)	**Recreational (n = 10)**	**Difference (%) [95% CI]**
FT 1000-meter TT (s)	254 ± 18	321 ± 42	−21 [−30, −12] **
$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	76.5 ± 3.8	63.5 ± 6.3	20 [13, 28] **
GE (%)	16.6 ± 0.9	15.5 ± 0.6	7.0 [2, 11] **
MAP (W)	330 ± 31	267 ± 25	24 [14, 34] **
MAOD (ml·kg^{-1})	96 ± 13	88 ± 13	9 [−5, 23]

Note: *FT 1000-meter TT = finish time for the 1000-meter TT.* $\dot{V}O_{2max}$ *= highest consecutive 60 seconds of* $\dot{V}O_2$ *measured during the 1000-meter TT.* GE *= average ratio between* P_{prop} *and metabolic power measured during the sub-maximal loads.* MAP = P_{prop} *yielding* $\dot{V}O_{2max}$ *according to the assumed linear relationship between* $\dot{V}O_2$ *and* P_{prop}. $MAOD$ *= maximal amount of oxygen deficit accumulated during the 1000-meter TT. CI = confidence interval. Asterisk = significant group difference (*$* = p < 0.05, ** = p < 0.01$*).*

Interval protocol

The competitive group had a 34 [3, 65] % longer TTE than the recreational group (473 ± 141 vs. 353 ± 94 s, p = 0.032) (Figure 2). No difference was observed between the two groups in end RPE (18.4 ± 1.0 vs. 18.3 ± 1.3, p = 0.810), HR_{peak} (191 ± 9 vs. 192 ± 10 bpm, p = 0.734) or $[La^{-}]_{peak}$ (11.4 ± 2.2 vs. 11.5 ± 2.1 mmol·L^{-1}, p = 0.943).

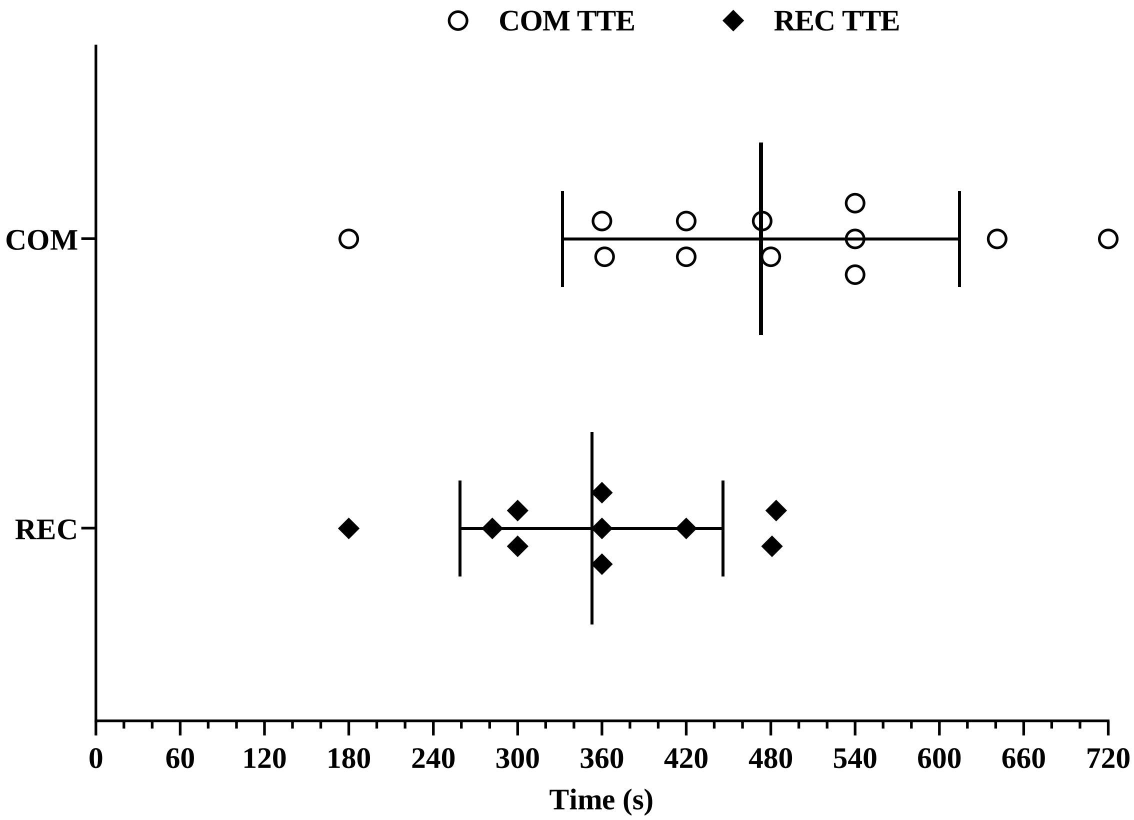


Figure 2: *Individual* TTE*. Group average is illustrated with a large vertical line and SD is illustrated with two smaller vertical lines.*

Figure 3 illustrates the average ${O_2}^{dem}$ and $\dot{V}O_2$ along with the number of subjects remaining for both groups during the interval protocol. Relative to $\dot{V}O_{2max}$, there was no difference between the two groups in ${O_2}^{dem}$. When excluding the initial acceleration phase, the average ${O_2}^{dem}$ was equal to $\dot{V}O_{2max}$ (100 ± 0.5 vs 100 ± 0.8 %$\dot{V}O_{2max}$, p = 0.494). There was also no difference in $\dot{V}O_2$ or $\dot{V}O_{2peak}$. The competitive group did, however, have a −8 [−13, 3] % lower $\dot{V}O_2$ during the first minute (43 ± 2 vs 47 ± 3 %$\dot{V}O_{2max}$, p = 0.005), and a −3 [−6, 0] % lower $\dot{V}O_2$ during the second minute (86 ± 3 vs 89 ± 3 %$\dot{V}O_{2max}$, p = 0.028), but there was no difference after.

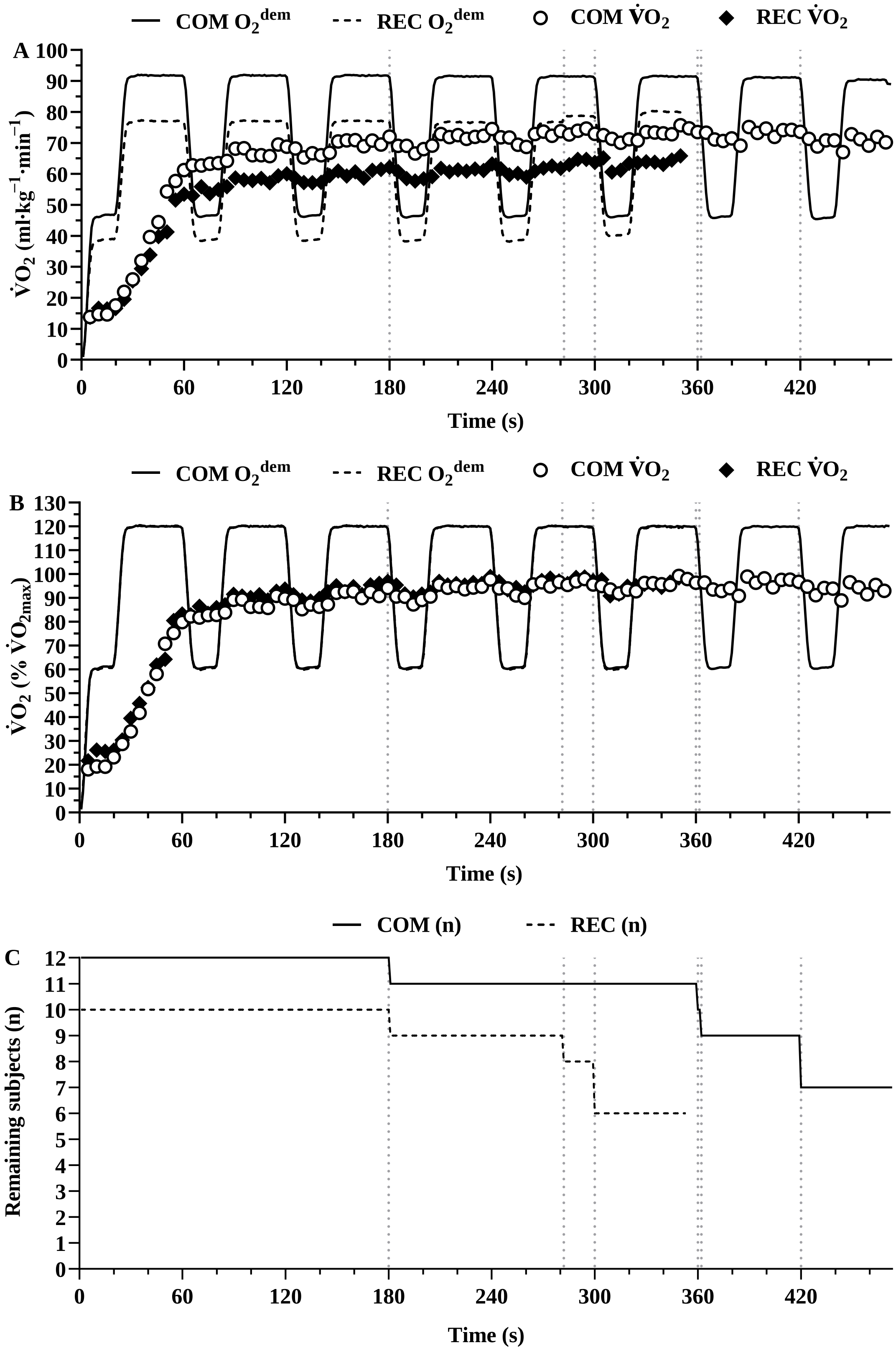


Figure 3: *Average $O_2{}^{dem}$ and $\dot{V}O_2$ along with number of subjects remaining for both groups during the interval protocol. $O_2{}^{dem}$ is calculated for every second, while $\dot{V}O_2$ is plotted every five seconds. The vertical semi-transparent dotted lines indicate individual TTE, and the data is shown for the duration of each group's average*

*TTE. **A**, $O_2{}^{dem}$ and $\dot{V}O_2$ are both expressed in ml·kg⁻¹. **B**, $O_2{}^{dem}$ and $\dot{V}O_2$ are both expressed in %$\dot{V}O_{2max}$. **C**, number of subjects remaining.*

Figure 4 illustrates the $\sum O_2{}^{def}$ and accumulated oxygen surplus (negative $\sum O_2{}^{def}$) within each phase of the interval protocol, and the sum $\sum O_2{}^{def}$ after each completed phase. The competitive group had a larger $\sum O_2{}^{def}$ during recovery phase R_1 and work phase W_1, W_2, W_3, W_4 and W_5. There was no difference in accumulated oxygen surplus. Additionally, the competitive group had a higher sum of $\sum O_2{}^{def}$ after both recovery phase R_1-R_6 and work phase W_1-W_6. When normalizing for $MAOD$, the competitive group had a larger $\sum O_2{}^{def}$ during recovery phase R_1 and work phase W_2 and W_3. There was no difference in accumulated oxygen surplus. The competitive group had a higher sum of $\sum O_2{}^{def}$ after recovery phase R_1-R_5 and work phase W_2-W_5.

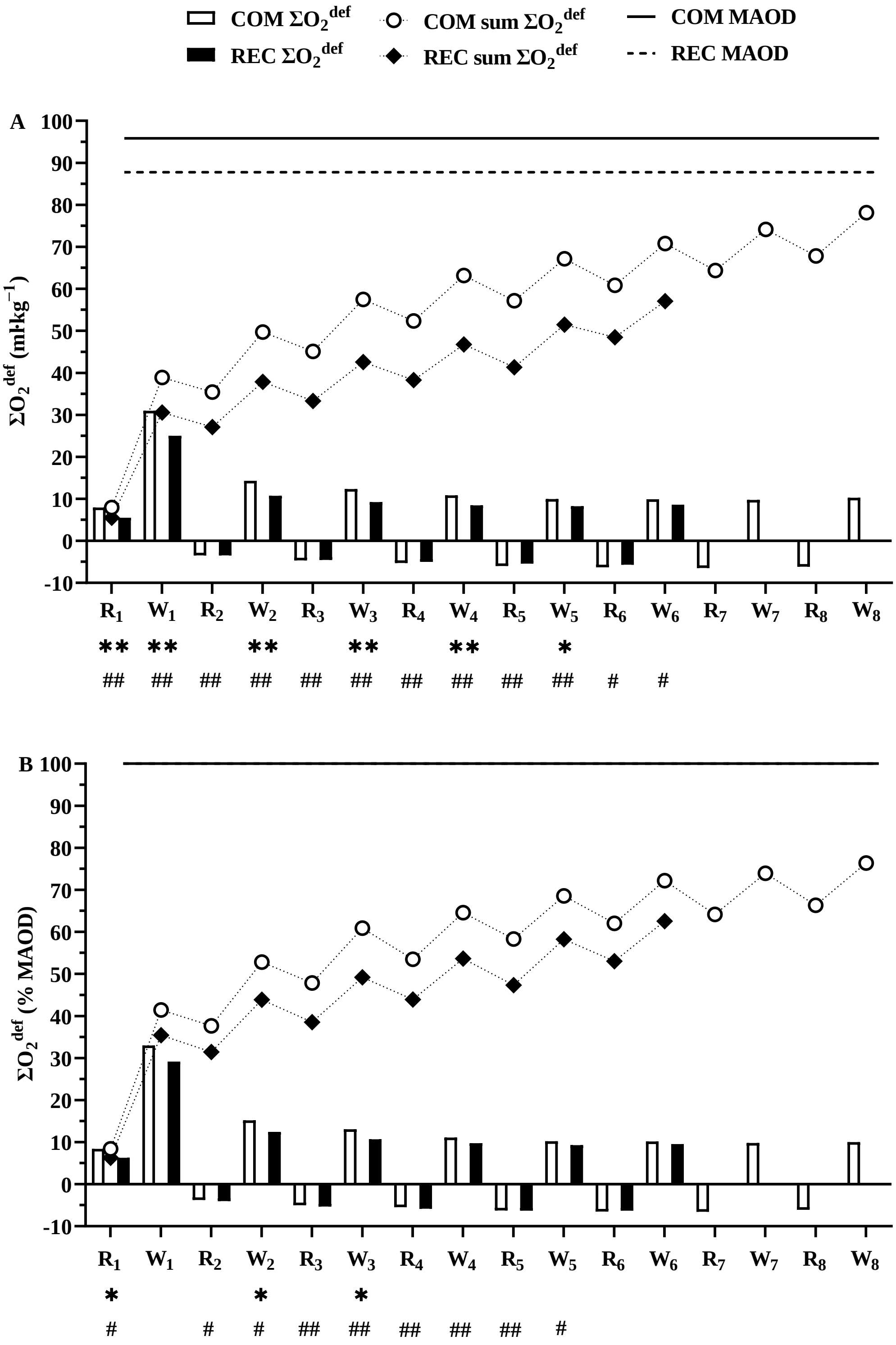


Figure 4: *Average $\sum O_2{}^{def}$ for each phase (R = recovery, W = work), and sum of $\sum O_2{}^{def}$ phase-by-phase for both groups during the interval protocol. $MAOD$ is also shown.* ***A****, $\sum O_2{}^{def}$ is expressed in ml·kg^{-1}.* ***B****, $\sum O_2{}^{def}$ is expressed in %$MAOD$. Statistical significance is indicated at the bottom for $\sum O_2{}^{def}$ (*) and sum of $\sum O_2{}^{def}$ (#). Calculations for each phase only include subjects who completed the respective phase, and the data is shown for the duration of each group's average TTE. The treadmill save file for one recreational skier was lacking data. Thus, $O_2{}^{dem}$ and $\Sigma O_2{}^{def}$ could not be calculated, and the subject is entirely excluded from this figure.*

Figure 5 shows total and average $\sum {O_2}^{def}$ during the interval protocol. The competitive group had a higher total accumulation of oxygen surplus during recovery phases, and a higher total $\sum {O_2}^{def}$ during work phases, which resulted in a higher net total $\sum {O_2}^{def}$. However, when normalizing for $MAOD$, there was no difference in total accumulation of oxygen surplus during recovery phases, but the competitive group still had a higher total $\sum {O_2}^{def}$ during work phases, thus higher net total $\sum {O_2}^{def}$. There was no difference in average accumulation of oxygen surplus during recovery phases, but the competitive group had a higher average $\sum {O_2}^{def}$ during work phases, thus a higher net average $\sum {O_2}^{def}$. When normalizing for $MAOD$, there was no difference in average accumulation of oxygen surplus or $\sum {O_2}^{def}$ during any phase, thus no net difference.

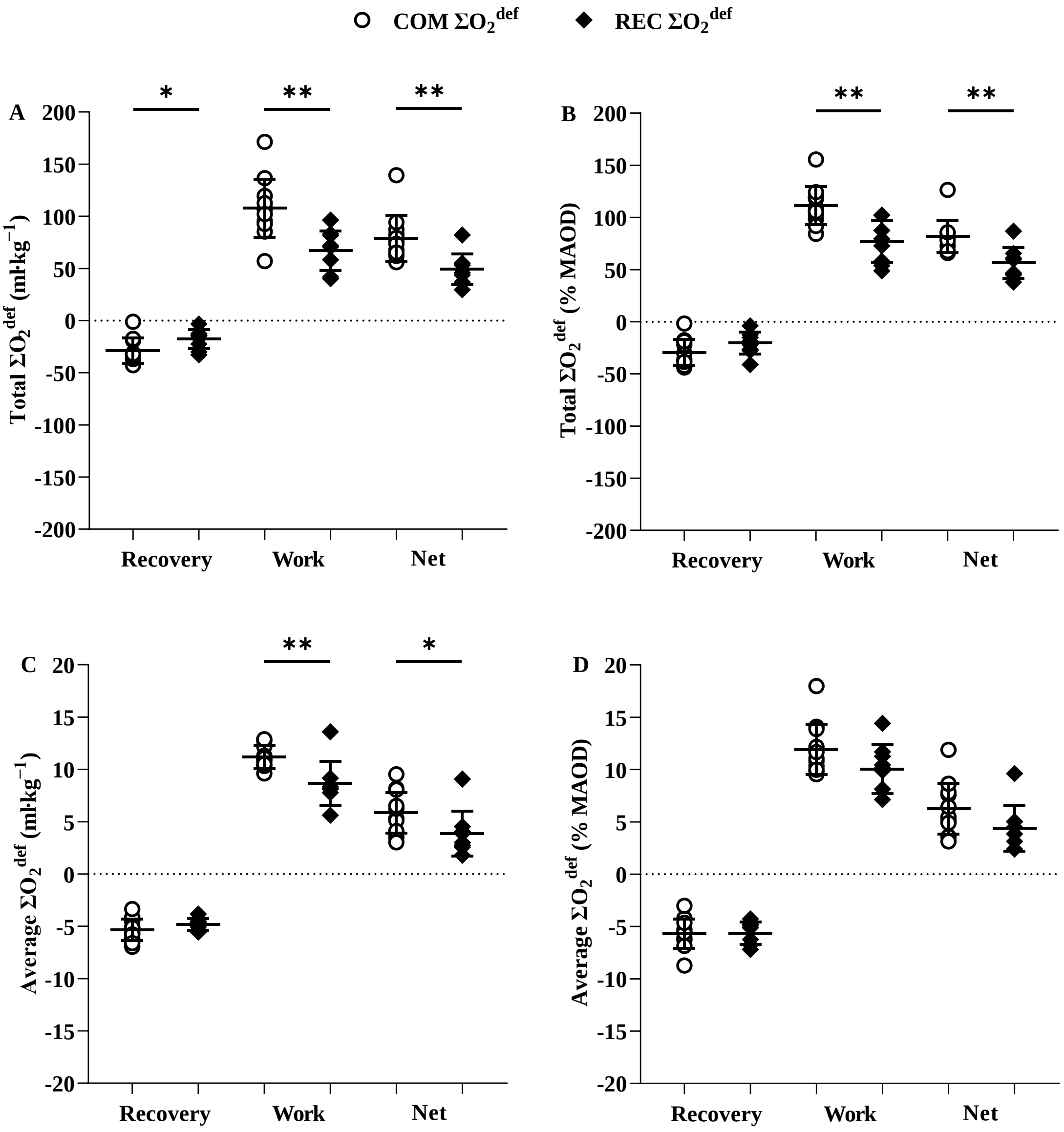


Figure 5: *Individual total and average* $\sum O_2^{def}$ *during both recovery- and work phases, as well as the net difference. Group average is illustrated with a large horizontal line and SD is illustrated with two smaller horizontal lines.* ***A****, total* $\sum O_2^{def}$ *in ml·kg*$^{-1}$*.* ***B****, total* $\sum O_2^{def}$ *in* $\%MAOD$*.* ***C****, average* $\sum O_2^{def}$ *in ml·kg*$^{-1}$*.* ***D****, average* $\sum O_2^{def}$ *in* $\%MAOD$*. The first cycle (*R_1 *+* W_1*) was excluded when calculating average* $\sum O_2^{def}$*, due to the latency of* $\dot{V}O_2$ *in response to the onset of physical exercise. The treadmill save file for one recreational skier was lacking data. Thus,* O_2^{dem} *and* ΣO_2^{def} *could not be calculated, and the subject is entirely excluded from this figure.*

Discussion

This study showed that a competitive group of XC skiers had a longer TTE and a larger $\sum O_2{}^{def}$ than a recreational group during an intermittent interval protocol standardized for MAP.

The competitive group was superior with regards to $\dot{V}O_{2max}$ and GE, and therefore had a higher MAP (Table 1). This is in agreement with previous studies showing elite XC skiers to have extremely high $\dot{V}O_{2max}$ (Saltin & Åstrand, 1967; Mahood, Kenefick, Kertzer, & Quinn, 2001; Losnegard, 2019), and a better GE (Sandbakk Ø. , Holmberg, Leirdal, & Ettema, 2010), and MAP is known to be a significant performance determinant in XC skiing (Losnegard, 2019). The difference in MAP was, however, accounted for in the interval protocol (Figure 3 B), and could therefore not explain the variety of TTE illustrated by Figure 2.

The difference in TTE was present despite the two groups performing at a similar $\dot{V}O_2$ relative to $\dot{V}O_{2max}$ (Figure 3 B). As the competitive group had a higher MAP than the recreational group, they performed the interval protocol at a higher absolute intensity (Figure 3 A) to achieve a similar relative intensity (Figure 3 B). The competitive group therefore had a greater delta between $\dot{V}O_2$ and $O_2{}^{dem}$, yielding a larger $\sum O_2{}^{def}$ per time (Figure 4 A and Figure 5 C). This is associated with a higher turnover rate of anaerobic energy, depleting phosphocreatine (PCr) stores and glycogen more rapidly, resulting in larger accumulation of fatigue related metabolites such as inorganic phosphate (P_i) and hydrogen ions (H^+) (Burnley & Jones, 2007). Glycogen stores are, however, large enough to sustain high-intensity exercise for two hours or longer (Joyner & Coyle, 2008), and so PCr would be the anaerobic energy source susceptible to depletion. The competitive group therefore had a longer TTE despite requiring a larger anaerobic contribution. This could mean they (1) had larger PCr energy stores (Park, Brown, Park, Cohn, & B, 1988), (2) had a greater tolerance (i.e., buffering of P_i and/or H^+) for fatigue related metabolites (Sahlin & Henriksson, 1984), and/or (3) were able to resynthesize PCr at a higher rate than the recreational group during the recovery phases (Bogdanis, Nevill, Boobis, & Lakomy, 1996). Surprisingly, contrary to the hypothesis presented for the study, there was no difference in recovery of $\sum O_2{}^{def}$ per time (Figure 4 A and Figure 5 C), suggesting no difference in oxidative processes such as resynthesis rate of PCr. The competitive group did, however, recover more $\sum O_2{}^{def}$ in total (Figure 5 A), which can be explained by the greater number of recovery phases they completed due to their longer TTE.

Statistical testing suggested a similar $MAOD$ (p = 0.176) measured for both groups during the 1000-meter TT (Table 1), implying a similar anaerobic capacity. However, a false negative due to limited statistical power remains a possibility, as indicated by the change in statistical significance in Figure 5 when converting from ml·kg^{-1} in A and C to %$MAOD$ in B and D. A potential difference between the two groups should therefore not be completely disregarded. The measured difference was, however, less than 10% (Table 1), while the difference in TTE was 34% (Figure 1). Thus, a potential difference in $MAOD$ seems unlikely to fully explain the difference in TTE. Additionally, neither group reached a net total $\sum O_2{}^{def}$ equivalent to $MAOD$ (Figure 5 B), implying that other fatigue mechanisms developed before $MAOD$ became a limitation.

The competitive group's total $\sum O_2{}^{def}$ exceeded their $MAOD$ (Figure 5 B), which means they accumulated a larger $O_2{}^{def}$ during the intermittent interval protocol than during the continuous 1000-meter TT. $MAOD$ is unrelated to time for durations of two minutes or longer (Medbø & Tabata, 1989). Both the 1000-meter TT and the interval protocol exceeded two minutes, implying the difference in $\sum O_2{}^{def}$ was made possible by the recovery phases of the interval protocol. The recreational group were, however, fatigued before their total $\sum O_2{}^{def}$ could reach $MAOD$. The competitive group therefore showed a greater ability to repeatedly accumulate smaller bulks of $O_2{}^{def}$ that amounted to a large total. It is, however, difficult to say whether the greater capacity for $\sum O_2{}^{def}$ allows for a longer TTE or vice versa, with the two perhaps sharing confounding factors.

The interval protocol was performed at a relatively high velocity during the work phases, and with frequent acceleration and deceleration in transition between phases, which could potentially pose as a technical challenge to lesser skilled XC skiers. Sandbakk et al. (2010) found that superior skiers were able to obtain higher velocities than inferior skiers, despite similar upper- and lower-body strength. It is therefore implied that superior skiers are able to achieve a greater technique-specific power by taking a greater advantage of their strength at high velocities through better technical execution. This might be related to a longer cycle length, which is shown to result in a more effective leg and pole push off (Bilodeau, Rundell, Roy, & Boulay, 1996). The competitive group could therefore be assumed to have a greater technique-specific power at high velocities in the V2 sub-technique, due to greater strength and/or technique, allowing for a greater and more efficient cycle length and a longer TTE. Technical qualities might therefore be related to TTE, and perhaps explain why the recreational group failed to accumulate an ${O_2}^{def}$ equivalent to their $MAOD$. However, one of the two XC skiers with the shortest TTE was also one of the most experienced skiers, and therefore unlikely to be limited by technical aspects.

Methodological considerations and limitations

The mixing chamber method is previously validated by Foss & Hallén (2005), although for steady state exercise. Thus, it might not be suited to analyzing $\dot{V}O_2$ for durations as short as the recovery or even the work phases, as it is usually utilized to determine average $\dot{V}O_2$ for durations of 60 seconds or longer. Another issue with the mixing champer method is that it does not account for O_2 stored in the blood at the onset of exercise. This O_2 acts as an aerobic contribution that should be subtracted from the calculated $\sum {O_2}^{def}$ (Losnegard, Myklebust, & Hallén, 2012). The data were not corrected with regards to this issue, and so the aerobic contribution would be slightly underestimated, while the $MAOD$ and $\sum {O_2}^{def}$ would be slightly overestimated. It should, however, not matter when comparing the two groups.

The methodological aspects related to the calculation of $MAOD$ are debated by Noordhof, de Koning, & Foster (2010). The authors argue that, although $MAOD$ does not fully reflect the anaerobic capacity, it can serve as a fair estimate if determined appropriately. They suggest using several and relatively short-lasting sub-maximal loads and a fixed y-intercept when calculating Eco to achieve reliable measurements. To save time, due to the limited availability of certain subjects, four (and in some cases only three) sub-maximal loads were used in this study, each lasting 5 minutes. The number of sub-maximal loads performed could therefore be considered a limitation in the estimation of Eco_{ski}. For the y-intercept, Noordhof, de Koning, & Foster (2010) recommend using the resting $\dot{V}O_2$ value. However, to save time, origin was chosen as the y-intercept for this study, which also might have resulted in underestimating the Eco_{ski}, but at least benefited reliability. An underestimation of Eco_{ski} would further result in an underestimated MAP and a lower interval protocol intensity, and an overestimated $MAOD$ and $\sum {O_2}^{def}$. This should be considered when interperating the results presented in this study.

The consequence of including a fixed versus an unfixed y-intercept, and three versus four sub-maximal loads, was further investigated. An unfixed y-intercept results in a ~10% higher MAP for both groups, but the ratio between them remains virtually the same (~1% change). The potential underestimation of MAP due to a fixed y-intercept is therefore not regarded as an issue for the comparisons presented in this study. Calculating Eco_{ski} from only the first three versus all four sub-maximal loads results in virtually the same MAP (~1% lower), and so the ratio remains the same (< 1% change). Three subjects aborting the protocol after the third sub-maximal load is thus considered a non-issue.

As the recreational XC skiers were less experienced than the competitive XC skiers, they were likely not as good at pacing their 1000-meter TT. This could potentially result in less robust measurements of $\dot{V}O_{2max}$ and $MAOD$, which would have implications for MAP and the individual interval protocol intensity, and the calculated $\sum {O_2}^{def}$. The recreational XC skiers' lesser experience could also perhaps influence their motivation during the interval protocol, preventing them from pushing themselves to their limit. However, the similar end RPE (p = 0.810), HR_{peak} (p = 0.734) and $[La^{-}]_{peak}$ (p = 0.943) between the two groups show that subjects reached a similar effort level at the end of the protocol, and supports the notion that they were able to push themselves to exhaustion. Additionally, both groups managed to reach a $\dot{V}O_{peak}$ during the interval protocol similar to the $\dot{V}O_{2max}$ they measured during the 1000-meter TT, supporting the notion of a consistent effort level across the two protocols.

Conclusion

Competitive skiers had a longer TTE and a larger $\sum {O_2}^{def}$ than the recreational skiers during an intermittent interval protocol standardized for MAP. This implies that TTE could be related to the ability to repeatedly accumulate smaller bulks of ${O_2}^{def}$ amounting to a large total.

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Tables	Figures
Table 1: Average results for, and difference between, the competitive and recreational group during the two baseline protocols (sub-maximal loads and 1000-meter TT).	**Figure 1:** A simplified overview of the experimental procedure, including protocol intensity, duration and measurements taken. Explanation for the measurements follows: HR = heart rate, $\dot{\mathrm{V}}\mathrm{O}_2$ = rate of oxygen consumption, $[\mathrm{La}^-]$ = blood plasma lactate concentration, RPE = subjective rate of perceived exertion. **Figure 2:** Individual TTE. Group average is illustrated with a large vertical line and SD is illustrated with two smaller vertical lines. **Figure 3:** Average $\mathrm{O_2}^{\mathrm{dem}}$ and $\dot{\mathrm{V}}\mathrm{O}_2$ along with number of subjects remaining for both groups during the interval protocol. $\mathrm{O_2}^{\mathrm{dem}}$ is calculated for every second, while $\dot{\mathrm{V}}\mathrm{O}_2$ is plotted every five seconds. The vertical semi-transparent dotted lines indicate individual TTE, and the data is shown for the duration of each group's average TTE. **A**, $\mathrm{O_2}^{\mathrm{dem}}$ and $\dot{\mathrm{V}}\mathrm{O}_2$ are both expressed in ml·kg^{-1}. **B**, $\mathrm{O_2}^{\mathrm{dem}}$ and $\dot{\mathrm{V}}\mathrm{O}_2$ are both expressed in $\%\dot{\mathrm{V}}\mathrm{O}_{2\mathrm{max}}$. **C**, number of subjects remaining. **Figure 4:** Average $\sum \mathrm{O_2}^{\mathrm{def}}$ for each phase (R = recovery, W = work), and sum of $\sum \mathrm{O_2}^{\mathrm{def}}$ phase-by-phase for both groups during the interval protocol. MAOD is also shown. **A**, $\sum \mathrm{O_2}^{\mathrm{def}}$ is expressed in ml·kg^{-1}. **B**, $\sum \mathrm{O_2}^{\mathrm{def}}$ is expressed in %MAOD. Statistical significance is indicated at the

bottom for $\sum O_2{}^{def}$ (*) and sum of $\sum O_2{}^{def}$ (#). Calculations for each phase only include subjects who completed the respective phase, and the data is shown for the duration of each group's average TTE. The treadmill save file for one recreational skier was lacking data. Thus, $O_2{}^{dem}$ and $\Sigma O_2{}^{def}$ could not be calculated, and the subject is entirely excluded from this figure.

Figure 5: Individual total and average $\sum O_2{}^{def}$ during both recovery- and work phases, as well as the net difference. Group average is illustrated with a large horizontal line and SD is illustrated with two smaller horizontal lines. **A**, total $\sum O_2{}^{def}$ in ml·kg^{-1}. **B**, total $\sum O_2{}^{def}$ in $\%\mathrm{MAOD}$. **C**, average $\sum O_2{}^{def}$ in ml·kg^{-1}. **D**, average $\sum O_2{}^{def}$ in $\%\mathrm{MAOD}$. The first cycle (R_1 + W_1) was excluded when calculating average $\sum O_2{}^{def}$, due to the latency of $\dot{V}O_2$ in response to the onset of physical exercise. The treadmill save file for one recreational skier was lacking data. Thus, $O_2{}^{dem}$ and $\Sigma O_2{}^{def}$ could not be calculated, and the subject is entirely excluded from this figure.

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I	Godkjenning fra etisk komité ved Norges idrettshøgskole
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Thomas Losnegard
Institutt for fysisk prestasjonsevne

OSLO 13. juni 2020

Søknad 138 - 180620 – Kan en variabel intensitetsprotokoll forklare forskjeller i utholdenhet og prestasjon hos langrennsløpere

Vi viser til søknad, prosjektbeskrivelse, spørreskjema, informasjonsskriv og innsendt søknad til NSD

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

Vurdering

I søknaden opplyses det at kvinner er ekskludert fra utvalget blant annet fordi fysiologiske målinger vil sammenlignes på tvers av grupper, og kjønnsforskjeller vil kunne påvirke sammenligningene negativt. Komiteleder aksepterer denne begrunnelsen, men anmoder om at prosjektleder vurderer en tilsvarende studie med kvinner ved en senere anledning. Det fremgår videre av søknaden at deltakerne er godt trente utøvere som er vant til å presse seg til utmattelse i konkurranser. Komiteen vil minne om at prosjektleder har et særskilt ansvar for å påse at deltakerne på testdagene ikke er syke eller har symptomer som er uforenlig med gjennomføringen av testene.

Vedtak

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

- *Vilkår fra NSD følges*
- *Prosjektleder vurderer å gjennomføre tilsvarende studie på kvinner ved en senere anledning*

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

Med vennlig hilsen

Professor Sigmund Loland
Leder, Etisk komite, Norges idrettshøgskole

NORSK SENTER FOR FORSKNINGSDATA

Meldeskjema 853738

Sist oppdatert

04.06.2020

Hvilke personopplysninger skal du behandle?

- Navn (også ved signatur/samtykke)
- Fødselsdato
- Adresse eller telefonnummer
- E-postadresse, IP-adresse eller annen nettidentifikator
- Bilder eller videoopptak av personer
- Gps eller andre lokaliseringsdata (elektroniske spor)

Type opplysninger

Skal du behandle særlige kategorier personopplysninger eller personopplysninger om straffedommer eller lovovertredelser?

- Helseopplysninger

Prosjektinformasjon

Prosjekttittel

Pacingstrategier i konkurranselangrenn -- rollen til hurtig restitusjon av anaerobe energiressurser

Begrunn behovet for å behandle personopplysningene

For å besvare problemstillingene i forskningsprosjektet behøver vi ulike arbeidsfysiologiske målinger (oksygenopptak, oksygenmetning, laktatkonsentrasjon). Posisjonsmålinger fra GPS-mottakerne brukes til å sammenligne deltakerenes prestasjon innad i testrenn på rulleski, samt i en modell for oksygenkravet (som er en matematisk funksjon av hastighet og helning). GPS-målinger vil kun gjøres over svært avgrenset tidsperiode (ca 2 timer) når deltakeren gjennomfører selve forsøksprotokollen.

Ekstern finansiering

- Andre

Annen finansieringskilde

Prosjektet finansieres av Norges Idrettshøgskole

Type prosjekt

Studentprosjekt, masterstudium

Kontaktinformasjon, student

Ånung Viken; Eivind Holsbrekken, anung.viken@hotmail.com; eivind.holsbrekken@gmail.com, tlf: 99413761

Behandlingsansvar

Behandlingsansvarlig institusjon

Norges idrettshøgskole / Seksjon for fysisk prestasjonsevne

Prosjektansvarlig (vitenskapelig ansatt/veileder eller stipendiat)

Thomas Losnegard, thomas.losnegard@nih.no, tlf: 99734184

Skal behandlingsansvaret deles med andre institusjoner (felles behandlingsansvarlige)?

Nei

Utvalg 1

Beskriv utvalget

Skiløpere over 18 år. Begge kjønn ønskes rekruttert. Må ha konkurrere regelmessig eller nylig ha lagt opp sin idrettskarrierere, men fortsatt holde et høyt skiteknisk nivå.

Rekruttering eller trekking av utvalget

Forsøkspersonene rekrutteres fra eget nettverk i skimiljøet. Aktuelle kandidater får skriftlig forespørsel via epost som inneholder et detaljert informasjonsskriv.

Alder

18 - 38

Inngår det voksne (18 år +) i utvalget som ikke kan samtykke selv?

Nei

Personopplysninger for utvalg 1

- Navn (også ved signatur/samtykke)
- Fødselsdato
- Bilder eller videoopptak av personer
- Gps eller andre lokaliseringsdata (elektroniske spor)
- Helseopplysninger

Hvordan samler du inn data fra utvalg 1?

Medisinsk undersøkelse og/eller fysiske tester

Grunnlag for å behandle alminnelige kategorier av personopplysninger

Samtykke (art. 6 nr. 1 bokstav a)

Grunnlag for å behandle særlige kategorier av personopplysninger

Uttrykkelig samtykke (art. 9 nr. 2 bokstav a)

Redegjør for valget av behandlingsgrunnlag

Felteksperiment/feltintervensjon

Grunnlag for å behandle alminnelige kategorier av personopplysninger

Samtykke (art. 6 nr. 1 bokstav a)

Grunnlag for å behandle særlige kategorier av personopplysninger

Uttrykkelig samtykke (art. 9 nr. 2 bokstav a)

Redegjør for valget av behandlingsgrunnlag

Informasjon for utvalg 1

Informerer du utvalget om behandlingen av opplysningene?

Ja

Hvordan?

Skriftlig informasjon (papir eller elektronisk)

Utvalg 2

Beskriv utvalget

Skiløpere over 18 år. Begge kjønn ønskes rekruttert. Må ha konkurrere regelmessig eller nylig ha lagt opp sin idrettskarrierere, men fortsatt holde et høyt skiteknisk nivå.

Rekruttering eller trekking av utvalget

Forsøkspersonene rekrutteres fra eget nettverk i skimiljøet. Aktuelle kandidater får skriftlig forespørsel via epost som inneholder et detaljert informasjonsskriv.

Alder

18 - 38

Inngår det voksne (18 år +) i utvalget som ikke kan samtykke selv?

Nei

Personopplysninger for utvalg 2

- Navn (også ved signatur/samtykke)
- Fødselsdato

- Adresse eller telefonnummer
- E-postadresse, IP-adresse eller annen nettidentifikator
- Gps eller andre lokaliseringsdata (elektroniske spor)

Hvordan samler du inn data fra utvalg 2?

Felteksperiment/feltintervensjon

Grunnlag for å behandle alminnelige kategorier av personopplysninger

Samtykke (art. 6 nr. 1 bokstav a)

Informasjon for utvalg 2

Informerer du utvalget om behandlingen av opplysningene?

Ja

Hvordan?

Skriftlig informasjon (papir eller elektronisk)

Utvalg 3

Beskriv utvalget

Mannlige skiløpere over 18 år. En gruppe med utøvere på elitenivå (verdenscup eller pallplass i norgescup), en gruppe på nasjonal nivå (30-100 plass i norgescup). Ca 10 personer i hver gruppe

Rekruttering eller trekking av utvalget

Forsøkspersonene rekrutteres fra eget nettverk i skimiljøet. Aktuelle kandidater får skriftlig forespørsel via epost som inneholder et detaljert informasjonsskriv.

Alder

18 - 38

Inngår det voksne (18 år +) i utvalget som ikke kan samtykke selv?

Nei

Personopplysninger for utvalg 3

- Navn (også ved signatur/samtykke)
- Fødselsdato
- Adresse eller telefonnummer
- E-postadresse, IP-adresse eller annen nettidentifikator
- Helseopplysninger

Hvordan samler du inn data fra utvalg 3?

Medisinsk undersøkelse og/eller fysiske tester

Grunnlag for å behandle alminnelige kategorier av personopplysninger

Samtykke (art. 6 nr. 1 bokstav a)

Grunnlag for å behandle særlige kategorier av personopplysninger

Uttrykkelig samtykke (art. 9 nr. 2 bokstav a)

Redegjør for valget av behandlingsgrunnlag

Informasjon for utvalg 3

Informerer du utvalget om behandlingen av opplysningene?

Ja

Hvordan?

Skriftlig informasjon (papir eller elektronisk)

Tredjepersoner

Skal du behandle personopplysninger om tredjepersoner?

Nei

Dokumentasjon

Hvordan dokumenteres samtykkene?

- Manuelt (papir)

Hvordan kan samtykket trekkes tilbake?

Deltakeren tar kontakt med prosjektansvarlig og informerer om at personen trekker seg. Kontaktinformasjon til prosjektansvarlig finnes i samtykkeskjemaet.

Hvordan kan de registrerte få innsyn, rettet eller slettet opplysninger om seg selv?

Deltakeren tar kontakt med prosjektansvarlig. Kontaktinformasjon til prosjektansvarlig finnes i samtykkeskjemaet. Deltakeren kan avtale et fysisk møte for å se på, eller eventuelt få en kopi av sine egne data. Ved forespørsel om kopi av egne rådata gis disse i et filformat som er allment tilgjengelig (MS Office, pdf eller rene tekstfiler).

Dersom deltakeren trekker seg fra prosjektet kan hen kreve å få slettet sine data, med mindre opplysningene allerede er inngått i analyser eller brukt i vitenskapelige publikasjoner.

Totalt antall registrerte i prosjektet

1-99

Tillatelser

Skal du innhente følgende godkjenninger eller tillatelser for prosjektet?

- Annen godkjenning

Annen godkjenning

Prosjektet skal godkjennes av Norges Idrettshøgskoles Etiske komite før oppstart.

Behandling

Hvor behandles opplysningene?

- Maskinvare tilhørende behandlingsansvarlig institusjon
- Mobile enheter tilhørende behandlingsansvarlig institusjon

Hvem behandler/har tilgang til opplysningene?

- Prosjektansvarlig
- Student (studentprosjekt)
- Interne medarbeidere

Tilgjengeliggjøres opplysningene utenfor EU/EØS til en tredjestat eller internasjonal organisasjon?

Nei

Sikkerhet

Oppbevares personopplysningene atskilt fra øvrige data (kodenøkkel)?

Ja

Hvilke tekniske og fysiske tiltak sikrer personopplysningene?

- Opplysningene krypteres under forsendelse
- opplysningene krypteres under lagring
- Adgangsbegrensning

Varighet

Prosjektperiode

01.07.2020 - 01.06.2021

Skal data med personopplysninger oppbevares utover prosjektperioden?

Ja, data med personopplysninger oppbevares til: 01.06.2026

Til hvilket formål skal opplysningene oppbevares?

Dokumentasjonshensyn eller vilkår fra Regionale komiteer for medisinsk og helsefaglig forskningsetikk

Hvor oppbevares opplysningene?

Internt ved behandlingsansvarlig institusjon

Vil de registrerte kunne identifiseres (direkte eller indirekte) i oppgave/avhandling/øvrige publikasjoner fra prosjektet?

Nei

Tilleggsopplysninger

Vil du delta i forskningsprosjektet

“Kan en variabel intensitetsprotokoll forklare forskjeller i utholdenhet og prestasjon hos langrennsløpere?”?

Dette er et spørsmål til deg om å delta i et forskningsprosjekt hvor formålet er å undersøke om det er en forskjell mellom gode og mindre gode langrennsløpere i forbindelse med restitusjon under korte hvileperioder innimellom perioder med høy intensitet. I dette skrivet gir vi deg informasjon om målene for prosjektet og hva deltakelse vil innebære for deg.

Formål

Over lengre tid er den høyeste intensiteten man evner å opprettholde begrenset. I utholdenhetsidretter konkurreres det derfor typisk med en relativt jevn intensitet. I langrenn er derimot intensiteten ofte svært variabel. Den varierende intensiteten kan forklares av skienes glidegenskaper og løypeprofilens topografi som tillater periodevis restitusjon i utforbakker. Muligheten til å restituere seg underveis i et renn muliggjør videre perioder med svært høy intensitet. Det kan være forskjeller i hvor raskt individer restituerer seg, noe som kan være avgjørende for prestasjonen i langrenn. Hvorfor enkelte individer restituerer seg raskere enn andre er enda ikke fult forstått. Formålet med denne studien er derfor å undersøke om det er en forskjell i tid til utmattelse mellom gode og mindre gode langrennsløpere under forhold som gjenspeiler den varierende intensiteten i langrenn. Forholdene simuleres med en jojo-test på rulleskimølle hvor intensiteten er høy, men hvor restitusjon også er mulig i regelmessige innlagte perioder med lavere intensitet.

Hvem er ansvarlig for forskningsprosjektet?

Norges idrettshøgskole er ansvarlig for prosjektet. Prosjektleder er Thomas Losnegard. Prosjektmedarbeidere er ingeniør Øyvind Gløersen, samt masterstudentene Eivind Holsbrekken og Ånung Viken.

Hvorfor får du spørsmål om å delta?

Du får spørsmål om å delta i dette prosjektet fordi du er mannlig aktiv langrennsløper over 18 år gammel, og med FIS-poeng under 30 eller over 70.

Hva innebærer det for deg å delta?

Hvis du velger å delta i prosjektet, innebærer det at du i løpet av august/september møter opp på laboratorium ved Norges idrettshøgskole for å:

- Gjennomføre fire ulike submaksimale drag på rulleskimølle med teknikken fristil. Dette for å estimere din arbeidsøkonomi, slik at energikravet i senere tester kan estimeres. Under denne testen måles ditt oksygenopptak, din puls og subjektive opplevelse av anstrengelse (RPE), samt dine laktatverdier etter hvert drag.
- Gjennomføre en 1000 meter sprint med maksimal innsats på rulleskimølle med teknikken fristil. Dette for å beregne det maksimale oksygenopptaket ($VO2_{maks}$) og -underskuddet du evner å akkumulere. Oksygenunderskuddet du akkumulerer gir et bilde på din anaerobe kapasitet. Utfra denne testen beregnes effekten som gir din $VO2_{maks}$ (MAP), en beregning som brukes for å tilpasse intensiteten i den følgende intervallprotokollen. Din anaerobe kapasitet er sammenligningsgrunnlag for målinger som gjøres under intervallprotokollen i forbindelse med restitusjon. Under denne testen måles ditt oksygenopptak, din puls og RPE, samt dine laktatverdier etter testen er avsluttet.

  - Gjennomføre en intervallprotokoll på rulleskimølle med teknikken fristil. Intervallprotokollen foregår til utmattelse med 20 sekunder lange hvileperioder hvor intensiteten tilsvarer 60 % av MAP, samt 40 sekunder lange arbeidsperioder hvor intensiteten tilsvarer 120 % av MAP. Dette for å undersøke eventuelle forskjeller mellom langrennsløpere av ulikt nivå i tid til utmattelse når korte hvileperioder implementeres i aktivitet med høy intensitet av samme relative størrelse. Ved å sammenligne det totale oksygenunderskuddet som akkumuleres under testen med anaerob kapasitet kan evnen til å restituere den anaerobe kapasiteten undersøkes. Under denne testen måles ditt oksygenopptak, oksygenmetning av muskelvevet, din puls og RPE, samt dine laktatverdier etter testen er avsluttet.

Dersom du ikke har tidligere erfaring med rulleski på mølle kan det gjennomføres en tilvenningsøkt noen dager i forkant av selve testdagen.

DINE FORDELER ved å delta er tilgang til informasjon om:

  - Din arbeidsøkonomi og laktatverdier ved flere ulike submaksimale belastninger
  - Ditt maksimale oksygenopptak

Dine testdata blir registrert elektronisk.

Det er frivillig å delta

Det er frivillig å delta i prosjektet. Hvis du velger å delta, kan du når som helst trekke samtykket tilbake uten å oppgi noen grunn. Alle dine personopplysninger vil da bli slettet. Det vil ikke ha noen negative konsekvenser for deg hvis du ikke vil delta eller senere velger å trekke deg.

Ditt personvern – hvordan vi oppbevarer og bruker dine opplysninger

Vi vil bare bruke opplysningene om deg til formålene vi har fortalt om i dette skrivet. Vi behandler opplysningene konfidensielt og i samsvar med personvernregelverket. Opplysningene om deg vil bare være tilgjengelige for prosjektgruppen, herunder prosjektleder Thomas Losnegard, ingeniør Øyvind Gløersen, samt masterstudentene Eivind Holsbrekken og Ånung Viken. Navnet og kontaktopplysningene dine vil bli erstattet med en kode som lagres på egen navneliste adskilt fra øvrige data. Dine testdata vil kun bli lagret på datamaskiner disponert av prosjektgruppen, samt Norges idrettshøgskoles forskningsservere.

Hva skjer med opplysningene dine når vi avslutter forskningsprosjektet?

Opplysningene anonymiseres når prosjektet avsluttes/oppgaven er godkjent, noe som etter planen er juni 2021. Dette gjøres ved at koblingslisten som knytter ditt navn til målingene vi har gjort, makuleres.

Dine rettigheter

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

- innsyn i hvilke personopplysninger som er registrert om deg, og å få utlevert en kopi av opplysningene,
- å få rettet personopplysninger om deg,
- å få slettet personopplysninger om deg, og
- å sende klage til Datatilsynet om behandlingen av dine personopplysninger.

Hva gir oss rett til å behandle personopplysninger om deg?

Vi behandler opplysninger om deg basert på ditt samtykke.

På oppdrag fra Norges idrettshøgskole har NSD – Norsk senter for forskningsdata AS vurdert at behandlingen av personopplysninger i dette prosjektet er i samsvar med personvernregelverket.

Hvor kan jeg finne ut mer?
Hvis du har spørsmål til studien, eller ønsker å benytte deg av dine rettigheter, ta kontakt med:

- Norges idrettshøgskole ved Thomas Losnegard
    - e-post: thomas.losnegard@nih.no
    - telefon: 23262377
- Vårt personvernombud: Rolf Haavik
    - e-post: rolf.haavik@habberstad.no
    - telefon: 90733760

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

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

Med vennlig hilsen

Thomas Losnegard
(Forsker/veileder)

Samtykkeerklæring

Jeg har mottatt og forstått informasjon om prosjektet *Kan en variabel intensitetsprotokoll forklare forskjeller i utholdenhet og prestasjon hos langrennsløpere?*, og har fått anledning til å stille spørsmål. Jeg samtykker til:

☐ å delta i forskningsprosjektet slik det er beskrevet over.

Jeg samtykker til at mine opplysninger behandles frem til prosjektet er avsluttet

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(Signert av prosjektdeltaker, dato)