THE EFFECT OF SITTING POSITION ON DOUBLE POLING CYCLE CHARACTERISTICS, TRUNK CONTROL AND PHYSIOLOGY IN SIT-SKIER: A CASE STUDY

Ville Sampolahti

Exercise Physiology Master Thesis
Faculty of Sport and Health Sciences
University of Jyväskylä
Spring 2020
Supervisors: Heikki Kyröläinen & Olli Ohtonen

ABSTRACT

Sampolahti, V. 2020. Faculty of Sport and Health Sciences. Master Thesis in Exercise Physiology. University of Jyväskylä. 65 pages.

Introduction. Paralympic sit-skiing was introduced in Paralympics 1988. Since that, it has been involved to International Paralympic Committee's competitions (IPC). The athletes have been divided into five different classes based on the level on impairment and loss of trunk control. The classification is three-stepped process, where the level of the impairment and trunk control of the athlete is evaluated. In cross-country sit-skiing, the athletes perform by using double poling technique

Methods. In this case study, the subject was a Finnish 28-years old sit-skier, who is classified to class LW11. The aim was to test the possible benefits of "kneeing" position with the impaired subject who has performed in "knee-high" position. The measurements took four days. During that time, the subject performed in both positions in maximal power output and submaximal tests in ski ergometer as well as in maximal oxygen uptake test and two anaerobic tests on treadmill. EMG, joint kinematics, cycle characteristics and blood lactate were measured from each test. The respiratory variables were measured from submaximal loads in ski ergometer and maximal tests on treadmill. Pole forces were measured from maximal tests on treadmill.

Results. The main finding of this case study was that in the "kneeing" position, the subject recorded longer time of exhaustion in maximal oxygen uptake test, higher maximal speed on treadmill, longer time of exhaustion in anaerobic uphill test and higher maximal power (W) in ski ergometer. There was no difference in VO_{2peak} values, but $B\text{-}La_{peak}$ was clearly higher in "kneeing" position in each test on treadmill. The trunk range of motion was limited in "kneeing" position compared to "knee-high" position. Longer cycle time and lower cycle rate were suggested to be the key patterns of double poling and connected with more economical double poling performance in the maximal test and in both anaerobic tests.

Conclusion. The present results show that even for the athlete with limited trunk control, the "kneeing "position can affect positively to sit-skiing performance. How this new sitting position will work in the future and will the athlete due to the increased workload of the erector spinae muscles be able to continue with the new position remains to be seen. Nevertheless, based on this case study, we have now a protocol to test sit-skiing athletes, the performance of them and the differences between the classes and the positions on a treadmill

Keywords: Paralympic sit-skiing, double poling, performance, sitting position, trunk control

CONTENTS

1 INTRODUCTION

Cross-country sit-skiing became part of Paralympic Winter Sports family in 1988, when it was introduced by the International Paralympic committee (IPC). Since that sit-skiing has been in IPC organized competitions.

The impaired athletes are classified into five different classes based on the evaluations of their trunk control during the classification process (IPC). Due the variations in limitations in trunk control, number of impairments and will to make competition even and fair, IPC has created a calculation system that takes certain percent away for the competition finishing time. The Classification process is not evidence based, so the given benefits and classification process are criticized by athletes and coaches. (Pernot 2011; Vanlandewijck et al. 2011) (Pernot 2011; Vanlandewijck et al. 2011). Two mostly used sitting positions in sit-skiing are “kneeing” (KL) and “knee-high” (KH) positions (Gastaldi et al 2012; Bernardi et al. 2013). Research made about sit-skiing with both impaired and abled-bodied subjects report many positive patterns of KL to sit-skiing performance (Rosso et al. 2019).

Double poling is the technique the athletes perform in cross-country sit-skiing (Gastaldi et al. 2012; Rapp et al. 2016). Several studies with abled-bodied athletes have been made about the physiology and biomechanics of skiing and double poling. The studies have reported the higher values of blood lactate threshold (B-La) and lower peak oxygen uptake ($VO_{2\ peak}$) levels in double poling compared to diagonal technique and running (Staib et al. 2000; Doyon 2001; Holmberg et al. 2007; Sandbakk et al. 2010). Holmberg et al. (2007) & Sandbakk et al. (2016) found that faster skiers were able to reach higher $VO_{2\ peak}$ values and higher blood lactate threshold values in double poling than slower skiers.

Recent studies have shown that the KL position is more effective and economical position to ski than the KH position. Respiratory patterns are reported to be higher on submaximal loads in the KH compared to KL position (Lajunen 2014). In the KL position the range of trunk motion is greater than in KH position. The correlation between greater range of trunk motion and the fatigue control, greater pole forces and better control of pole angles to greater trunk motion was found by Gastaldi et al. (2012) According to the findings of Lajunen (2014) & Hofmann et al. (2016), the KL position works better with modern double poling key patterns investigated by (Holmberg et al 2005; Lindinger 2009b; Lindinger & Holmberg 2011; Stöggl et al. 2011).

This study was a part of the project, where the Vuokatti Sports Technology Unit (University of Jyväskylä) developed a new sit-skiing sledge to a Finnish sit-ski athlete. The project started with a contact meeting where the prototype of the new sledge was created. The preparation and training phase of the project lasted ten months. During that time, the athlete trained in the new skiing position (KL) on roller skis, in ski ergometer and on snow and had competitions in the KL position. During the training time, the group had pilot measurements with the athlete, where the protocol and measurements were piloted and tested, and new prototypes of the sledge were developed.

The aim of this case study was to compare the KL- and KH- positions and differences in athlete's performance with them in different tests. The aim was to examine possible benefits of the KL position and its big affections to skiing performance. Physiological and biomechanical aspects of skiing between the positions were compared. The real differences between the positions and their impacts to maximal performance, speed and force production were compared in ski ergometer and on treadmill. The project included MVC-test and two submaximal tests in ski ergometer with both skiing positions. Test included also maximal oxygen uptake test, maximal speed test and maximal angle of the hill test on treadmill. All the tests were performed with both skiing positions.

2 PARALYMPIC SIT-SKIING

International Paralympic Committee (IPC) has organized competitions in cross-country sit-skiing since Paralympic Games 1988 when the sport was introduced (IPC). In the sport, athletes perform using double poling technique and using the right and left pole simultaneously as they generate forward propulsion forces (Rapp et al. 2016). The athletes in cross-country sit-skiing have different kinds of impairments, which effect on their body function, especially trunk control (IPC). To make competition fair and as even as possible, the athletes have been divided into five different classes with similar physical limitations (IPC). The classes are LW10, LW10.5, LW11, LW11.5, and LW12 (IPC). Cross-country sit-skiers can compete in biathlon and Nordic skiing. The competition distances are from 1 km sprint competitions to 15 kilometers long distance competitions. (IPC)

2.1 Kneeing and knee-high position

In cross-country sit-skiing, the athletes use different sitting positions to perform the sport (IPC). The positions that are used are based on the trunk control of the athlete (Gastaldi et al. 2012). In sit skiing competitions, the athletes have used four different positions (figure 1) but two commonly used positions are “kneeing” - (KL) and “knee-high” positions (KH) (Gastaldi et al 2012; Bernardi et al. 2013). The KL position needs better control of trunk muscles because of greater functionality of trunk muscles during the poling cycle. By that reason, the KL position is used by athletes with minimal impairments in trunk control (Gastaldi et al. 2012; Rosso et al. 2019). The KH position is used by the athletes with limitations in trunk control. Research that has been made have pointed several benefits of the KL position compared to the KH position (Rosso et al. 2019).

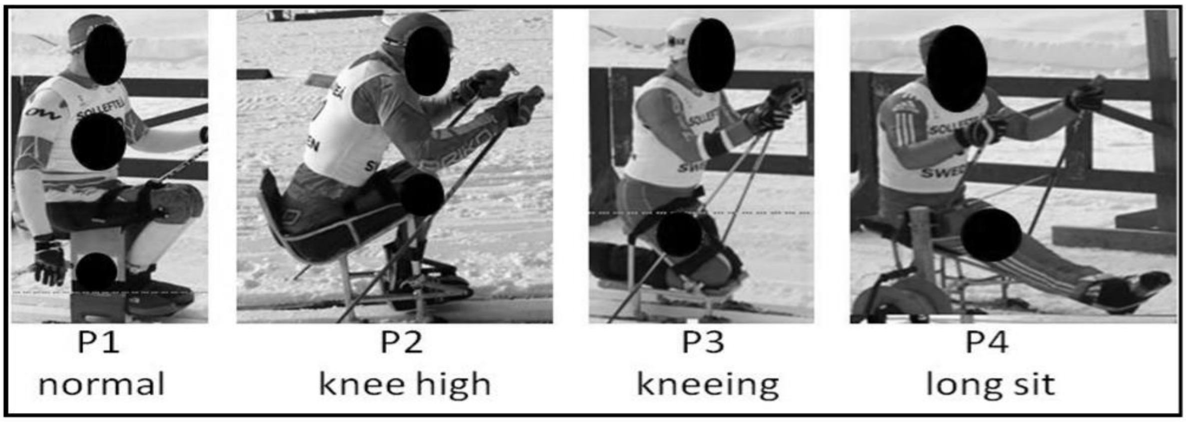

FIGURE 1: Most commonly used sitting positions in Paralympic sit-skiing competitions. Rapp et al. (2016)

2.2 Classification in sit-skiing

According to researches, the trunk flexion plays a significant role in total force production, generation for propulsion forces and in control of muscular fatigue during the performance (Gastaldi et al 2012; Rosso et al. 2017). The athletes in cross-country sit-skiing are divided in five different classes according to their trunk control ability (IPC). Top class is LW12 where the athletes have no limitations in their trunk control (table 1). These athletes can, for example, be amputee. The lowest class is LW10, where the athletes have no trunk function and abdominal muscles (IPC). The level of impairment and trunk control between the classes are presented in Table 1.

TABLE 1**:** Nordic Skiing and Biathlon Paralympic Sport Classes (IPC)

LW 10	Impairment limits leg and trunk function. Unable to sit without support of the arms, for example due to paraplegia
LW 10.5	Limited trunk control, but sitting balance can be maintained when not moving sideways.
LW 11	Leg impairment and fair trunk control, which enables them to balance even when moving sideways.
LW 11.5	Near to normal trunk control
LW 12	Impairements same as skiers with leg impairments. Leg impairment, but normal trunk control. Eligible to compete standing or sitting.

Because all classes compete in the same competition, IPC modifies the finishing times based on the class. Each class gets certain percent off from their finishing time and as a result of that the athlete gets his final time (IPC). The aim is to minimize the impairment effects on performance and by that make the competition fair. The time benefit percent are presented in Table 2.

TABLE 1: The time benefit percent for the athletes in different classes. IPC

	% away from finishing time
LW 10	14
LW 10.5	10
LW 11	6
LW 11.5	4
LW 12	0

Behind of this separation to classes is a process called classification (IPC). Classification is a complex process ruled and leaded by IPC. To get a classification the classifier performing the evaluation must be internationally educated and approved by IPC. The biggest nations may have their own national classifiers, educated and approved by IPC but most of the athletes get their classification from IPC. Classification process includes medical documentation, observation and functional testing of capacity to stabilize trunk with so called Test-table-test (Pernot 2011). In that test, athletes sit legs properly strapped and try to bend the trunk into all movement plane. According to the result and needed help of arms, the athletes get point which divide them to classes. LW10 are unable to sit without strapping (Pernot 2011). Even though the classification process has three sections, it is not evidence based and both athletes and coaches argue against classification allocations (Pernot 2011; Vanlandewijck et al. 2011). Studies have shown that benefits got from larger hip range of motion (ROM) and increased trunk ROM and the effects of them to force production, kinematics and physiology in cross-country sit-skiing performance are much greater than the rebate of classes for the finishing time (Vanlandewijck et al. 2011; Rosso et al. 2019).

3 PHYSIOLOGY IN DOUBLE POLING

There are quite a lot of studies in physiology concentrated to double poling technique. Individual level of performance is strongly related to physiological patterns together with biomechanical patterns. Successful performance involves a smooth combination of physiological variables, biomechanics and different techniques. (Moxnes & Hausken 2009)

3.1 $VO_{2\ max}$ values and measurements

The ability to perform on different skiing techniques with high aerobic power and the development of that have been reported to be the key factors of cross-country skiing performance (Holmberg et al 2007; Sandbakk et al. 2010; Sandbakk & Holmberg 2014). The highest maximal aerobic powers reported for men cross-country skiers is 94 ml/kg/min and for female 77 ml/kg/min (Åstrand et al., 2003, 511). In their study Saltin and Åstrand (1967) compared VO_{2max} values of athletes from various sports. They found out that cross-country skiers had the highest values in both genders and concluded this is because cross-country skiing involves almost all major muscle groups.

Age, genetics, body composition/weight, gender and training affect individual level of VO_{2max} (Åstrand et al. 2003,511). Performed sport and technique also have influence on VO_{2max}. Doyon (2001) compared VO_{2peak} values in double poling, diagonal skiing and running during maximal test on treadmill. He found out that in double poling, the value was lowest while highest in running. In their study with international level cross-country skiers, investigating the effects of double poling, diagonal skiing and running to VO_{2peak}, Holmberg et al. (2007) also found out that in double poling, the VO_{2peak} was the lowest compared to diagonal skiing and running. In their study, there was a significant difference in $VO_{2absolute}$ values between double poling and running.

In their research with ten female Italian national team skiers, Fabre et al. (2010) compared physiological responses in double poling and diagonal skiing. They found out $HR_{peak,}$ VE_{peak} and $VO_{2anaerobic\ threshold}$ to be significantly higher on diagonal. No differences between VO_{2peak}

between techniques were found. Fabre et al. (2010) found out significant correlation at $VO_{2 peak}$ in double poling to FIS points ($p<0.01$). Sandbakk et al. (2016) compared six World cup level Norwegian cross-country skiers to six National cup level Norwegian skiers. They found out that on submaximal loads, WC level athletes recorded 4-6% lower $\%VO_{2peak}$, 10-11% lower $\%HR_{peak}$ and lower blood lactate threshold in both double poling and diagonal. VO_{2peak} was 10% higher in double poling with WC level athletes. With both WC and NC levels, the VO_{peak} values with double poling represented 91% of VO_{2peak} values in diagonal. That finding is corresponding to findings with elite male skiers (Holmberg et al. 2007).

Previous studies suggested that due the lower muscle mass, VO_{2peak} is lower in double poling. That reflects the lower oxygen extraction that is related to lower oxygen conductance in upper body (Calbet et al., 2005). The intra-arterial blood pressure in higher and VO_{2max} 70% lower in arms compared to legs, which cause a higher demand for the heart (Åstrand et al., 2003, 513). Results of comparing double poling and diagonal on treadmill reported higher metabolic demand for skiing up a steeper incline in double poling technique. That is a result of higher and less efficient work rate compared to diagonal (Hoffman et al., 1995). Van Hall et al. (2005) suggested that the arm muscles have a lower ability to capitalize lactate paired with increased ability to produce lactate, whereas leg muscles have higher lactate uptake paired with lower lactate release.

3.2 Blood lactate threshold

Blood lactate threshold represents the exercise intensity that shows the increase in blood lactate from resting levels (Jones and Carter, 2000). The main producer of lactate acid during the performance is skeletal muscles (Åstrand et al., 2003, 513). Lactate is an important factor in endurance sports. Endurance training affects increase in lactate threshold levels, due to a rightward shift, which permits for a higher exercise intensity to be reached (Bassett & Howley, 2000; Jones & Carter, 2000).

Van Hall et al. (2001) compared legs and arms lactate levels during exercise. They suggested that arm muscles have a lower ability capitalize lactate with increased ability to produce lactate. Doyon et al. (2001) & Holmberg et al. (2007) showed the highest blood lactate concentrations on submaximal loads in double poling compared to diagonal and running, supporting that finding.

Stöggl et al. (2006b) investigated maximal double poling performance by 1000 meters maximal skiing on a treadmill. They found out no correlation between high blood lactate concentration and performance time. Staib et al. (2000) found that in double poling, the subjects reached higher level of $B\text{-}La_{max}$ than in diagonal. They found significant difference between the levels of skiers. The successful skiers were able to reach the higher level of blood lactate concentration. Holmberg et al. (2007) & Sandbakk et al. (2016) found in their research that higher-level cross-country skiers record lower values of blood lactate threshold, heart rate and respiratory variables on submaximal loads. Sandbakk et al. (2016) found no differences between the groups in $B\text{-}La_{peak}$ values.

4 BIOMECHANICS OF DOUBLE POLING

During the last decade, use of the double poling technique in competitions has increased. Harder and better tracks and the development of skiers and equipment have increased the speed in competitions. Training methods have also changed due the sprint and mass start competitions (Lindinger et al 2009b). Increased focus on upper body training and speed training have made skiers more explosive capable to reach higher velocities in double poling. Double poling is the main technique and critical component and is often an exclusive technique in competitions today. (Lindinger et al. 2009b)

There are quite a lot of studies about double poling showing that the technique has developed during the years. The basic studies of double poling focused on forces, cycle characteristics, joint kinematics during the double poling cycle. Present studies have concentrated more on specific variables, differences between sexes, effects of the different trails, longer duration effects to double poling patterns and development of double poling. (Pellegrini et al. 2018)

4.1 Double poling cycle

Double poling cycle describes the moment that begins the moment of the pole ground contact to the next pole ground contact. Poling cycle can be separated to poling and recovery phase. (Holmberg et al., 2005) The poling phase describes the time when arm moves, and pole contact ends and pole is released. The recovery phase describes the gliding phase when the pole is not contacted to ground. The length of the recovery phase depends on the intensity, incline and the existed speed (Holmberg et al., 2005; Lindinger et al. 2009a).

The main factors in double poling cycle are the cycle time (CT) and cycle rate (CR) that describes poling frequency (Holmberg et al., 2005). Double poling speed is regulated by the product of cycle length and cycle rate (Lindinger & Holmberg 2011). The ability of longer recovery time at lower or similar cycle rates in different techniques has reported to be the key factor between fast and slow skiers (Stoggl et al. 2007; Lindinger et al. 2009a). Latest research about double poling state that faster skiers in double poling exhibit shorter relative poling time, longer relative recovery time and later peak pole force than slower skiers (Holmberg et al., 2005; Stöggl et al. 2011). Previous studies about cycle characteristics suggested that increases in cycle length were not typical and the increase in speed was primarily due to increases in the poling frequency (Hoffman et al. 1995). Present knowledge about double poling disagrees with previous studies by suggesting that skiers control their double poling speed by increasing the poling frequency and cycle length (Lindinger et al. 2009a; Halonen et al. 2015). Differences between present and previous findings of double poling in terms of poling frequency and cycle length are presented in Figure 2. The increase in cycle length is paired with increased pole forces which can be results of more focused upper body training or technical development of double poling where lower body produces force (Holmberg et al. 2005; Lindinger et al .2009a; Stöggl et al. 2011).

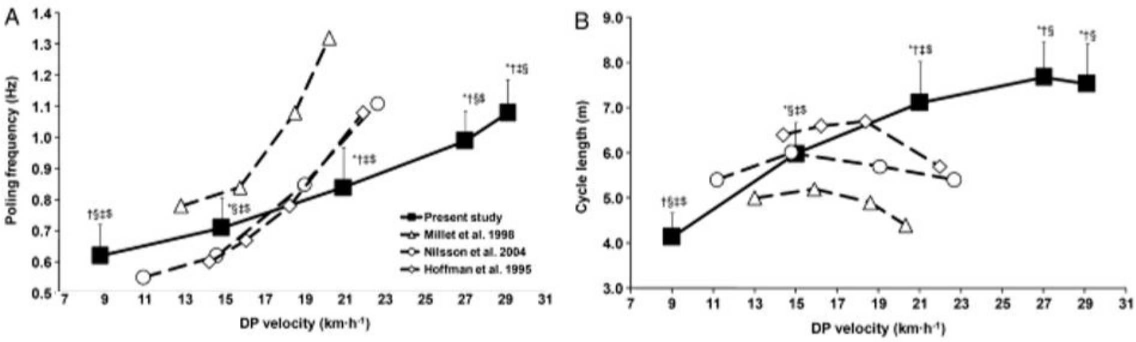

FIGURE 2: Submaximal and submaximal double pole velocities. All values presented as mean values. *different to 9 km/h; † different to 15 km/h;§ different to 21 km/h; ‡ different to 27 km/h; $ different to V_{max} (P<0.005). (**A**) poling frequency, (**B**) Cycle length (m). Modified from Lindinger et al. (2009a)

There is lack of research about cycle characteristics development in steeper terrains. Millet et al. (1998) found out in their research when the inclination increased from 1.2˚ to 2.9˚, pole forces increased, recovery time shorted but duration of the poling phase unchanged. Stöggl & Holmberg (2016) compared cycle characteristics in flat terrain (1˚) and steep terrain (7˚) on treadmill. As a result, they got that compared to flat, the cycle rate was 30% higher and cycle length 23% shorter in uphill, thus the speed was slower. Due to the loss of speed on steeper terrain, skier is forced to use more rapid and shorter cycles. Stöggl & Holmberg's (2016) finding about cycle rate is in line with Millet et al. (1998). Stöggl and Holmberg (2016) found that compared to flat, the relative poling time (rPT) consisted of 51% of total cycle time, whereas on flat it consisted of 25% of total cycle time.

Stöggl et al. (2018) investigated the impacts of incline, sex and level of performance during cross-country skiing competition. Based on the results, the skiers were classified to fast- and slow skiers. They investigated 41 women and 41 men. All were filmed in different parts of the track in different inclinations of 0˚, 3.5˚, 7.1˚ and 11˚. As a result, they found out that as the incline increased, cycle velocity and recovery time decreased while poling time and external power output rose. Both men and women such as fast- slow skiers had differences with longer and faster cycles. (Stöggl et al.2018)

4.2 Forces

The recent studies represent a strong correlation between maximal double poling velocity and upper body force production. Upper body force production capacity is reported to be beneficial to performance in sprint and long-distance competitions (Holmberg et al. 2005; Stöggl et al. 2007). One of the main findings of Holmberg et al. (2005) was to present the positive correlation between peak pole force and performance on 85% level of velocity. The peak pole force was reached at 0.10 ± 0.02 time of total cycle time (figure 3). Lindinger et al. (2009a) found the peak pole force at 0.07 ± 0.004. Faster skies produce the peak pole force at the later point of the poling cycle than slower skiers (Lindinger et al. 2009a; Stöggl et al. 2011).

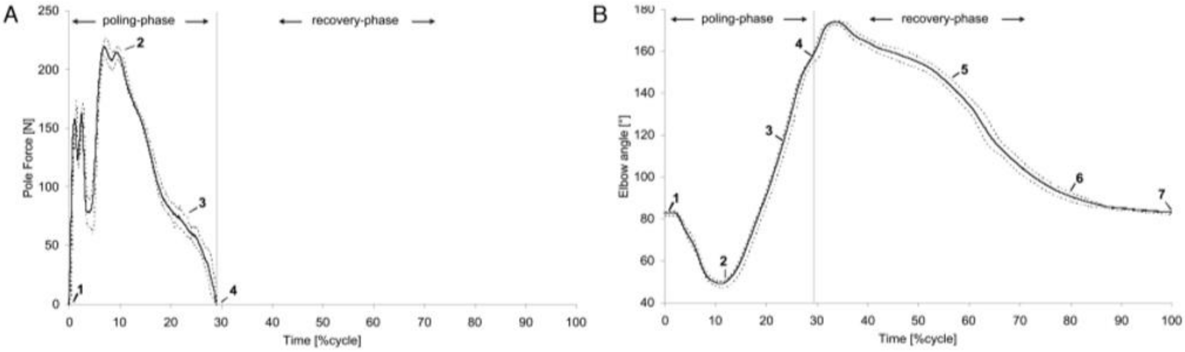

FIGURE 3: (**A**) Pole force behaviour and (**B**) elbow angle behaviour (% cycle time) during double poling cycle at 85% V_{max}. Holmberg et al. (2005).

Upper body and trunk activity produce the propulsive forces in double poling. Forces are released through the poles. Hand placement and the control of shoulder, elbow and trunk have an influence on the effectiveness of poling forces (Holmberg et al.2005; Stöggl et al. 2007; Lindinger &Holmberg 2011). Holmberg et al. (2006) presented that the activation of lower body muscles increases the performance in double poling. When lower body muscles were activated and elastic, compared to “locked” situation, duration of maximal test increased 11.7%, $VO_{2\ peak}$ was 7.7% higher and the maximal velocity increased by 9.4% (Holmberg et al. (2006).

Increased force production and double poling velocity is also shown with higher lower and upper body activations. Increase in forces and velocities have developed double poling technique (Stöggl et al. 2011). Modern double poling technique includes ”wide elbows” that activates *latissimus dorsi* and *teres major* muscles and, therefore, the athletes can create greater pole forces and reach the peak forces in a shorter time compared to present “narrow elbow”-style (Holmberg et al. 2005; Stöggl et al. 2011). The development of double poling has increased the need of muscles pre-activation (Lindinger et al.2009b). Holmberg et al. (2005) reported that pre-activation in muscles leads to higher muscle stiffness that prepares the body to the poling phase and increases the pole forces. According to Lindinger et al. (2009b), pre-activation is important that also II-type muscle fibers can activate on their maximal level right at the beginning of the poling phase. (Holmberg et al. 2005; Lindinger et al. 2009b) The new strategy and level of pre-activation consists of smaller joint angles, higher flexion velocities, and higher pole force applied during a shorter poling phase (Holmberg et al., 2005; Lindinger et al. 2009b).

4.3 Joint kinematics

Lindinger et al. (2009b) investigated the neuromuscular activity and the role of stretch shortening cycle in arm and shoulder extensor muscles at maximal and submaximal velocities. According to the findings, the poling phase was divided to flexion-extension pattern in elbow joint. The pattern became more visible while double poling velocity increased (figure 4). That meant the elbow stretch shortening cycle was needed to adapt to higher velocities with faster elbow flexion and instant transition between flexion and extension (Lindinger et al. 2009b).

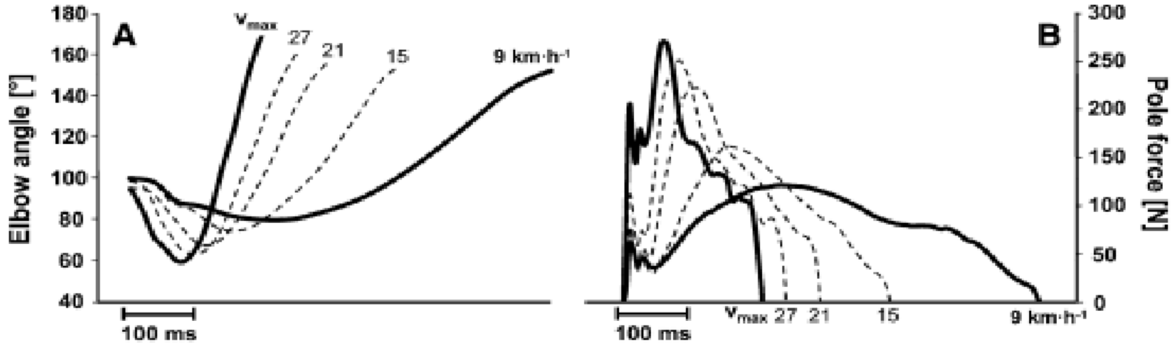

FIGURE 4: Elbow angle behaviour at various velocities (A), Pole force s behaviour at various velocities (B) (Lindinger et al., 2009b)

The velocity of angular flexion and extensions in elbow are the highest at lower cycle rate. This is connected with higher force values, which make it possible for the skier to cover longer cycle lengths and increase cycle rate (Lindinger and Holmberg, 2011). Lower body joints of knee and hip also perform greater flexion- extension pattern at lower cycle rates. Faster skiers are more capable to react to changing speeds (Lindinger et al. 2009b).

Joint kinematics in double poling and in all techniques depend on personal preferences. One size of an angle is not the best for everyone (Lindinger and Holmberg, 2011). Similar patterns have been found in well-performed skiers. It is well recorded, that the greatest pole forces can be produced with small elbow angle, a wide range of motion in shoulder and relaxed lower body joints (Holmberg et al. 2005; Stöggl et al. 2007; Lindinger et al. 2009b).

5 THE EFFECT OF SITTING POSITION TO SIT-SKIING PERFORMANCE

The field of studies about cross-country sit skiing is not wide. There is not lots of research available about physiology and cycle characteristics. The biggest numbers of studies have concentrated on biomechanics and trunk control. The aims of the studies have been specific, focusing on certain variables. One reason to lack of evidence is a low number of subjects. Some research about physiology and biomechanics has been made with abled-bodied subjects (Lajunen 2014; Lund Ohlsson & Laaksonen 20017). Fobres et al. (2010) did a physiological study with impaired athletes. Hofmann et al. (2016) investigated physiology and kinetics in their case study with an impaired athlete. Research about biomechanics has been done with impaired athletes (Gastaldi et al. 2012; Bernardi et al. 2013; Rosso et al. 2016; Rosso et al. 2017).

5.1 Trunk control

There are quite a lot of studies about biomechanics in cross-country sit-skiing. Most of the research has been made with impaired athletes. The athletes have performed in tests representing their own class, using the sitting position in which they compete.

Gastaldi et al. (2012) found in their field study in Vancouver Paralympics 2010, that athletes in the KL have greater trunk range of motion (ROM) than athletes in the KH. Gastaldi et al. (2012) found that trunk flexion is important while creating greater pole forces, limiting fatigue and controlling pole angles. Lajunen (2014) had same kind of finding. He also found hip range of motion to be from 46.6% to 46.8.% smaller in the KH than in the KL on higher submaximal loads. Bernardi et al. (2013) analysed long-distance races in Torino Paralympics 2006. They found that on uphill section of the course, the diminished shoulder-hand distance correlated with cycle speed and cycle length. Decreased cycle length and cycle speed were tried to cover with greater trunk inclination by athletes with worst performance (Bernardi et al. 2013).

Rosso et al. (2016) did maximal speed tests on ski ergometer. They showed that in the KH, the athletes had lower trunk maximal forward inclination and range of motion than in the KL. That finding was in line with Gastaldi et al. (2012). Rosso et al. (2016) suggested that reason to lower trunk maximal frontal inclination and trunk range of motion in the KH is a result from used straps that athletes need to use for better balance and control of trunk because of limitations in muscle control. Rosso et al. (2016) found that athletes in KH had values under 0˚ as maximal trunk backward inclination, whereas in the KL, athletes recorded values over 14˚.

5.2 Double poling cycle

According to the researches with able-bodied skiers, the key factors in modern double poling are longer CT and lower CR, shorter relative poling phase and longer relative recovery phase (Holmberg et al., 2005; Lindinger et al. 2009b; Lindinger & Holmberg 2011; Stöggl et al. 2011). Double poling with cross-country sit-skiers has been investigated more during past years. Gastaldi et al. (2012) did a proper analysis of biomechanics about cross-country sit-skiing. Based on their findings in all classes, Gastaldi et al. (2012) suggested separation of double poling cycle to three phases instead of two. The phases were poling phase (PP), transition phase (TP) and recovery phase (RP) (figure 5). Phases are slightly different from Holmberg et al. (2005). According to Gastaldi et al. (2012), the main finding for PP is that it starts with maximal body and arm extension. During that, the athletes can reach an elbow angle of 140˚, which decreases to values under 90˚. TP concludes PP and ends to maximal elbow angle extension when the poles are no longer in contact to the ground. Gastaldi et al. (2012) showed also differences between the KL and KH positions in biomechanics (figure 6 & figure 7). Gastaldi et al (2012) found that during TP, lower classified athletes (LW10 & LW 11) reach a back extension of the wrist with respect to the hip smaller than LW12-athletes.

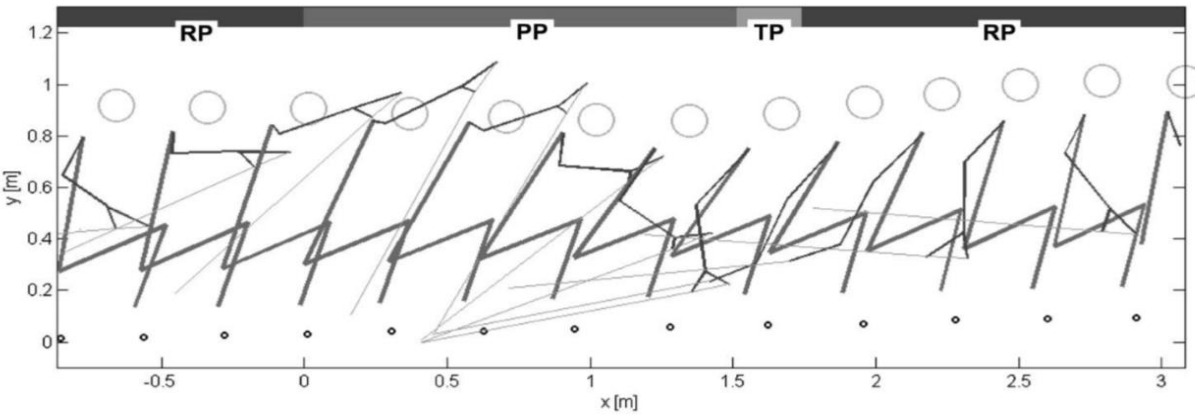

FIGURE 1: Double poling cycle for cross-country sit skier. Gastaldi et al (2012)

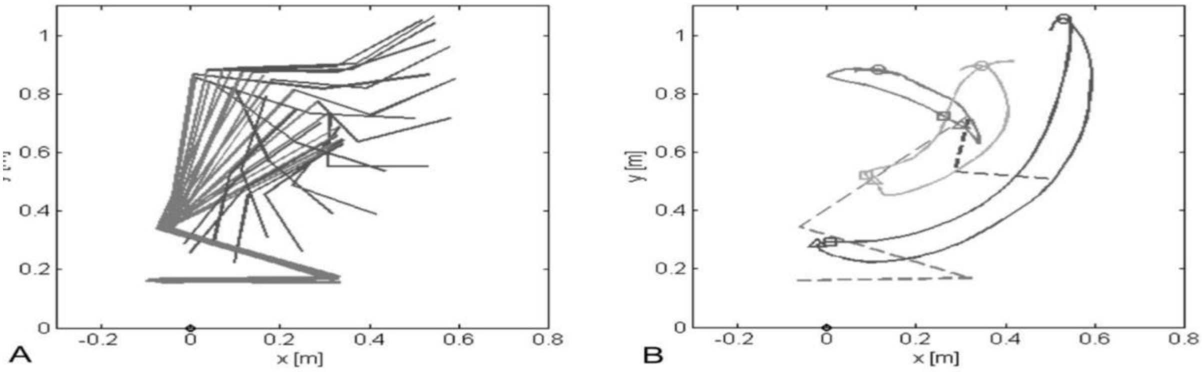

FIGURE 6: Biomechanics of the double poling cycle in KL. (**A**) Stick diagram of the joint angles, (**B**) elbow, shoulder and wrist trajectories circle represents PP, square TP, and triangle RP. Gastaldi et al. (2012)

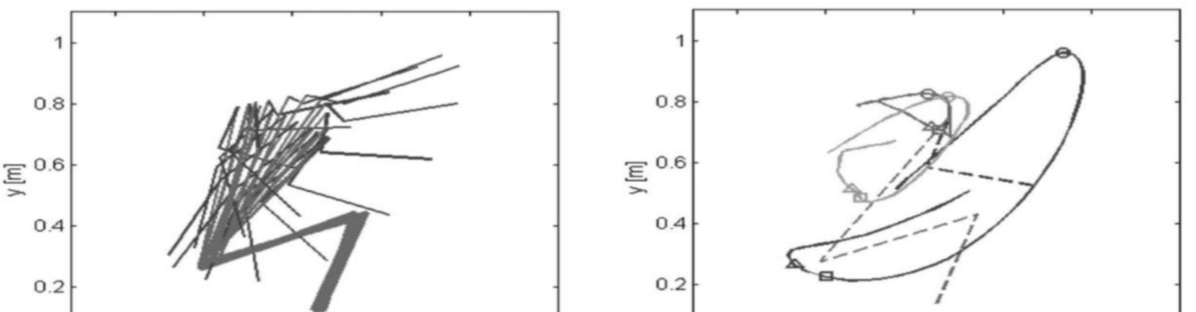

FIGURE 7: Biomechanics of the double poling cycle in KH. (**A**) Stick diagram of the joint angles, (**B**) elbow, shoulder and wrist trajectories circle represents PP, square TP, and triangle RP. Gastaldi et al. (2012)

Rosso et al. (2015) found in their research with Paralympic sit-skiers a positive correlation in maximal speed between simulated and natural skiing (r = 0.79, P<0.001). The main finding was that athletes skiing faster on field, performed better also in simulated skiing in ski ergometer. This finding was in line with Halonen et al. (2015) finding with abled-bodied skiers. Rosso et al. (2017) found a correlation between fast performance on ski ergometer and on field with Paralympic sit-skiers. Rosso et al. (2017) found force production during double poling present in two peaks (figure 8). First peak occurred impact force, which showed higher force with respect to peak force than reported with unimpaired skiers (Holmberg et al. 2005). The second peak of force lead to propulsion Rosso et al. (2017). Generated forces during poling phase are related to sitting position. Difference between positions becomes best visible in the hip and trunk muscles (Gastaldi et al. 2012; Lappi 2014; Rosso et al. 2016).

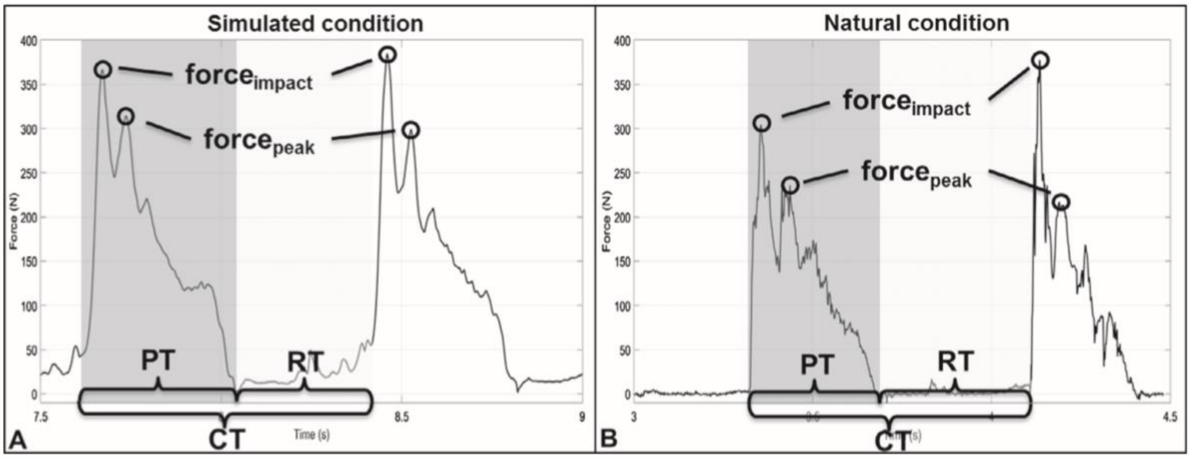

FIGURE 8: Force and cycle characteristics (PT, RT and cycle time) in two conditions. (**A**) Simulated conditions, (**B**) natural conditions. Rosso et al. (2017)

Rosso et al. (2016) found a high correlation in the peak and average values of muscle activity, in time to impact, peak force, and average force between natural uphill (2.5˚) skiing and ski ergometer skiing. The finding pointed that ability to create higher absolute muscle activity and force production in ski ergometer reacts similarly in field, while in ski ergometer cycle time (0.89 ± 0.15 vs. 0.66 ± 0.11) and poling time (PT) (0.47 ± 0.08 vs. 0.30 ± 0.04) were longer with higher integral force. Rosso et al. (2017) measured EMG from triceps brachii, pectoralis major, latissimus dorsi, erector spinae, and rectus abdominis muscles. The findings suggested that the ski ergometer is a good machine for specific upper body maximal strength training and testing aerobic and anaerobic capacity in sport-specific reliable and repeatable conditions (Rosso et al. 2017).

Rapp et al. (2016) compared muscle activation with EMG between LW10 and LW12 athletes. They found no EMG activation in the abdominal and back muscles in the LW10 athlete (figure 9).

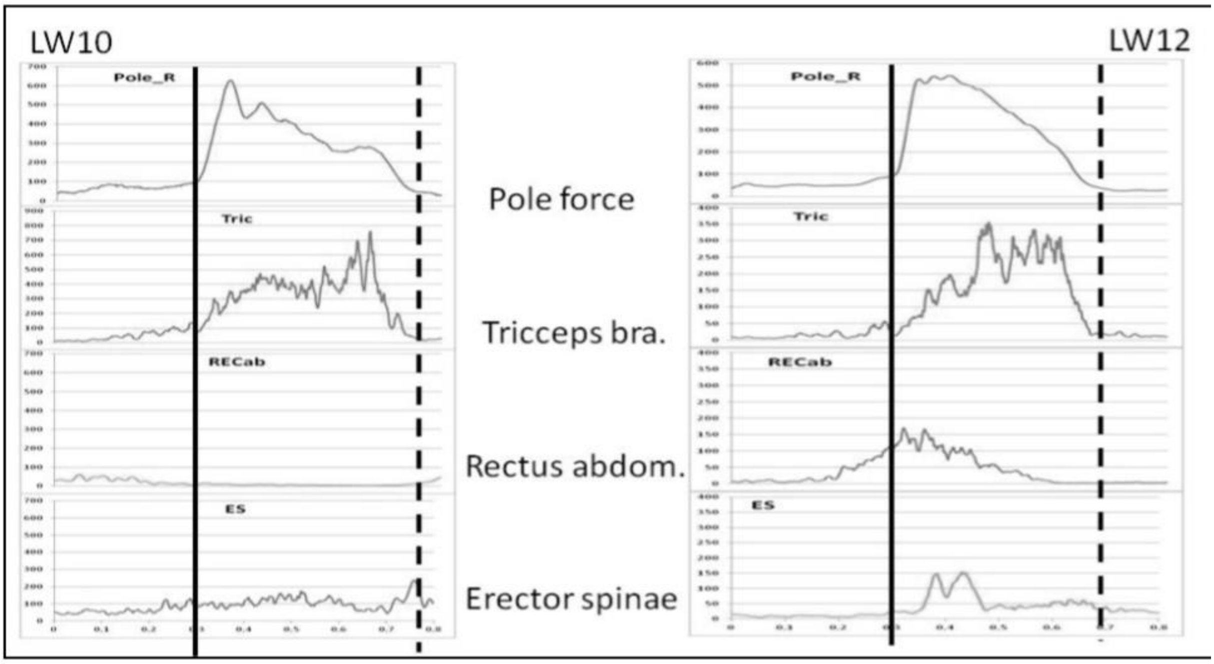

FIGURE 9: Pole forces and EMG samples for two athletes from classes LW10 and LW12 during one poling cycle in ski ergometer. Vertical solid line represents start of movement, dotted line the start of RP. Rapp et al. (2016)

In his study, Lajunen (2014) found higher cycle rate, lower impulse of force and limited trunk ROM to be connected to uneconomical performance in sit-skiing. In his study, Lajunen (2014) also found differences in relative poling time between positions. On different submaximal loads in ski ergometer, the relative poling time (rPT) was 9.9 %, 8.0 % and 13.7% higher in the KH position than in KL at loads 50 %, 60 % and 70 %, respectively. These findings and their connection to better performance are supported by the findings of Holmberg et al. (2005), Lindinger et al. (2009b), Lindinger & Holmberg (2011) and Stöggl et al. (2011). Lund Ohlsson & Laaksonen (2017) found no differences between the positions in cycle time or cycle rate. They found relative poling time longer in the KL with frontal support. Hofmann et al. (2016) findings with impaired athlete were in line with Lajunen's (2014) findings. They found cycle rate to be the lowest and relative poling time the shortest in the KL and longest in KH

5.3 Physiology

To the author's knowledge, there are only a few studies that have researched biomechanics and physiology of cross-country sit-skiing. Lajunen (2014) & Lund Ohlsson & Laaksonen (2017) performed with abled-bodied skiers in the KH and KL positions. Lajunen (2014) found higher oxygen consumption (VO_2), ventilation (VE) and blood lactate concentration (B-La) in the KH position on submaximal loads. Lajunen (2014) found KH less economical than KL. In the study, they did not use trunk support in KL position. Lund Ohlsson & Laaksonen (2017) used a frontal trunk support in the KL, the hypothesis was that athletes could improve performance in seated double poling by improving respiratory function. Lund Ohlsson & Laaksonen (2017) found no main effect of position. VO_{2peak} did not differ, VE was significantly higher in the KL, HR was lower in the KH on submaximal loads, but showed no difference on MAX load and HR_{peak}. B-La was higher on higher submaximal workloads in the KL but showed no difference on maximal load. (Lund Ohlsson & Laaksonen (2017). Lajunen (2014) listed smaller hip range of motion, higher cycle rate and lower impulse of force in the KH as the main factors for higher VO_2 and uneconomical performance.

In a case study, Hofmann et al. (2016) investigated differences in three sit-skiing positions with impaired athlete in ski ergometer. They tested KL, KH and "knees on level" positions on 7 minutes trials at 80% VO_{2max}. They found oxygen consumption to be 12% higher in KH compared to other positions. HR and VE were lower in KL. The main finding of the report was that they found that the KL position is the best for the subject.

Forbes et al. (2010) did their study during the Winter Paralympics in Vancouver 2010. Their main finding was to find the similarity in VO_{2peak} values in modified ski ergometer test compared to the field test. As a result, Forbes et al. (2010) also found significantly lower HR_{peak} and lower B-La_{peak} in field test, compared to ski ergometer. All these findings were in line with Wisloff & Helgerud (1998) findings with abled-bodied skiers.

6 PURPOSE OF THE STUDY AND RESEARCH QUESTIONS

The aim of this case report was to compare the KL- and KH positions and differences in athlete's performance with them in different tests. The aim was to proof the possible benefits of the KL position and its effects to sit-skiing performance. Recent studies have proved that KL is more effective and economical position to ski than KH. The project included maximal voluntary contraction-test (MVC) and two submaximal tests in ski ergometer with both skiing positions. Tests also consisted of maximal oxygen uptake test, maximal speed test and maximal angle of the hill test on treadmill. All the tests were made with both skiing positions. The idea of the report was to compare physiological and biomechanical aspects of skiing in ski ergometer and treadmill and see the real differences between the positions and their impacts to maximal performance, speed and force production. Research questions and hypotheses are as follows:

1. Does the better performance in ski ergometer predict better performance in treadmill tests?

H1: Yes. The previous studies have found that athletes skiing faster on field, performed better also in simulated skiing in ski ergometer. These findings have been made with both impaired and abled-bodied subjects.

Halonen et al. (2015), Rosso et al. (2015) & Rosso et al. (2017) have found a correlation between fast performance on ski ergometer and on field. No previous studies have reported results in cross-country sit-skiing on treadmill and with protocol like this.

2. Does the "kneeing" (KL) position effect positively on double poling cycle characteristics, trunk control and physiological variables during performance?

H2: Yes. Previous studies have reported positive effects of "kneeing" (KL) position to double poling cycle characteristics, trunk control and physiological variables.

“kneeing” position’s positive effects on double poling performance found by Lajunen (2014), Hofmann et al. (2016) & Rosso et al. (2016) are in line with the findings with abled-bodied skiers (Holmberg et al. 2005; Lindinger & Holmberg 2011). Study of Lajunen (2014) study was made with abled-bodied subjects. Study of Hofmann et al. (2016) was a case study with an impaired athlete. The findings were in line with Lajunen et al. (2014) and the findings with abled-bodied subjects.

3. Does the “kneeing” (KL) position increase the muscle activation in erector spinae muscles?

H3: Yes. Previous studies have reported smaller trunk maximal backward inclination in KL position. Then the back-area muscles are activated. Due to the impairment of the subject, this is the key point of success.

Rosso et al. (2016) reported all positive values with trunk maximal backward inclination in ski ergometer while testing maximal speed. Previous researches have not reported the effects of sitting position to level of activation in lower back muscles or compared the level of activations between the positions.

7 METHODS

The subject in this case study was a 28-years old Finnish female sit-skiing athlete who is classified to LW11. The subject competes in both Nordic skiing and Biathlon in IPC World Cup. The subject also competes in Paracycling. The subject has her impairment in lower back muscles. Due to the impairment of hers, the subject has competed in Paralympic sit-skiing in “knee-high” (KH) position. Because of the medical observation, some muscle activity and muscle growth in lower back muscles have been observed after the training. The subject also has activation in her leg muscles. The subject has proved “kneeing” (KL) position once before, but was forced to give up with it due to the problems in lower back muscles.

All tests were done in the skiing laboratory at Vuokatti at Sports Technology Unit, University of Jyväskylä (Snowpolis, Vuokatti, Finland). The subject volunteered to the project. She was informed about the becoming measurements and the protocols of the tests. She also signed the concession paper.

7.1 Overall design

This case report is part of a project of Vuokatti Sports Technology Unit, where the aim is to develop a new sit-skiing sledge to Finnish LW11 classified athlete who has competed with “knee-high” position. The project started 07/2018 at Vuokatti when the group tested, if it is possible that the athlete would try “kneeing” position. When the position was found the group tested different props so that the subject would be able to hold the KL position. The props and capability to ski were tested in ski ergometer. After a short training the group piloted 15 maximal pulls in ski ergometer. During the time in Vuokatti the group also piloted the measurements on treadmill with the athlete. Pilot measurements were done in the KH position to get the subject familiar with skiing on the treadmill. The subject got the pilot version of the sledge to home, where she was able to train in new position in ski ergometer.

Second meeting for the group was on 09/2018 in Vuokatti. Then the aim was to get the subject to ski in the KL position on treadmill with the new prototype of the sledge. During this session, the group also tested roller skis under the sledge and how they work on treadmill. Also, during this session, the performance tests on treadmill were piloted and tested in both positions.

The measurements were held in 05/2019 in Vuokatti. Before the tests, the subject had about ten months of training with the KL position. Subject had trained in the KL in ski ergometer, on roller skiing and on snow. Subject did few competitions in the KL but changed back to the KH. Subject had also trained and piloted the performance tests in ski ergometer and on treadmill.

7.2 Protocol

The measurements took four days. *On the first day* there were maximal power output tests in both positions and submaximal load-test in the KH position on ski ergometer. In the afternoon, the subject had a change to go skiing on treadmill in the KH position. *On the second day*, there were maximal oxygen uptake test and both anaerobic tests (ANA_speed, ANA_uphill) in the KH position. *On the third day*, there were submaximal tests in ski ergometer in the KL position. Before the loads, the subject did the same warm up as at the first day. Subject did the maximal power output test in the KL before the loads. These results were not calculated to submaximal loads. In the afternoon, the subject had a change to go to skiing on treadmill in the KL position. *On fourth day*, there were maximal oxygen uptake test and both anaerobic tests in the KL.

The protocol was decided based on pilot measurements. During all measurements, the athlete used the same trunk of the sledge in both positions. The seat of the sledge needed to be changed between the positions. In addition, the change of the position forced to do lot of small technical preparations to trunk of the sledge. The preparations took a lot of time and that is why the group decided to separate the test days. Now the test days were not too long, and there was time for the subject to train on a treadmill.

7.3 Measurements

The tests were done in ski ergometer (Concept2, Morrisville, Vermont, USA) and on a treadmill (RL 3500, Rodby Innovation AB, Södertälje, Sweden). In ski ergometer, the subject performed maximal power output test and submaximal test. On the treadmill, the subject performed maximal oxygen uptake test and two anaerobic double poling tests.

7.3.1 Ski ergometer tests

First, in ski ergometer the subject performed maximal velocity test. That was three times 15 pulls (10-15 s) of maximal sprint in both positions. Recovery time between the loads was 2 min and 20 minutes between the positions. The test started at the up-position of poling and subject needed to be still two seconds before the start. In the study of Lajunen et al. (2014), the subjects performed only one maximal velocity test in each position. Because in this project the impaired athlete was performing the test, the group decided to use three performances to minimize the variation in results. The resistance was set at level 6 (1-10) throughout the present study (Lajunen et al. 2014). The ergometer gave the value for maximal power output as watts (W). The screen of ergometer was monitored by the group, but the screen was filmed on GoPro5 (Woodman Labs, Inc. San Mateo, California, USA) so the values were checkable. The warmup for the test was 10 minutes skiing on ski ergometer. After that, the subject did two easy 10 s sprints.

The results of maximal power outputs (W) of the performances for both positions were aggregated separately. The averages for both positions were calculated from the sums of the results. The average of the maximal watts was called as result for the position. The loads for submaximal loads were calculated from the highest result that was recorded in the KL. The loads were 40% and 60% of the maximal watt value. Submaximal loads were performed after 20 minutes break from the maximal power output test. The duration of the loads was 4 minutes. The recovery time between the loads was 2 min. In his study, Lajunen (2014) performed three 4 minutes submaximal loads on 50%, 60% and 70% levels of maximal watts. Loads on 50% and 70% were tested in this case study during the pilot measurements. Based on the results of pilot measurements, the group decided to use loads on 40% (SUB40) and 60% (SUB60) in this case study. During the loads, subject was instructed to maintain the correct level of watts as accurately as possible. The group monitored the screen of ergometer and gave verbal feedback if necessary, to maintain the target level of watts. Feedback was given two times and if the subject could not hold the target level of watts, the test was stopped.

7.3.2 Maximal oxygen uptake test

Maximal oxygen uptake test. The treadmill incline was 1.5˚ throughout the test. Speed increased 1 km/h to next load. The load was three minutes, including short, about 20 seconds stop at the end of the load for taking blood lactate sample from fingertip. The starting speed was 6 km/h based on the previous maximal oxygen uptake test results the subject had done in the KH position. The test lasted as long as the subject was totally exhausted or wasn't able to hold the speed of the treadmill. The subject had the right to stop the test also before that.

The warmup was 10 minutes with variation of speeds on treadmill. First three minutes were at 5 km/h, next two minutes at the starting speed of the test, sixth and seventh minutes were at 8 km/h speed. Eight and ninth minutes were at the starting speed and the last minute of warm up at 5 km/h speed. After that, the subject had a possibility to drink before the last preparations for the test. After the test ended, the subject cooled down on treadmill eight minutes before 10 minutes break before anaerobic tests.

7.3.3 Anaerobic tests

Anaerobic tests were done 10 minutes after the maximal oxygen uptake test's cool down was finished. The anaerobic test of speed (ANA_speed) was performed first. The inclination of treadmill was 1˚ throughout the test. After the first load that lasted 60 seconds, the speed increased 1 km/h every 15th second. The treadmill did not stop during the test. Stöggl et al. (2011) used the same kind of protocol in their study. They used 10 s loads. Lajunen (2016) used 15 s loads in their study with abled-bodied skiers. They used inclination of 3.5˚. After the pilot measurements, the group decided to use 15 second loads and decided to use 10 km/h as starting speed. The test lasted as long as the subject was not able to hold the speed of a treadmill. Before the test, the subject performed short five minutes warm up, including two 10 s intervals at 10km/h and 12 km/h speeds. After the test, the subject did a short cool down before the uphill- test.

In anaerobic tests the pole forces were not measured, because, the subject used owns poles. To maximize the reliability of the measurements, based on the pilot measurements, the group decided to use subject’s own poles. The pole forces were measured in maximal oxygen uptake tests.

After 10 minutes break after ending of ANA_speed, the anaerobic test of uphill (ANA_uphill) was performed. In this test, the speed was 5 km/h throughout the test. The inclination increased after the first load that took 60 seconds 0.5˚ every 15th second. The treadmill did not stop during the test. The protocol was a modified from ANA_speed protocol, which was decided after the pilot measurements. The speed during ANA_uphill test and the starting incline of 2.0˚ were decided, based on the pilot measurements.

7.4 Data collection and analysis

7.4.1 Physiology

Blood lactate (B-La) was taken after submaximal loads in ski ergometer, in the end of each load in maximal oxygen uptake test and after both anaerobic tests. The sample was taken from a fingertip. Blood lactate samples were taken into mini capillary. The samples were analyzed with a Biosen C-line (EKF Diagnostics, Magdeburg, Germany)

The respiratory variables during submaximal loads in ski ergometer and maximal test on treadmill were monitored breath-by-breath using Cosmed K5 (COSMED, Italy). Via Cosmed K5 breathing rate, VE, VO_2 and CO_2 production were measured. Heart Rate (HR) was recorded using Polar V800 (Polar electro Oy, Kempele, Finland)

7.4.2 Pole forces and cycle characteristics

Poling forces during ski ergometer test were measured using custom-made strain gauge sensors (University of Jyväskylä) that were fixed between the ropes and the handles.

In treadmill tests, the pole forces and cycle characteristics were measured with a custom-made light-weight pole force system (University of Jyväskylä, AUT/FIN) via Coachtech system (University of Jyväskylä). Propulsion forces from maximal oxygen uptake test were calculated from pole forces and pole angles.

7.4.3 Joint kinematics

3D motion analysis from all treadmill tests were recorded with a motion analysis system (Vicon Motion Systems Ltd., Oxford, UK) composed of eight Vicon cameras with sample frequency 400Hz. Motion analysis of elbow, shoulder, hip and pole angles were done in Vicon Nexus software that was also used to register trunk movements during tests. Markers were attached to wrist, elbow, shoulder, hip, knee and both poles. To calculate the pole angles, three markers were attached to the lower head of both poles.

The angles of elbow, shoulder and hip angles during poling phase in treadmill tests were calculated in Microsoft Excel 2018 (Microsoft Corporation, Redmond, Washington, USA) based on marker values after analysis of software.

To calculate trunk flexion extension angle with respect to a vertical plane (considered as 0˚) in treadmill tests, the shoulder and hip markers were used. Trunk maximal forward inclination (TMF) and backward inclination (TMB) were evaluated during the poling cycle. Value of inclination was reported positive, when shoulder moved anterior and negative when shoulder moved posterior from the vertical plane (considered as 0˚). TRUNK_ROM of the poling phase was the difference between forward and backward inclinations. (Rosso et al. 2019) The model of calculation is presented in figure 10.

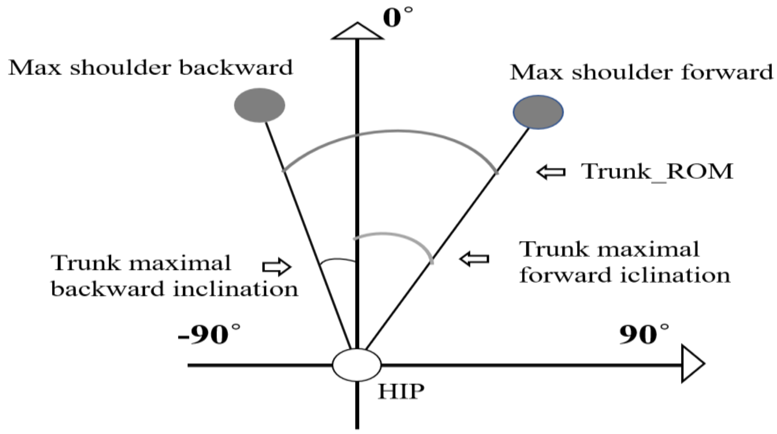

FIGURE 10: Trunk maximal forward position and trunk maximal backward position. Modified from Rosso et al. (2019)

2D motion analysis from ski ergometer tests were recorded with GoPro Hero3+ (Woodman Labs, Inc. San Mateo, California, USA). The markers were attached to same places as in 3D analyses. 2D analyses were done using Kinovea 0.8.27.

7.4.4 EMG

EMG was measured by using Mega ME6000 (Mega Electronics Ltd. Kuopio. Finland) EMG recorded from the muscles by using Ambu Bluesensors- electrodes (AmbuSdn.Bhd. Malaysia). Two electrodes were attached to muscle close to each other. The reference electrode was attached to muscle five cm away from two electrodes. Data was collected to Mega ME600's memory card and transferred to computer via USB. EMG was recorded the same way throughout all the measurements. EMG was recorded with sample frequency of 1000 Hz.

EMG was recorded from eight muscles. Muscles were collected based on previous studies of double poling and Paralympic sit-skiing. The level of activation was recorded from *rectus abdominus*, *external abdominal obliques* (OBL), *erector spinae high* (ESH), *erector spinae low* (ESL), *triceps brachii* (TRI), *latissimus dorsi* (LD), *subscapularis* and *iliacus.*

EMG data was normalized to MVC of each muscle. MVC was computed as the maximum voltage of three sprints in ski ergometer in the KL position, where the subject reached the higher maximal power output and maximal voltage. In their study Lund Ohlsson & Laaksonen (2017) used the maximum voltage of two 30-s all out test trials to compute MVC.

The results for the level of muscle activation in both positions were analyzed from three different phases of the double poling cycle: The pre-activation (*pre*), the activation during the poling time (*poling)*, and the activation during the recovery time (*recovery*).

7.4.5 Data analysis

All data was analyzed in IKE Master Software (IKE Software Solutions, Salzburg Austria). In Ike Masters Software force, joint kinematics and EMG data were synchronized and analyzed by nine poling cycles. Nine cycles were analyzed from each load of all the tests. The results for EMG, joint kinematics and forces are reported as averages of nine cycles. Force data from ski ergometer tests and reading of EMG were done with Skpike2 version 5.21

Respiratory data was analyzed in Microsoft Excel 2018 (Microsoft Corporation, Redmond, Washington, USA). The calculation of elbow, shoulder and hip angles and propulsive forces were also done in Excel. All the graphs, figures and tables were done in Excel.

Due to the low number of subjects (one) statistical analysis do not exist.

8 RESULTS

The results are presented in a same way to make it easier to follow the variations of the values in different tests. Each value for angles, cycle characteristics and EMG in the tables and figures are calculated and presented from averages of nine poling cycles from each load of the tests.

8.1 Performance in ski ergometer

The main finding from Ski ergometer tests were that the subject was capable to produce more watts in the KL position (figure 11). On three sprints, the subject was able to reach higher cycle rate and shorter cycle time in the KL position (table 3). In the KL position, the subject was capable to record 14.4% higher maximal power output (MAX_watts) in the KL than KH position. The target levels of watts on submaximal loads were on SUB40 71W and on SUB60 106W. The target levels of watts were calculated from the average of highest MAX_watts that the subject recorded in the KL position (figure 11).

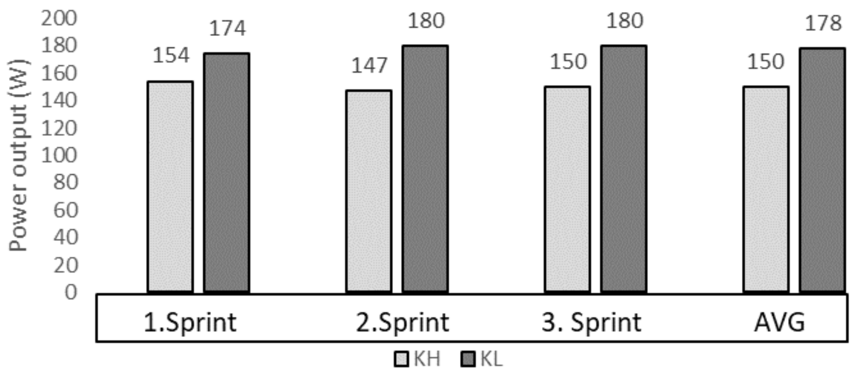

FIGURE 11: The Maximal power output test in ski ergometer. The power values of three sprints and the averages for the positions.

TABLE 3: Cycle characteristic values for both positions in ergometer sprint tests. Cycle time (CT) and cycle rate (CR).

Load	1. Sprint		2. Sprint		3. Sprint	
Sitting position	KH	KL	KH	KL	KH	KL
CT(s)	0.67	0.65	0.74	0.66	0.7	0.63
CR (cycle/s)	1.5	1.53	1.35	1.52	1.42	1.59

Submaximal loads. There were no differences between positions on first submaximal load (SUB40) in physiological data. The subject could not held the target level of watts on SUB60 in any position. In the KL position, the time the load was stopped, was 1 min 30 sec and in KH 30 sec. Other results from SUB60 are not presented.

On SUB40 the subject recorded higher CT (1.33 s vs. 1.10 s) and lower CR (0.75 cycle/s vs. 0.91 cycle/s) in the KL position. There were no differences in physiological data. Blood lactate did not differ and VO_2 (ml/min/kg) was 32 in both positions.

Both ESL and ESH recorded the greater level of activation in KH during *poling* (table 4). TRI recorded greater level of activation in KL. All reported muscles seemed more activated during *pre* in KH. LD was more activated in KL during *recovery*.

TABLE 4: Muscle activities on SUB40 (%MVC) during pre-, poling and recovery phases. Triceps brachii (TRI), latissimus dorsi (LD), erector spinae low (ESL) & erector spinae high (ESH).

Load	Pre		Poling		Recovery	
Sitting position	KH	KL	KH	KL	KH	KL
TRI (%MVC)	29.11	20.90	44.38	47.41	7.01	4.50
LD (%MVC)	6.42	4.15	12.28	11.08	1.80	3.10
ESL (%MVC)	13.95	3.07	44.56	23.47	11.66	5.13
ESH (%MVC)	19.52	4.29	38.71	20.37	5.32	2.65

Hip range of motion was 3.41˚ greater in the KH position on SUB40. Elbow range of motion was 2.37˚ greater in the KL. Shoulder range of motion was 38.7˚ greater in the KL.

8.2 Maximal oxygen uptake test

The main finding from maximal oxygen uptake test was that in the KL position, the subject recorded longer duration for the test. In the KH position, the time of exhaustion was 21min as it was 22 min 30 s in the KL position.

8.2.1 Effects on physiology

The KL position was uneconomical on lower loads (figure 12). Oxygen uptake (VO_2.) is higher on all loads, thus there was no big difference in VO_{2peak}. VO_2 (ml/min/kg) value was in the KL 42 and in KH 41. Blood lactate (B-La) was higher on third and fourth loads. There was difference in $B\text{-}La_{peak}$ values. At the end of the KL test $B\text{-}La_{peak}$ value was 11.57mmol/l, which was 29.8 % higher than $B\text{-}La_{peak}$ in the KH. Heart rate (HR) was higher for the first four loads in the KL but there was no difference in HR_{peak}. Ventilation (VE) was higher on second and fifth load in the KL, but lower on the seventh one.

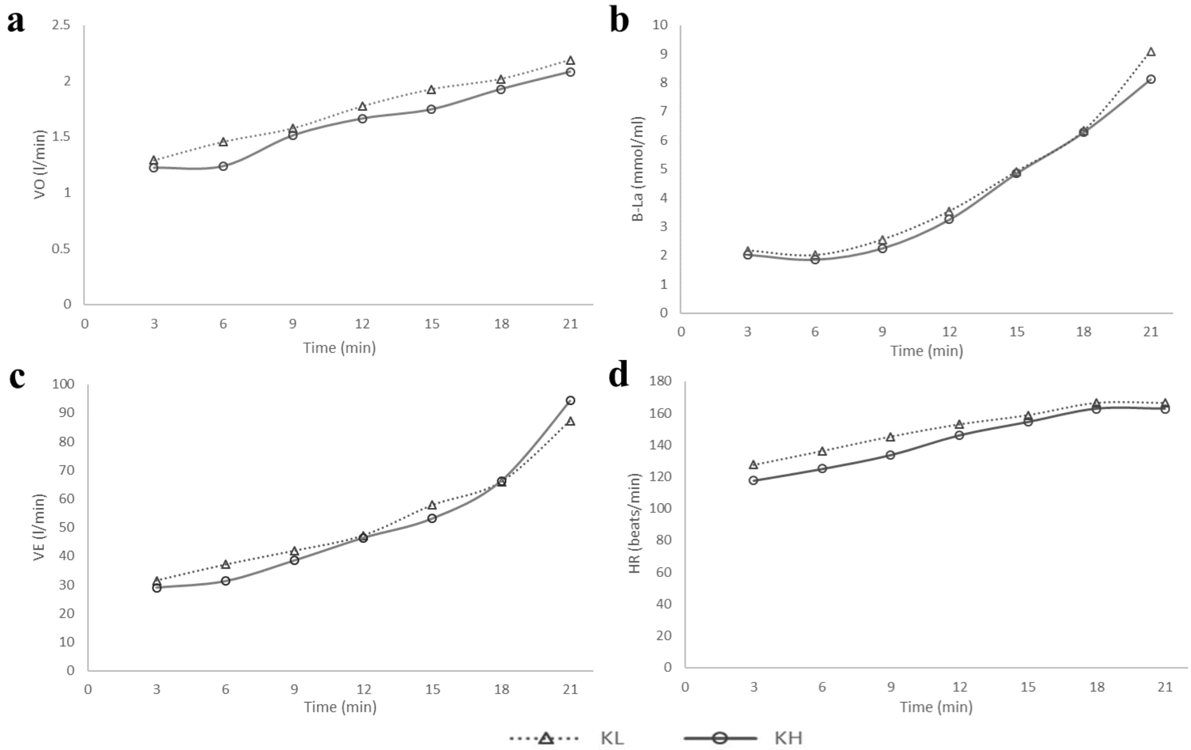

FIGURE 12: Physiological changes in both positions during maximal oxygen uptake tests. (**a**) Oxygen uptake (VO_2), (**b**) blood lactate (mmol/min), (**c**) minute ventilation (VE) and (**d**) heart rate.

8.2.2 Effects on cycle characteristics

During the first four loads of the tests, the KH position was better compared to the KL (table 5). Cycle time (CT) was higher and cycle rate (CR) was lower. In addition, relative force values were higher in the KH than in the KL. The “turning load” was the fifth load (table 5). When the speed increased, CT and CR recorded better values in the KL position compared to the KH position. On the last two loads of the test, cycle rate was clearly lower in the KL than in KH (figure 13).

Relative poling time (rPT) values were lower in the KL position during whole test. Relative recovery time (rRT) values were higher in the KL.

TABLE 5: Cycle characteristic values for both positions. Relative force values calculated from right pole. Cycle time (CT), cycle rate (CR), relative poling time (rPT) & relative recovery time (rRT).

Load/Speed	1./6 km/h		2./7 km/h		3./8 km/h		4./9 km/h		5./10 km/h		6./11 km/h		7./ 12km/h	
Sitting position	KH	KL	KH	KL	KH	KL	KH	KL	KH	KL	KH	KL	KH	KL
CT(s)	1.97	1.83	1.86	1.8	1.74	1.68	1.56	1.56	1.4	1.41	1.15	1.36	0.87	1.15
CR (cycle/s)	0.51	0.55	0.54	0.56	0.57	0.59	0.64	0.64	0.72	0.71	0.87	0.73	1.15	0.96
rPT (%CT)	12.1	8.9	17.7	10.6	17.9	13.4	20.5	16.7	22.9	18.2	28.8	19.4	33.1	30
rRT (%CT)	87.9	91.1	82.3	89.4	82.1	86.6	79.5	83.7	77.1	81.8	71.2	80.6	66.9	70

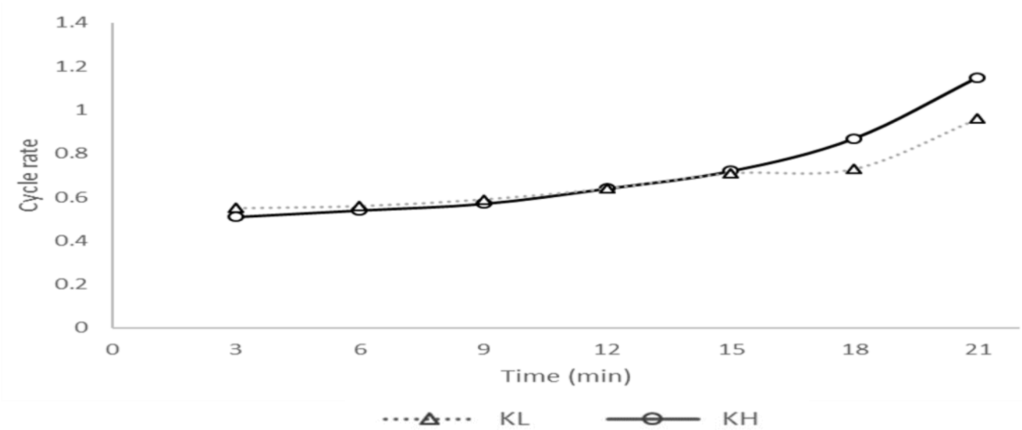

FIGURE 13: Poling cycle rate (cycle/s) for both positions.

Peak pole force (PPF) increased steadily in KL during the test (figure 14). PPF reaches its top value in KL on the last load of the test. In the KH position, PPF increased less compared to KL position. The value increased only a bit and PPF reaches its top value on the fifth load. Even though, both CT and CR recorded more uneconomical values for double poling during the first four loads in the KL position, the subject reached the peak pole force at the later point of the poling cycle in the KL during whole test.

Remarkable finding was the higher value of PPF on left pole in both positions. The differences are great in both positions, especially on the first three loads of the test. The differences on these loads in PPF values between right and left pole were in the KH position 12.5%, 14% and 16.3%. In the KL, the differences were 15.4%, 23.3% and 23.4%. After that, PPF value on both poles gets more stable in the KH. In the KL, the stability of the PPF values was reached on the last load.

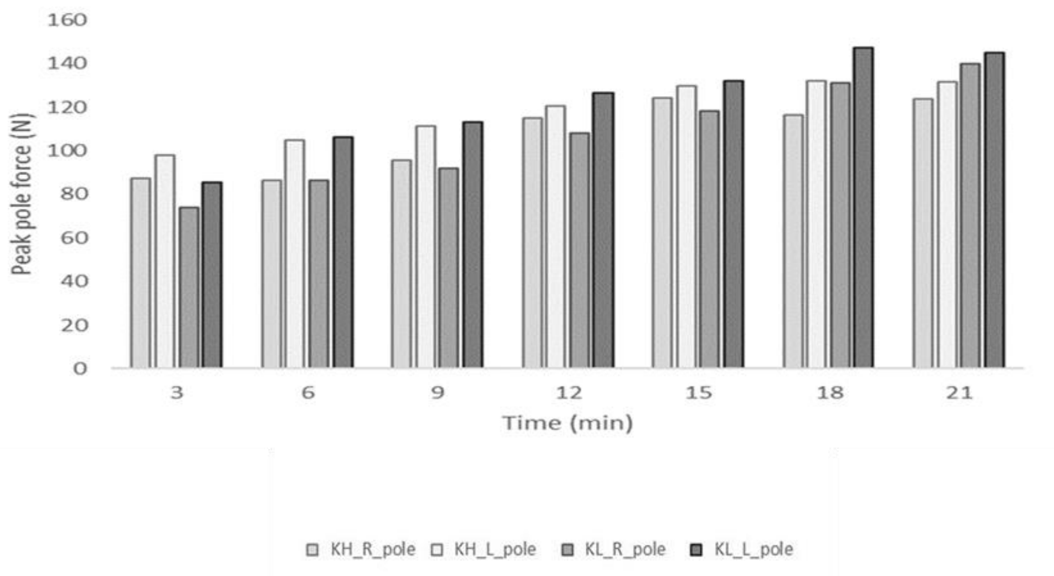

FIGURE 14: Peak pole force values of both poles for both positions.

8.2.3 Effects on joint kinematics

The KH position recorded greater values both frontal (TMF) and backward maximal inclination values (TMB). The KL position recorded smaller trunk range of motion (TRUNK_ROM) during almost the whole test (table 6). The total ROM of trunk was from 5.77˚ to 14.59˚ lower in the KL position than in KH during the first six loads. The difference between the positions was the biggest during the first load and smallest on the sixth load. On the last load, both TRUNK_ROM and TMB were greater in the KL. TMF values were from 0.44˚ to 7.18˚ smaller in the KL than in KH during the whole test.

TABLE 6: Trunk movement. Maximal frontal and backward inclinations and total ROM for both positions. The inclination of the treadmill was calculated in. Trunk maximal frontal inclination (TMF), maximal backward inclination (TMB) and trunk range of motion (TRUNK_ROM).

Load/Speed	1. / 6 km/h		2. /7 km/h		3. / 8 km/h		4./ 9 km/h		5./10 km/h		6./11 km/h		7./ 12 km/h	
Sitting position	KH	KL	KH	KL	KH	KL	KH	KL	KH	KL	KH	KL	KH	KL
TMF (˚)	38.21	31.03	38.69	35.69	39.17	37.3	40.47	37.75	38.84	38.4	41.27	40.75	45.15	42.53
TMB (˚)	-20.55	-13.14	-24.21	-16.4	-22.31	-15.78	-25.43	-15.58	-23.79	-15.02	-20.56	-15.3	-4.68	-7.68
TRUNK_ROM (˚)	58.76	44.17	62.9	52.09	61.49	53.08	65.9	53.32	62.63	53.43	61.82	56.05	44.03	50.21

During the double poling cycle, the behaviour of hip and elbow angles were more stable (figure 16) in the KL position. There was greater variation in angle's minimum (MIN) and poling ending (Pole_OUT) values in the KH position. Especially on the fifth and seventh loads, there was more variation in Hip angle values in the KH than KL. The MIN and Pole_OUT values of the hip angle decreased stable in the KL position compared to KH. In addition, Pole_OUT value of elbow angle decreased more linearly in the KL. Elbow angle recorded greater extension on higher loads in the KL position. The function of hip angle was more stable in the KL compared to KH, where the poling begins with clearly smaller values of an angle during the last loads compared to the first loads.

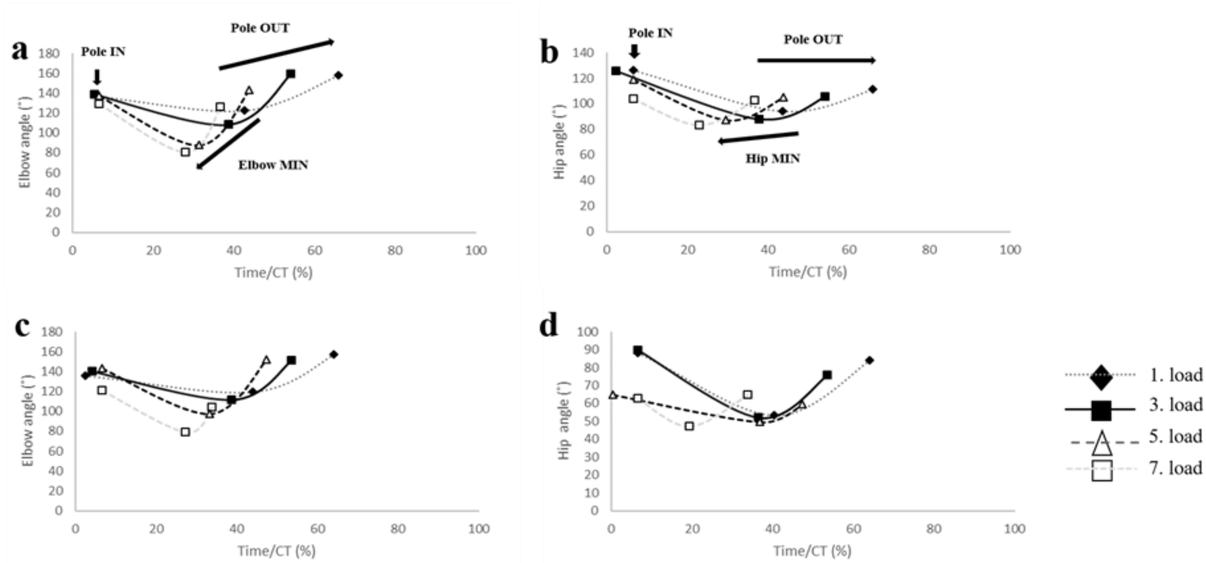

FIGURE 15: Behaviour of elbow (**a**, **c**) and hip (**b**,**d**) angle change at four loads of the test during the poling phase. KL position presented in figures **a**,**b**, KH position in figures **c**,**d.** Cycle time was calculated from all CT averages for both positions during the test.

8.2.4 Effects on EMG

TRI activation recordings were higher in *poling* and LD lower *poling* activation in the KL position. Apart the last load of the test, TRI recorded its lowest level of activation in *poling* in the KH position (figure 16). LD was clearly more activated during *pre* and *recovery* phases in the KL position.

ESL was more activated in the KL, except the last load of the test. The level of activation in *poling* increased progressively during the test in the KL in both ESL and ESH. ESL was more activated during *pre* and *recovery* phases in both positions compared to ESH.

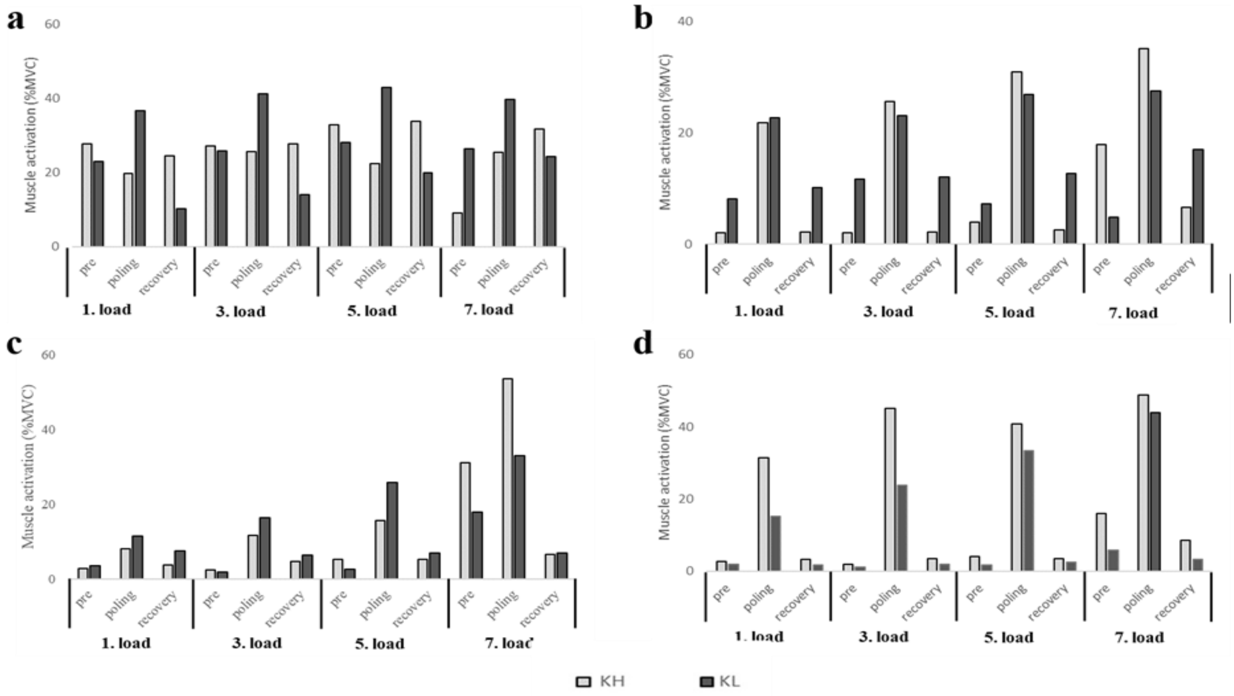

FIGURE 16: Normalized EMG activation of four muscles for both positions at four loads of the test. Activation levels during pre-, poling- and recovery phases of poling cycle (**a**) triceps brachii (TRI), (**b**) latissimus dorsi (LD), (**c**) erector spinae low (ESL), (**d**) erector spinae high (ESH).

8.3 Anaerobic test, speed

The main finding of the ANA_speed-test was that in the KL position, the subject recorded longer time for the test. In the KL position, the test time was 2 min 39 s and in KH 2 min 30 s. Right after the test B-La $_{peak}$ was 5.83 mmol/l in KL and 4.89 mmol/l in KH.

8.3.1 Effects on cycle characteristics

Relative values of poling time increased in both positions during the test (table 7). In the KL, the values of rPT were smaller and the values of rRT were greater throughout the test. On the first three loads, CT was longer in the KH and CR was a bit smaller than in the KL. After the fourth load, CT was longer and CR a bit smaller in the KL. During its last four recorded loads, CR value increased by 0.38 in (cycle/s) the KL, whereas it increases by 0.28 (cycle/s) in the KH (figure 17).

TABLE 7: Cycle characteristic values for both positions. Relative force values calculated from right pole. Cycle time (CT), cycle rate (CR), relative poling time (rPT) & relative recovery time (rRT).

Load/ speed/ time (s)	1./ 10 km/h / 60		2. /11 km/h / 15		3. /12 km/h / 15		4. / 13 km/h /15		5./14 km/h /15		6./15 km/h / 15		7./ 16 km/h/15		8. / 17 km/h/ 9	
Sitting position	KH	KL	KH	KL	KH	KL	KH	KL	KH	KL	KH	KL	KH	KL	KH	KL
CT(s)	1.58	1.45	1.45	1.33	1.3	1.29	1.16	1.22	1	1.13	0.91	1.02	0.87	0.87		0.79
CR (cycle/s)	0.64	0.7	0.69	0.7	0.77	0.78	0.87	0.82	1	0.89	1.1	0.99	1.15	1.16		1.27
rPT (%CT)	41.9	38.9	42.4	39.2	47.9	36.2	45.1	37.7	45.9	36.1	46.3	41.6	45.5	46.4		47.5
rRT (%CT)	58.1	61.1	57.6	60.8	52.1	63.8	54.9	62.3	54.1	63.9	53.7	58.4	54.5	53.6		52.3

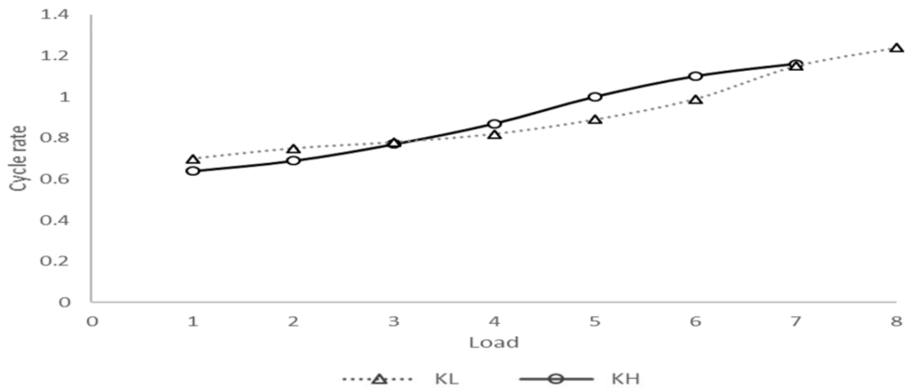

FIGURE 17: Poling cycle rate (cycle/s) for both positions.

8.3.2 Effects on joint kinematics

For the first six loads, the TRUNK_ROM was from 2.29˚ to 11.84˚ smaller in the KL position compared to the KH position (table 8). Maximal trunk forward inclination was higher in the KH for the first six loads. TMB was clearly smaller in the KL during the test. In both positions, the subject recorded positive values of TMB during the last loads.

TABLE 8: Trunk movement. Maximal frontal and backward inclinations and total ROM for both positions. The inclination of the treadmill was calculated in. Trunk maximal frontal inclination (TMF), maximal backward inclination (TMB) and trunk range of motion (TRUNK_ROM).

Load/speed/time (s)	1./ 10 km/h / 60		2. /11 km/h / 15		3. /12 km/h / 15		4. / 13 km/h / 15		5./14 km/h / 15		6./15 km/h / 15		7./ 16 km/h/ 15		8. / 17km/h / 9	
Sitting position	KH	KL	KH	KL	KH	KL	KH	KL	KH	KL	KH	KL	KH	KL	KH	KL
TMF (˚)	18.73	20.79	33.98	32.11	35.3	33.9	34.5	32.57	37.01	36.59	39.8	36.7	37.4	40		40.48
TMB (˚)	-18.63	-4.73	-12.7	-3.2	-11.06	-3.47	-9.01	-5.75	-4.6	-2.29	0.6	-0.21	3.91	1.01		9.03
TRUNK_ROM (˚)	37.36	25.52	46.68	35.31	46.36	37.37	43.51	38.32	41.61	38.88	39.2	36.91	33.49	38.99		31.45

When the speed increased, the behaviour of the hip and elbow angles in the KL became more controlled compared to the KH position during the poling phase (figure 18). On lower loads, the behaviour of the angles was more controlled in the KH. Both elbow and hip angles reached the angle minimum fast and the extension happened stable to Pole_OUT. The same happened in the KL position during faster loads (figure 18). In the KH, it was remarkable that the movement of the hip started right when the poling phase started, whereas elbow started the movement later. In the KH position, the extension of the hip angle did not happen during the poling phase. There was a greater variation with the size of the hip angles at the beginning of the poling in the KL position compared to the KH position.

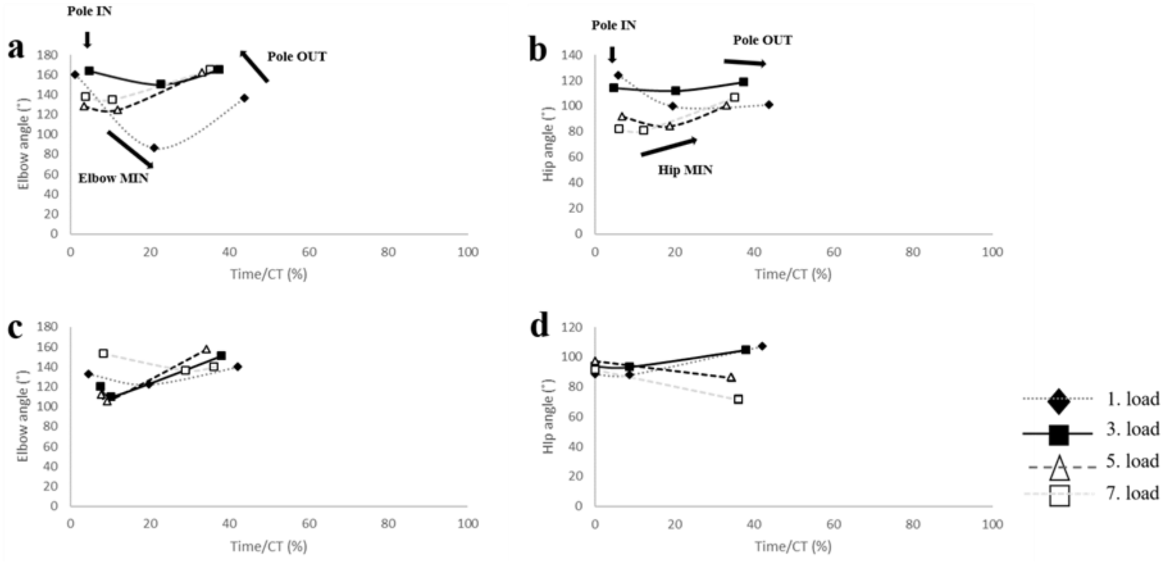

FIGURE 18: Behaviour of elbow (**a**, **c**) and hip (**b**,**d**) angle change at four loads of the test during the poling phase. KL position presented in figures **a**,**b**, KH position in figures **c**,**d.** Cycle time was calculated from all CT averages for both positions during the test.

.

8.3.3 Effects on EMG

TRI recorded greater level of activation during *pre* and *poling* phases in the KL position throughout the test (figure 19). In the KH, the level of activation in TRI was on its lowest in *pre*, but highest in *recovery*. In LD, there was more variation in levels of activation, but LD recorded greater levels of activation during *recovery* in the KL. The activation of ESH increased stable during the test in the KH. On the last loads, the activation of ESH increased explosively in the KL. The same kind of increase in level of activations also occured with ESL in both positions. ESL was more activated in the KL during the whole test (figure 19).

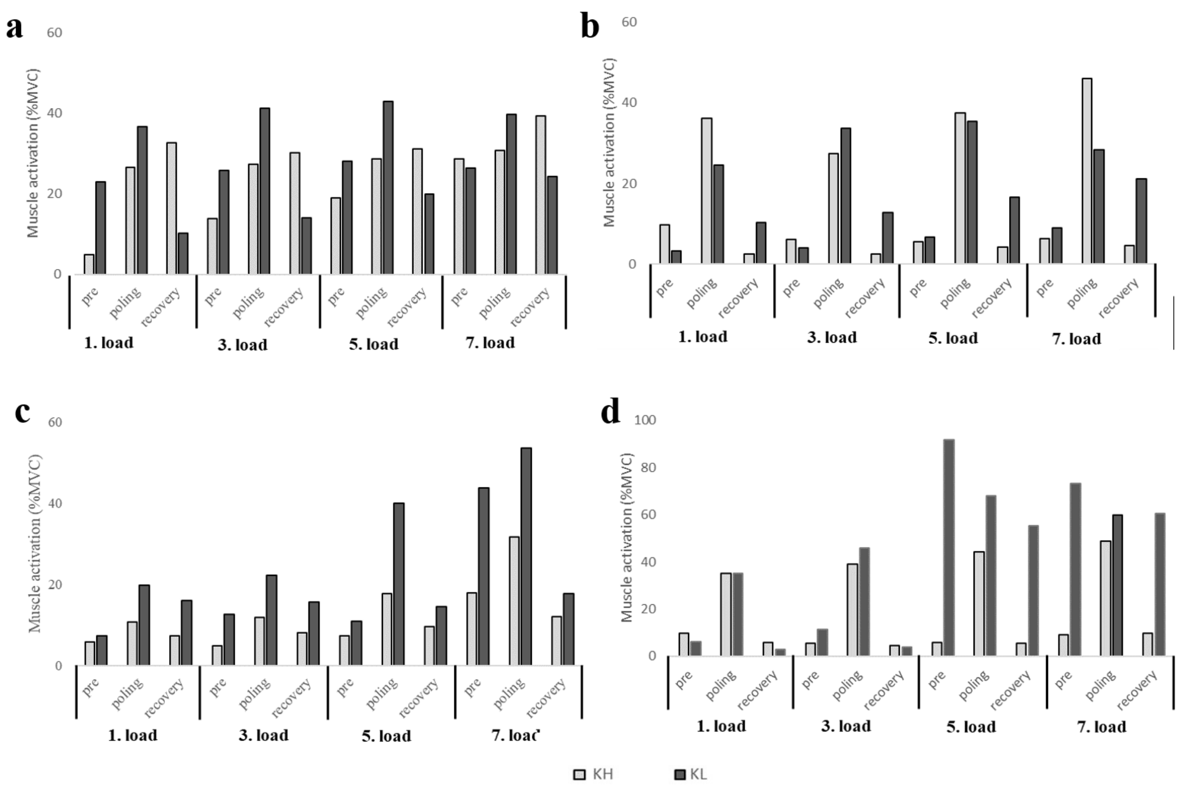

FIGURE19: Normalized EMG activation of four muscles for both positions at four loads of the test. Activation levels during pre-, poling- and recovery phases of poling cycle (**a**) triceps brachii (TRI), (**b**) latissimus dorsi (LD), (**c**) erector spinae low (ESL), (**d**) erector spinae high (ESH).

8.4 Anaerobic test, uphill

The main finding from the ANA_uphill was, that in the KL position, the subject recorded longer time in the test. The test time was 3 min 15 s in the KL and 3 min 5 s in the KH. Right after the test B-La was mmol/l in KL 4.95 and 3.45 mmol/l in KH.

8.4.1 Effects on cycle characteristics

Relative poling time increased during the test in both positions. In the KL position, rPT values were lower and rRT values higher throughout the test (table 9). CT was lower in the KL on first three loads. From the fourth load, CT was longer, and CR was lower in the KL position. On the last load, CR was lower in KH position compared to KL. During the test, CR increased stable in the KH position, whereas it increased more like step-by step in the KL position (figure 20).

TABLE 9 Cycle characteristic values for both positions. Relative force values calculated from right pole. Cycle time (CT), cycle rate (CR), relative poling time (rPT) & relative recovery time (rRT).

Load/angle (˚)/ time (s)	1./ 2.0 / 60		2. /2.5 / 15		3. /3.0 / 15		4. / 3.5 / 15		5./ 4.0 /15		6./ 4.5 / 15		7./ 5.0 / 15		8./ 5.5 /15		9./ 6.0 /15		10. / 6.5	
Sitting position	KH	KL	KH	KL	KH	KL	KH	KL	KH	KL	KH	KL	KH	KL	KH	KL	KH	KL	KH 5 s	KL 15 s
CT(s)	1.88	1.82	1.82	1.82	1.69	1.67	1.59	1.62	1.47	1.64	1.28	1.35	1.1	1.15	0.96	1.1	0.9	0.98	0.93	0.91
CR (cycle/s)	0.54	0.55	0.55	0.55	0.59	0.6	0.63	0.62	0.68	0.61	0.78	0.74	0.91	0.87	1.04	0.91	1.11	1.02	1.08	1.1
rPT (%CT)	40.01	36.71	44.73	41.94	45.89	42.22	48.91	43.97	49.21	45.55	50.74	48.21	53.47	50.11	57.93	52.19	58.75	54.11	60.11	54.24
rRT (%CT)	59.99	63.29	55.27	58.06	54.11	57.78	51.09	56.03	50.79	54.45	49.26	51.79	46.47	49.89	42.07	47.81	41.25	45.89	39.89	45.76

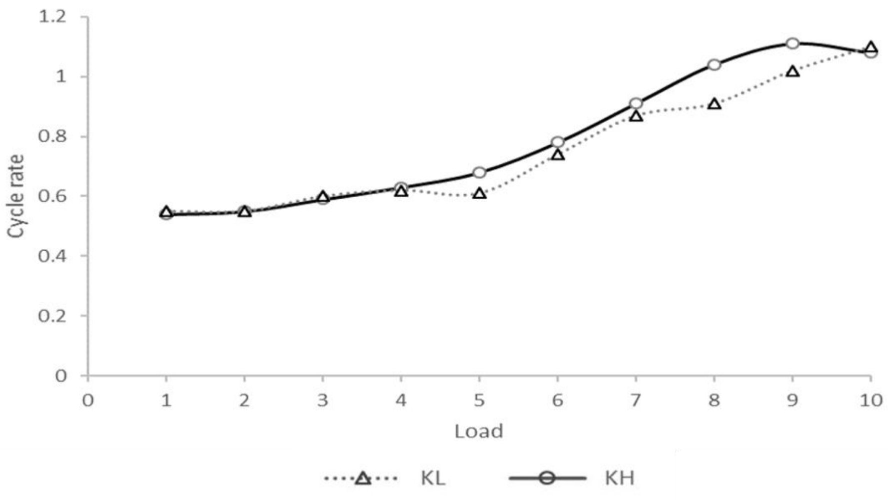

FIGURE 20: Poling cycle rate (cycle/s) for both positions.

8.4.2 Effects on joint kinematics

TRUNK_ROM recorded greater values in the KH position (table 10). The KL position recorded from 1.67˚to 18.67˚ lower values in TRUN_ROM than the KH. Maximal backward movement was clearly lower in the KL. TMB got positive values during the last loads, when in the KL position the subject recorded greater positive values (table 10). During the whole test, the greater values of maximal frontal inclination were recorded in the KH position. The difference between positions on the first four loads in TMF were from 5.33˚ to 11.38˚ greater in the KH position. After that, the differences decreased.

TABLE 10: Trunk movement. Maximal frontal and backward inclinations and total ROM for both positions. The inclination of the treadmill was calculated in. Trunk maximal frontal inclination (TMF), maximal backward inclination (TMB) and trunk range of motion (TRUNK_ROM).

Load/angle (˚)/time (s)	1./ 2.0 / 60		2. /2.5 / 15		3. /3.0 / 15		4. / 3.5 / 15		5./ 4.0 /15		6./ 4.5 / 15		7./ 5.0 / 15		8./ 5.5 /15		9./ 6.0 /15 s		10. / 6.5	
Sitting position	KH	KL	KH	KL	KH	KL	KH	KL	KH	KL	KH	KL	KH	KL	KH	KL	KH	KL	KH 5 s	KL 15 s
TMF (˚)	38.73	31.54	37.01	30.62	36.9	25.52	35.7	30.37	35.31	33.78	38.02	36.5	37.61	35.6	36.42	36.01	36.13	37.26	36.98	36.84
TMB (˚)	-15.1	-9.38	-12.61	-9.32	-10.97	-3.68	-9.01	-2.9	-6.75	-2.33	-2.56	-1.1	-0.98	0.78	2.15	3.41	4.41	8.57	9.08	14.74
TRUNK_ROM (˚)	53.83	40.92	49.62	39.94	47.87	29.2	44.71	33.27	42.06	36.11	40.58	37.6	38.59	34.82	34.27	32.6	31.72	28.69	27.9	22.1

There were many differences in a behaviour of hip and elbow angles during poling. In the KL position, with both joints the variation of the size of the angle when the poling starts was clearly smaller compared to the KH position (figure 21). In addition, the behaviour of the angles had more variation in the KH position compared to the KL position.

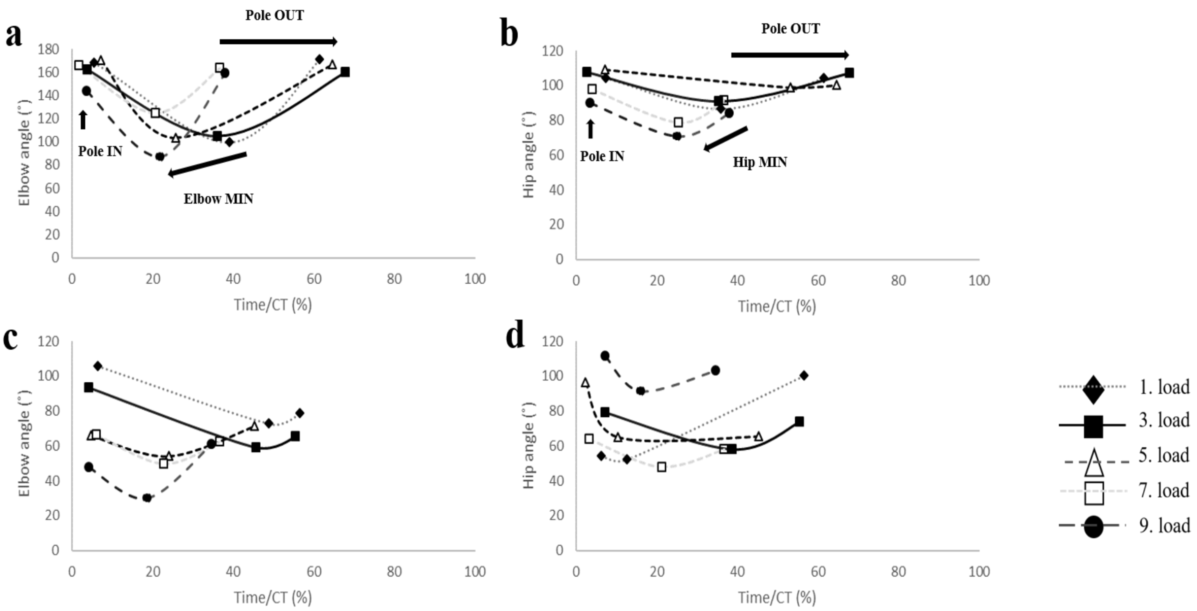

FIGURE 21: Behaviour of elbow (**a**, **c**) and hip (**b**,**d**) angle change at four loads of the test during the poling phase. KL position presented in figures **a**,**b**, KH position in figures **c**,**d.** Cycle time was calculated from all CT averages for both positions during the test.

8.4.3 Effects on EMG

ESL was clearly more activated in the KH than in the KL (figure 22). There was a greater variation in level on of activation in ESL in *pre* and *recovery* activation in the KH compared to the KL. ESH was more activated in *pre* and *recovery* in the KL. The activation of ESH increased stable in the KH, whereas the level of activation stayed stable in the KL on the lower load. LD was less active in *pre* values but recorded greater levels of activation in *recovery* in the KL position (figure 22). The level of *pre-activation* of TRI was clearly higher in the KL position. TRI recorded its greatest level of activation in the KH position in *poling* (figure 22).

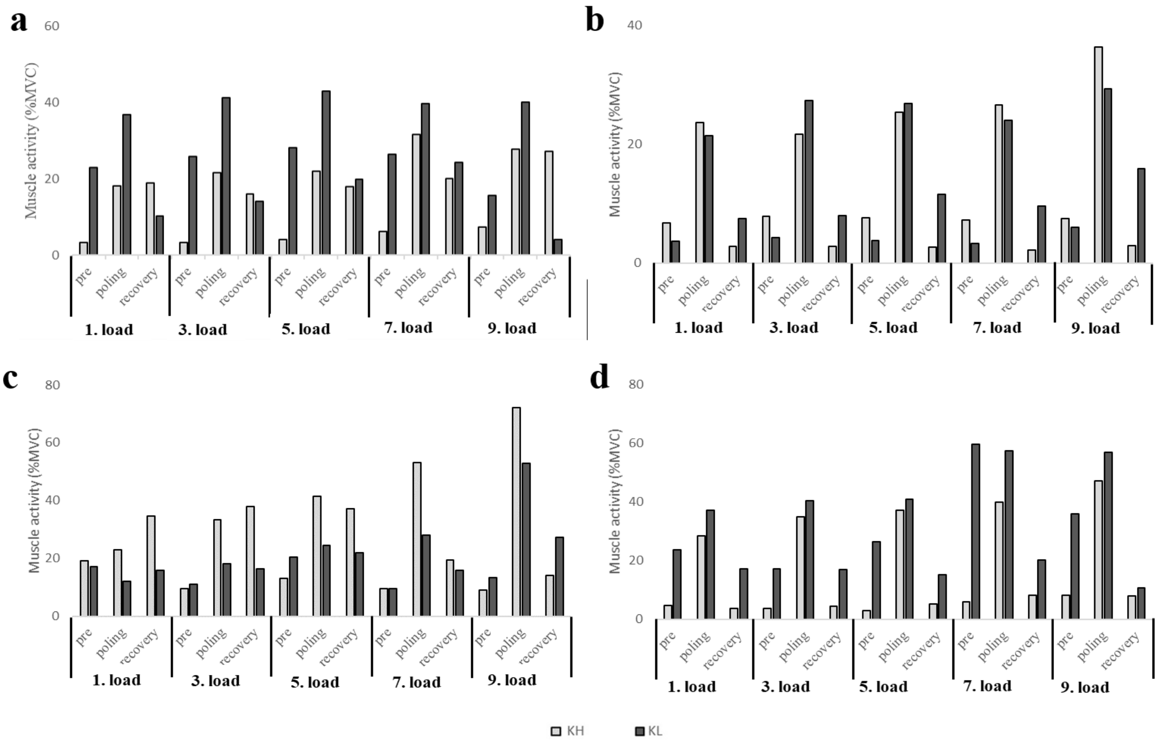

FIGURE 22: Normalized EMG activation of four muscles for both positions at four loads of the test. Activation levels during pre-, poling- and recovery phases of poling cycle (**a**) triceps brachii (TRI), (**b**) latissimus dorsi (LD), (**c**) erector spinae low (ESL), (**d**) erector spinae high (ESH).

9 DISCUSSION

The aim of this case study was to compare the KL- and KH positions and differences in athlete's performance with them in different tests. To author's knowledge, this is the first study to investigate cross-country sit-skiing on treadmill tests, and also the first study where the impaired athlete tries different positions. Because this was a case study, the statistical analyses were not exist, and the results represent only individual findings.

The main finding of the study was, that in the KL position, the subject reached longer duration in each performance test. The subject was able to produce higher maximal power in maximal power output test in ski ergometer and better performance on submaximal loads. On treadmill tests, the subject reached the longer time of exhaustion in maximal test and in both anaerobic tests. According to the findings from this case study, there is a connection between lower cycle rate and longer cycle time to economical double poling performance. In the KL position, the other measured cycle characteristics were in line with the previous findings of better double poling performance (Holmberg et al. 2005; Lindinger et al. 2009b; Lindinger & Holmberg 2011). Findings of trunk range of motion were not in line with previous findings (Lajunen 2014; Rosso et al. 2016; Rosso et al.2019). This may be caused by the support that the subject had in the KL position. Even though the KL position seemed to be better for the subject, she was forced to change back to the KH position about nine months after the measurements in January 2020 due to the problems in her lower back-area muscles and, therefore, limited sit-skiing performance.

According to the findings of this case study, the better performance in ski ergometer is connected to better performance on treadmill. Previous findings of Halonen et al. (2015), Rosso et al. (2015) and Rosso et al (2017) have shown the correlation between better performance in ski ergometer and faster skiing on field. In this case study, the subject performed better in ski ergometer in maximal power output test (figure 11) and recorded longer duration on SUB60 load. The difference between the positions in maximal power output was 14.4% bigger in the KL than in the KH position. The subject performed better in all treadmill tests in the KL position. In the maximal endurance test, the time of exhaustion was 7% longer in the KL position compared to the KH position. In anaerobic speed test, the difference between the positions in test duration was 6% longer, and in uphill test 5.4% longer in the KL position. According to these findings, it can be suggested, that better performance in ski ergometer is connected to better performance in maximal longer duration test and to better performance in uphill and faster skiing on treadmill. Based on the findings from previous research made about the connection of the ski ergometer tests and field skiing, and the findings of this case study, it can be suggested that better performance in ski ergometer in maximal power output test and submaximal tests is connected to better endurance performance both on treadmill and field. The connection between the evaluations in performance in field compared to laboratory tests were not measured in this case study. Findings of this case study confirm suggestion of Rosso et al. (2017) that ski ergometer is a good machine for specific upper body maximal strength training and testing aerobic and anaerobic capacity in sport-specific reliable and repeatable conditions.

Cycle characteristics. In each treadmill test, the relative poling time was shorter in the KL position than in the KH position (table 5, 7 & 9). The subject was able to produce the poling forces faster in the KL position. The peak pole forces increased in both positions during the maximal test (figure 14). Relatively, PPF increased less in the KH position, where it reached its the highest value in KH on the fifth load of the test. In the KL position, the PPF reached its the highest value on the seventh load. In the KL position, the subject reached the relative PPF in later time during the poling cycle than in the KH position. These findings were in line with previous studies about successful double poling (Holmberg et al. 2005; Lindinger et el. 2009b; Lindinger & Holmberg 2011; Stöggl et al .2011). The differences between the values can be explained due to the higher poling position and better ability to use trunk muscles. In the KL position, the subject can start the poling from higher and more attacking position. The poling starts in a position, where her fists are on the level of her eyes (figure 23). Therefore, she can use the mass of her body and transfer it to the poles. That related to the higher impulse and makes it possible to reach the higher poling forces in a shorter time. Instead, in the KH position, the fists are on higher level compared to skiing in the KL position (figure 23). In the KH position, the fists are on the level of the forehead, which forces the athlete to use more the TRI muscles to get the poling started. That makes poling phase longer and increases the work rate in the TRI muscles (figure 16, 19 & 22). The duration of the poling phases increased in both position in anaerobic tests. These findings were in live with Stöggl et al. (2011) & Stöggl & Holmberg (2016) findings. The poling phases were recorded to be longer in this case study, compared to previous findings about the effects of inclination and speed to relative poling and recovery times, due to the subject was able not to use her lower body and legs to poling force production.

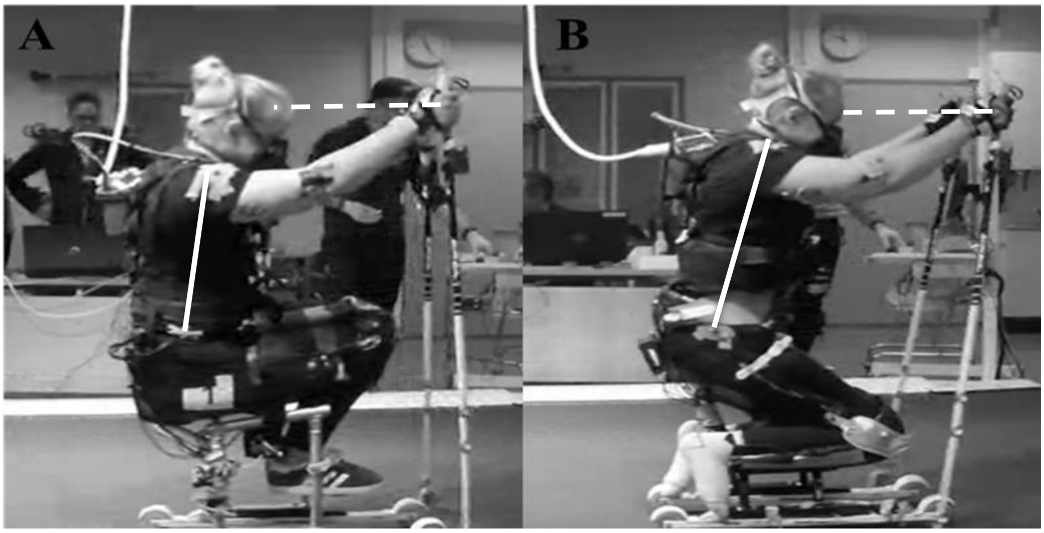

FIGURE 23: The differences between the positions in the poling start positions. (**A**) KH & (**B**) KL. The pictures have been taken from the fourth load of the maximal oxygen uptake tests from the moment the double poling cycle begins. The solid line describes the position of the trunk from hip to shoulder and the dashed line the position of the fists.

One of the main findings of this case study was to point out the benefits of longer cycle time and lower cycle rate on the same relative speeds (figure 5, 7 & 9), and the connection of them to better performance and to economical skiing (figure 12). In this case study, the physiological patterns were higher in the KL position in lower loads, when both cycle time and cycle rate were also recording better values in the KH position. In the maximal test, the “turning load” was the fifth load. After that, CT and CR recorded better values in the KL position, which effected on physiological patterns, especially on HR, B-La & VE (figure 12). In anaerobic tests, the “turning load” was the fourth load in both tests. After that, both CT and CR recorded better values in the KL position. In addition, in ski ergometer, CT and CR recorded better values in the KL position on the first submaximal load. The positive benefits of longer CT and CR to double poling performance were found in previous studies (Holmberg et al. 2005; Lindinger et el. 2009b; Lindinger & Holmberg 2011; Stöggl et l .2011; Lajunen 2014). Lajunen (2014) & Hofmann et al. (2016) pointed CT time to be longer and CR lower in the KL position in their studies about sit-skiing and connected to better performance. The findings of this study were in line with the previous findings.

Interesting fact was that in all treadmill tests, during the first loads, the subject recorded longer CT and lower CR in the KH position compared to the KL position (figure 5, 7 & 9). This is probably due to the background and history of the subject, who had performed in the KH position almost whole her career. But it can also be due to the lower speed of the treadmill, when the subject cannot totally control her body in the KL position. The need of control of the trunk decreases when the load increases. Third option, the most obvious one, was based on upper body force production capacity (Holmberg et al. 2005; Stöggl et al. 2007). Activation of upper body muscles can be seen in figures 16, 19 & 22. TRI was working whole the time, recording its greatest levels of activation during *recovery*-phase in the KH position. In the KL position, TRI was clearly more activated during *pre*-phase and the muscle got its recovery during the *recovery*-phase. In the KL position, the subject was able to use her upper body force capacity. On the flat terrain tests (maximal & ANA_speed), the subject pre-activated her LD clearly more in the KL position. Especially during the maximal test (figure 16). During the ANA_speed, the pre-activation increased in KL, when the speed increased (figure 19). Pre-activation of LD is the key element of modern successful double poling strategy and the greater pre-activation of the muscles is connected to greater force production (Holmberg et al. 2005; Lindinger et al. 2009b).

Peak poling force values pointed out the differences between the left and right poles in both positions (figure 14). The differences were clear between the poles as reported previous in results-section. When the subject reached the top values of PPF, the difference between the poles were at their smallest. This finding was one element that could resist the performance of the subject. The other sided skiing could increase the resistance and total workload of trunk muscles, especially in the KL position, where the trunk muscles work rate is higher compared to the KH position. The EMG was not recorded from both sides of the body, only from the right side. Due to that, no differences in muscle activation between the left-and right side muscles were observed. In figure 24, the positions are presented from behind at the beginning of the poling phase. The pictures are from the third loads of the maximal oxygen uptake tests, when the differences between the poles were at their biggest (figure 14). Even though the camera did not locate straight behind the subject, from the figure 24 can be seen that the upper body is slightly rotated to left in both positions. In addition, in the both positions, the position of the left elbow is wider compared to the right.

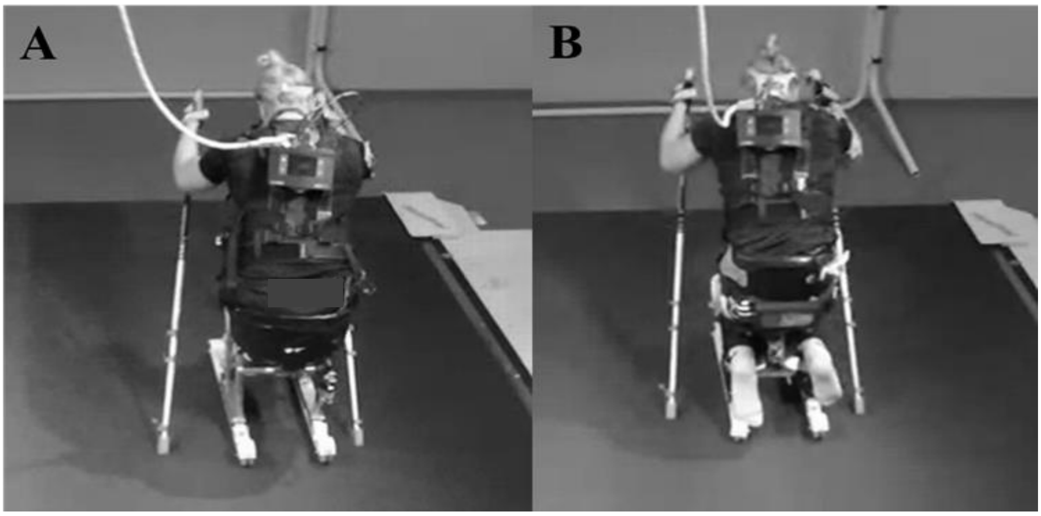

FIGURE 24: The differences between the poles. (**A**) KH & (**B**) KL. The pictures have been taken from the third load of the maximal tests from the moment the beginning of the poling phase.

Physiology. Physiological variables were connected to the CT and CR values (figure 12). When CT and CR were recording weaker values, the physiological variables were also higher on lower loads in KL. But when CT and CR turned to be better in the KL position, the physiological variables turned to be similar or lower than in the KH position. The effect of CT and CR can be seen the best from the HR-graphs. From the fifth load, the values in the KL position got closer to the values for the KH position. At the end of the test, there was no difference between HR_{peak} values. One of the main physiological findings was that there were no differences in the VO_2 ml/kg/min and VO_{2peak} values between the positions. Important finding was, that in the KL position, the subject recorded higher $B\text{-}La_{peak}$ than in the KH position. That tells that the subject had more capacity to work in higher levels of performance in the KL position and that she can get more out of herself in KL the position. The B-La was higher in the KL position in both anaerobic tests. In ski ergometer, there was no difference on SUB40, which was in line with the finding of Lajunen (2014). Even though the B-La_{peak} values were higher in both anaerobic tests, the values were in the KL position, 50.3 % (ANA_speed) & 42.7% (ANA_uphill) and in the KH position, 60.2% (ANA_speed) & 42.4% (ANA_uphill) out of the position's maximal test B-La_{peak} value. That finding pointed out, that on ANA_speed, the subject reached higher speed on easier work rate in the KL compared to KH position. In ANA_uphill, there was no difference between the positions. That points out, that the performance in uphill is more related to technical and trunk controlling variables than physiology.

Trunk control. The findings of this case report did not support the findings of previous studies (Rosso et al. 2016; Rosso et al. 2019). In this case study, the subject had smaller TRUNK_ROM in each test in the KL position compared to the KH position (table 6, 8 & 10). The difference of TRUNK_ROM were at their biggest on lower loads, but the differences decreased when CT and CR turned to be positive in the KL position. TRUNK_ROM was greater in the KL position during the last loads of maximal test anaerobic speed test. The reason, why the TRUNK_ROM was limited in this case study, may be due to the subject's limited control of the trunk in the KL position at slower speeds. The main reason may be the support that was built to sledge. The built support, together with limited trunk control may explain the limitation of TMB and TMF in the KL position, compared to the KH position and the disagreement with previous studies. In addition, Lund Ohlsson & Laaksonen (2017) found limitation in hip range of motion in the KL compared to the KH position. They used in their study frontal support in KL. Support was placed in front of the body. In this case study, the athlete was supported from the back of the sledge and a wide weightlifting belt on a front. The belt was attached to sledge. The supports on back and on front in the KL position, may have limited the TRUNK_ROM in this case study.

Anyway, it is good to remember, that in previous studies of Rosso et al. (2016) & Rosso et al. 2019), the findings have been made with classified athletes performed with their own sit-skiing positions. In these studies, the athletes of the lowest class (LW10) were reported to be used the supports to hold their position. Lajunen (2014) used no supports, but the subjects were abled-bodied. In this case study, the athlete with limited trunk control performed in the

KL position. In addition, due to her previous try with the KL position and her impairment, the support was planned to design to limit TMF that the subject manages to return to poling start position. In the KH position, the subject needed no support.

The limitation of TMB may have increased the workload of the trunk muscles, because they cannot get total recovery and relaxation (Rosso et al. 2016). In this case study, TMB was clearly smaller in the KL position, which could increase the workload of trunk muscles. But it can also be seen as a beneficial pattern. The smaller TMB holds the mass of the body more in front in the KL position than in the KH position. The preparation of the poling does not take that much time that makes it easier for the subject to hold the faster speed and lower cycle rate. Smaller TMB makes it also possible to pre-activate upper body muscles due to the more attacking position. Holmberg et al. (2005) found that faster skiers are able to start the poling in higher and more attacking frontal position. That helps to produce higher poling forces and greater propulsion.

Joint kinematics. There were no clear differences between total range of motions in elbow, hip and shoulder joint angles in this case study. Hip angle behaved like TRUNK_ROM in all measured tests. It was greater in KH on lower loads but increased in the KL position: In the end of the test, it was greater in the KL position. In elbow angle, the differences between the positions started after the "turning loads" in each test. The elbow ROM was slightly greater in the KL position at the end of the tests.

Lindinger et al. (2009b) presented the behavior of and elbow angle, when the speed increases (Figure 4 A). In this case study, the behavior of the elbow and hip angles were presented in figures 15, 18 & 21. In these figures, it can be seen that the function of the elbow angle was in line with Lindinger et al (2009b) findings. The differences in elbow angle's behavior were not that big between the positions during the maximal test (figure 15), but the differences in behavior of the angles became clearer, when the speed and incline decreased. In ANA_speed (figure 18) can be seen, how the elbow angle behaved more like Lindinger et al. (2009b) suggest in the KL position. When the inclination increased, the function of the elbow angle became more unstable in the KH position compared to the KL position (figure 21). In the KL position, the behavior of the angle was more like double poling in flat, and the development was more progressive compared to the KH position. The results of the behavior of the elbow angle told about the greater upper body force production capacity in the KL position. The subject was able to hold and control the poling phase longer in the KL position than in the KH position. The limited upper body force production capacity was tried to cover by activating lower muscles (figure 16, 19 & 22) and by increasing the activation of the hip angle in the KH position.

The behavior of the hip angle told about the big difference between the positions, and also explains the differences in performance between the positions. During the maximal test (figure 15), the hip angle behaved controlled in both positions, the evaluation was more controlled in the KL position compared to the KH position. The greatest difference between the positions was that form the angle minimum to poling end value, hip angle increased faster and poling ended with greater angle in the KH position than in the KL position. This is due to the shorter hip working during poling and TMB. When the speed increased, the differences in hip control between the positions became more obvious (figure 18). The hip angle started the poling clearly earlier than the elbow in the KH position. In KH position, the hip movement was not synchronized with elbow and lots of forces was lost. In addition, at the end of the poling (Pole_OUT) the hip angle did not return to up-position. This pointed out that the subject did not control her hip in the KH position, due to that, cannot reach the faster speeds. This was in line with the findings from the subject herself. She told, that in faster sections of the track she cannot accelerate the speed in the KH position. In uphill (figure 21), the evaluation and behavior of the hip angle in the KL position was more stable and controlled. The angle decreased controlled. In the KH position, the extreme load was seen as a huge variation and differences in hip angle behavior during the test. There was no controlled evaluation in behavior of hip the angle in the KH position. The findings about the behavior of the hip angle in anaerobic tests, pointed out the explaining differences between the performances for the positions. In the KL position, the subject was able to use both upper body and trunk muscles synchronized to force production.

EMG. The main finding from the EMG was that in the KL position, the subject was able to use the capacity of her upper body to force production (figures 16, 19 & 22). The TRI muscle was more activated in the KH position during *poling*, but in the KL position, TRI was more pre-activated and more relaxed during *recovery* phase. Better relaxation during *recovery* helps to create greater force production (Holmberg et al. 2005; Lindinger &Holmberg 2011). As Holmberg et al. (2005) pointed out, the successful double poling technique needs greater activation of LD. Greater pre-activation of LD happened in the KL position in both flat terrain tests on treadmill in this case study. At the higher speeds, when it is needed to produce great pole forces in shorter time, it is important to be able to use upper body muscles (Lindinger & Holmberg 2011).

From the EMG- graphs can be seen the effect of fatigue to muscle activations (figure 16, 19 & 22). The effect of fatigue can be seen in the erector spinae muscles on the last loads. In maximal test (figure 16), when the activation of TRI dropped on the last load in the KH position, there was an increase in LD, ESL and ESH muscles pre-and poling activation. Fatigue can be seen also in the KL positions in both anaerobic tests (figure 19 & 22), where on the last loads the activation of both ESL and ESH increased clearly. That can be caused by the drop of TRI and LD activations. In addition, the limited TRUNK_ROM and smaller TMB could cause the increase in levels of activation.

The interesting finding from EMG was that in the KH position, TRI was activated almost the whole poling cycle, and it recorded its highest levels of activation during *recovery* phase. In the KL position, LD was more activated during *recovery* phase compared to the KH position, but he level of activation was clearly lower than during *poling* phase. The literature did not give answers for these findings, but according the conversations with the subject, researchers and coaches and based on the findings from figures 15, 18 & 21, the suggestion for both is that by that way the subject controls the trunk and body during the cycle. In the KL position, the *recovery* activation of LD helped the subject to lift herself up and to hold the position. Same thing was with the KH position. The TRI muscle gave the rhythm for the poling. Via activating TRI during *recovery* phase, the athlete can lead her trunk forward and to more attacking position.

The subject in this case study was a Finnish sit-skiing athlete who is classified into class LW11. That means that she has a fair trunk control that makes her enable to balance even when moving sideways (table 1). The subject got her impairment in an accident that damaged her lower back muscles and spine. Due to the rehabilitation and training, the lower back muscles have improved, and the control of the trunk has increased a bit. The subject had tried the KL position for one season couple years before this case study, but she was forced to change back to the KH position. To observe the differences in muscle activation in the lower back muscles during the tests, EMG was measured from the erector spinae (ESL & ESH) muscles (figure 16, 19 & 22). The main finding was, that ESL seemed clearly more activated in the KL position when the speed increased (figure 19). ESL was clearly more activated in all reported loads during the ANA_speed in all three phases (*pre, poling* & *recovery*). During the last load of the ANA_speed, both *pre* and *poling* values were clearly higher in the KL position compared to the KH position. That was possibly caused by the limited TRUNK_ROM in the KL position (table 8). In maximal test, ESL was more activated during *pre*- and *poling* phases in the KL position, except the last load (figure 16). In ANA_uphill, in the KH position, ESL was clearly more activated during all the three phases (figure 22). With ESH, the muscle activation was higher in the KH position in maximal test at lower speeds (figure 16), but when the speed increased during the ANA_speed test, the levels of *pre* & *recovery* activations in ESH were clearly higher in the KL position (figure 19). During the ANA-uphill, ESH was clearly more activated in the KL position during *pre*- & *recovery* phases (figure 22).

The findings from the figures showed that at the lower speeds and on the flatter terrain, the differences between erector spinae muscle's activation were not clear between the positions. ESH was more activated at the lower speed in the KH position compared to KL. When the speed increased, especially the muscle activation during *pre* & *recovery* increased in the KL position in both muscles. The differences were clear compared to values in the KH position (figure 19). During the ANA_uphill, ESL was more activated in the KH position compared to the KL position. The differences in muscle activation can suggested to be explained to be caused by the limited TRUNK_ROM in the KL position, which was caused by the limited trunk control of the subject and the built support.

The findings from anaerobic tests may explain the reason, why the subject was forces to change back to the KH position during the winter 2020. The muscle activation of both erector spinae muscles increased, when the inclination and speed increased. When the speed increased, both ESL and ESH were clearly more activated in the KL position compared to the KH position. When the inclination increased, ESL was much alike between the positions, but the activation of ESH was clearly higher in the KL position compared to KH position. Due to the fact that on a field the racing speeds and inclinations of the tracks are more like in anaerobic tests, it can be seen, why the subject reported that her back was hurt and why she cannot do high intensity training in the KL position in a field.

Limitation of the study. As this study is a case study for one subject, with a specific impairment, specific training status and performance level, the results cannot be generalized. It cannot be suggested that the effects of the sitting positions would be the same to all sit-skiing athletes in lower classes, or not even to athletes in class LW11. Analyzing the results in this case study is hard, due to the lack of subjects. It is hard to say, are all the presented differences between the patterns clear, and are the findings trustable or are the differences under the margin of error and what are the real effects of them to the performance and cycle characteristics. Even though the recordings and analyzing methods in this case study were done with the protocols, equipment and methods used in previous studies, and the results were checked with the professionals, the lack of subjects, forces to observe the results critically.

The measurement protocol may have affected to the results. The four day-session of high-intensity measurements have affected to the subject. One rest day at the third day would have be in order. Then the measurements would have taken five days. Thus that, the subject performed better in all treadmill tests in the KL position during the last days, even though, on the last day of measurements, she told feeling tired. The differences between the positions in the treadmill tests could have been greater with one rest day between the measurements.

Ethically, the situation in this case study is hard, due to the fact that in Finland there is only one international level sit-skier. The knowledge about the project has been hard to hold in secret, when many of the people know about the project. Before the measurements, the author had a discussion with the subject about the ethics and secret keeping in the project. In that discussion, it was contracted the allowances to tell about the project to the people outside the project.

CONCLUSION

The findings of this case study support the previous findings about the positive effects of the KL position to sit-skiing performance. This case study supports the finding, that longer CT and lower CR at the same level of speed are related to better performance and more economical skiing. The findings from this case study suggest, that even with athletes with limited trunk control could improve their performance in the KL position. The trunk control needs to be on high level and the trunk need to be supported.

The practical implications from this case study are the presented connections of longer CT and lower CT to better more economical performance and the positive connection of sit-skiing ergometer performance to the maximal performance. The used protocol in anaerobic tests in this case study give a good protocol for becoming studies. In addition, the used anaerobic tests are a good training and control testing protocol for the athletes. Based on this case study, we have now a protocol to test sit-skiing athletes, the performance of them and the differences between the classes and the positions on a treadmill. By these protocols it is possible to create a global testing protocol, which can be used to develop the classification and benefit the development of the sport. This case study gives an example to the athletes and teams to test different positions and effects of them on the performance.

REFERENCES

Bassett, D. R. & Howley, E. T. 2000. Limiting factors for maximum oxygen uptake and determinants of endurance performance. Medicine & Science in Sports & Exercise. 31.1:70-84.

Bernadi, M., Janssen, T., Bortolan., Pellegrini, B. Fischer, G. & Schena, F.2013. Kinematics of cross-country sit-skiing during a Paralympic race. Journal of electromyography and Kinesiology 23, 94-101.

Calbet, J. A. L., H.-C. Holmberg, H. Rosdahl, G. Van Hall, M. Jensen-Urstad and B. Saltin. 2005. Why do arms extract less oxygen than legs during exercise? Am J of Physiol Regul Intergr Comp Physiol 289:R1448-R1458.

Doyon, K., Perrey, S., Abe, D. & Hughson, R. 2001. Field testin VO2 peak in Cross-country skiers with portable breat-by-breath system. Canadian joural of applied physiology 26, 1-11.

Fabre, N., balestreri, F., Leonardi, A. & Schena, F. 2010. Racing performance and incremental double poling test on treadmill in elite female cross-country skiers. Journal of Strength and Conditionin Research 24 (2), 401-407.

Forbes, S.C., Chilibeck, P. D., Craven, B. & Bhambhani, Y. 2010. Comparison of a double poling ergometer and field test for elite cross country sit skiers. North American journal of sports physical therapy, 5(2), pp.40–46.

Gastaldi, L., Pastorelli, S. & Frassinelli, S. 2012. Clinical Journal of Sport Medicine 22, 58-64.

Gastaldi, L., Pastorelli, S. & Frassinelli, S. 2013. Motion capture of the push gesture in cross-country sit-skiers during paralympics. In A. Hakkarainen, V. Linnamo, & S. Lindinger (Eds.), Science and nordic skiing II. Jyväskylä : University of Jyväskylä, 225–233.

Halonen, J., Ohtonen, O., Lemmettylä, T., Lindinger, S., Rapp, W., Häkkinen, K. & Linnamo, V. 2014. Biomechnics of double poling when skiing on snow and using and ergometer. In Sciene of Skiing VI, Muller, E.,Kröll, J.,Lindinger, S., Pfusterschmied & Stöggl, T. Eds. Meyer and Meyer Sport, 2014, pp. 387-395.

Hoffman, M.D., Clifford, P.S., Watts, P. B., O'Hagen, K. P. and Mittelstadt, S. W. 1995. Delta efficiency of uphill roller skiing with the double pole and diagonal stride techniques. Canadian Journal of Applied Physiology. 20.4:465-479.

Hofmann, K. B., Ohlsson, M. L., Höök, M., Danvid, J. & Kersting, U. G. 2016. The influence of sitting posture on mechanics and metabolic energy requirements during sit-skiig: a case report. Sports Engeneerin 19, 213-218.

Holmberg, H-C., Lindinger, S., Stöggl, T., Eitzlmair, E. & Müller, E. 2005. Biomechanical analysis of double poling in elite cross-country skiers. Medicine and Science in Sports and Exercise 37(5), 807–818

Holmber, H-C., Lindinger, S., Stöggl, T., Björklund, G & mUller, E. 2006. Contribution of the legs to double poling performance in elite cross-country skiers. Medicine & Science in sports & exercise,1853-1860

Holmberg, H-C, H. Rosdahl and J. Svedenhag. 2007. Lung function, arterial saturation and oxygen uptake in elite cross country skiers: influence of exercise mode.Scand J Med Sci Sports. 17:437-444.

International Paralympic Committee. IPC athlete classification code, https://www.paralympic.org/sites/default/ files/document/170704160235698_2015_12_17%2BClassification%2BCode_FINAL2_0.pdf (2015, accessed 12 February 2020).

International Paralympic Committee. World Para Nordic skiing—classification rules and regulations, https://www. paralympic.org/sites/default/files/document/170803114654801_World%2BPara%2BNordic%2BSkiing%2BClassification%2BRules%2Band%2BRegulations_0.pdf (2017, accessed 12 February 2020).

Jones, A. M. & Carte, H. 2000. The effect of endurance training on parameters of aerobic fitness. Sports Medicine. 29.6:373-386.

Lajunen, K. 2014. Effect of sitting posture on sit-skiing economy. Barchelor thesis. University of Jyväskylä.

Lajunen, K. 2016. Physical performance, heart rate variability and hormone concentrations in cross-country skier throughout the season. Master thesis. University of Jyväskylä.

Lindinger, S., Stoggl, T., Müller, E. & Holmberg, H. 2009a. Control of speed during the double poling technique performed by elite cross-country skiers. Medicine and Science in Sports and Exercise 41(1), 210–220.

Lindinger, S., Holmberg, H-C., Muller, E. & Rapp, W. 2009b. Changes in upper body muscle activity with increasing double pole velocities in elite cross-county skiing. European Journal of Applied Physiology. 106:353-363.

Lindinger, S.J. & Holmberg, H.C., 2011. How do elite cross-country skiers adapt to different double poling frequencies at low to high speeds? European Journal of Applied Physiology, 111(6), pp.1103–1119.

Lappi, T. 2014. Effect of sitting position ovn muscle activation and force generationin simulated sit-ski double poling and balance perturbation test. Master thesis. University of Jyväskylä.

Lund Ohlsson, M & Laaksonen, M.S. 2017. Sitting position affects performance in cross-country sit-skiing. European Journal of Applied Physiology. 117, 1095-1106.

Millet, G., Hoffman, M., Candau, R., Clifford, P. 1998.Poling forces during roller skiing: effects of grade. Med Sci Sports Exerc.30(11):1637–44.

Moxnes, J. & Hausken, K. 2009. A dynamic model of nordic diagonal stride skiing, with a literature review of cross country skiing. Computer Methods in Biomechanics and Biomedical Engineering. 12.5:531-551.

Pellegrini, B., Stöggl, T. & Holmber, H-C. 2018. Developments in biomechanics and equipment of Olympic cross.country skiers. Frontier in Physiology 9, article 976.

Rosso, V., Gastaldi, L., Rapp, W.,Lindinger, S., Vanlandewijck, Y. & Linnamo, V. 2015. Differences in skiing speedamong maleand female sit-skiersin simulated and natural skiing. Conference paper.

Rapp, W., Rosso, V., Ohtonen, O., Gastaldi, L., Vanlandewijck, Y., Lindinger, S. & Linnamo, V. 2016.Role of muscle activation in it-skiing performance and classification process. https://www.researchgate.net/publication/313799390

Rosso, V., Gastaldi, L., Rapp, W.,Lindinger, S., Vanlandewijck, Y. & Linnamo, V. 2017. Biomechanics of simulated versus natural cross-country sit-skiing. Journal of Electromyography and Kinesiology 32, 15-21.

Rosso, V., Linnamo, V., Rapp, W., Lindinger, S., Vanlandewijck, Y. & Gastaldi.2016. Trunk kinematics during cross-country sit-skiing ergometer. Skiing strategies associated to neuromusculoskeletal impairment. Conference paper. https://www.researchgate.net/publication/304781516

Rosso, V., Linnamo, V., Rapp, W., Lindinger, S., Karczewska-Lindinger, M.,Vanlandewijck, Y. & Gastaldi, L. 2019. Simulated skiing as a measurement tool for performance in cross-country sit-skiing. Journal of Sports and Technology, 1-12.

Saltin, Bengt and Per-Olof Åstrand. 1967. Maximal oxygen uptake in athletes. Journal of Applied Physiology. 23.3:353-358.

Sandbakk, O., Hegge, A. M., Losnegard, T., Skattebo, O.,Tonnessen, T. & Holmberg, H-C.2016. The physiological capacity of the world's highest ranked female cross-country skiers. Medicine & Science in Sport & Exercise 48, 1091-1100.

Sandbakk, O. & Holmberg, H-C. 2014. A reappraisal of success factors for Olympic cross-country skiing. Int j Sports Physiol Perform 9 (1),117-121

Sandbakk, O., Holmberg, H-C., Leirdal, S. & Ettema, G.2010. Metabolic rate and gross efficiency at high work rates in world calss and national level sprint skiers. Eur J Appl Physiol 109 (3), 473-481

Staib, J. L., IM, J., Caldwell,Z. &Rundell, K. W.2000. cross-country ski racing performance predicted by aerobic and anaerobis double poling power. Journal of strength and conditioning research 14, 282-288

Stöggl, T. & Holmber, H-C. 2016. Double poling biomechanics of elite cross-country skiers: Flat versus uphill. Medicine & Science in sports and exercise 10, 1580-1589.

Stöggl, T., Lindinger, S. & Muller, E. 2006b. Reliability and validity of test concepts for the cross-country skiing sprint. Medicine &Science in sports & exercise. 586-591

Stöggl T, Lindinger S, Muller E .2007. Analysis of a simulated sprint competition in classical cross- country skiing. Scand J Med Sci Sports 17:362–372

Stöggl, T., Müller, E., Ainegren, M. & Holmberg, H. 2011. General strength and kinetics: fundamental to sprinting faster in cross country skiing? Scandinavian Journal of Medicine & Science in Sports 21, 791–803.

Stöggl, T., Welde, B., Supej, M., Zoppirolli, C., Rolland, C., Pellegrini, B. &Holmberg , H-C.2018.Impact of incline, sex and level of performance in kinetics during a distance race in classical cross-country skiin.g, Journal of sports science and medicine, 17 (19),124-133.

Van Hall, G., Jensen-Urstad, M., Rosdahl, H., Holmberg, H-C., Saltin, B. & Calbet, J. A. L 2003. Leg and arm lactate and substrate kinetics during exercise. American Journal of Physiological Metabolics. 284:E193-E205.

Vanlandewijck Y., Verellen J., Tweedy S. 2011. Towards evidence-based classification in wheelchair sports: Impact of seating position on wheelchair acceleration. Journal of Sports Sciences vol 29, 1089-1096.

Wisloff, U. & Helgerud, J. 1998. Evaluation of a new upper body ergometer for cross country skiers. Med Sci Sports Exerc.30, 1314–1320.

Åstrand, Per-Olof, Kaare Rodahl, Hans A. Dahl, and Sigmund B. Stromme. 2003. Textbook of Work Physiology: Physiological Bases of Exercise. 4th ed. Canada: Human Kinetics, 2003. Print.