EFFECT OF SITTING POSITION ON MUSCLE ACTIVATION AND FORCE GENERATION IN SIMULATED SIT-SKI DOUBLE POLING AND ON BALANCE PERTURBATION TEST

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ABSTRACT

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Sit-skiing is part of Nordic skiing for disabled athletes. It is governed by International Paralympic Committee (IPC) that provides guidelines for sit skiers' classification process. Classification process analyses key factors on level of impairment and the impact of the disability to the performance on the sport in question. Classification process parameters are based on functional characteristics such as force generation capabilities, range of movements and medical assessments. Due to individualistic nature of disabilities, the functional classification leaves room for discussion about fairness of class allocation.

This study presents a sit skiers' test set-up that analyses four different sitting positions the sit-skiers use. The test set-up is verified with able bodied test subjects to be applicable to be extended on disabled athletes. It can be used to obtain scientific information to develop the sit-skiers' classification process. Tests collects information on muscle electronic activation and force generation capabilities on double poling and balance maintenance activities. On maximal speed double poling P3 (kneeing) was concluded to have significant advantage over P2 (knee high) with $p=0.011$. In balance maintenance Rectus Abdominus' EMG indicated significant difference between the same positions with $p=0.016$, P3 having higher value.

Keywords: IPC, sit-skiing, muscle activation, sitting positions, classification.

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Kelkkahiihto kuuluu vammaishiihtolajeihin, joita hallinnoi Kansainvälinen Paralympiakomitea (IPC). IPC ylläpitää kelkkahiihtäjien luokitteluprosessia joka pohjautuu hiihtäjän vammojen ominaisuuksiin ja suorituskykyyn kelkkahiihdossa. Luokittelujärjestelmän parametrit perustuvat lihasten ja nivelten toimintakykyyn, jota arvioidaan voimantuoton, liikkuvuuden sekä lääketieteellisen analyysin kautta. Vammojen yksilöllisen luonteen takia toiminnallisuuteen pohjautuva luokittelujärjestelmä jättää tulkinnanvaraa luokan määrittämisessä.

Tämä tutkimus esittelee kelkkahiihtäjien testijärjestelmän joka analysoi neljää kelkkahiihtäjien käyttämää istuma-asentoa. Järjestelmä todennetaan toimivaksi terveillä testihenkilöillä, ja osoitetaan soveltuvaksi myös vammaisurheilijoille. Testijärjestelmää voidaan käyttää tiedon keräämiseen kelkkahiihtäjien luokittelujärjestelmän kehittämiseksi. Testit keräävät tietoa lihasten aktivaatiotasosta ja voimatuotosta tasatyöntösuorituksessa sekä tasapainon säilyttämistilanteissa. Tilastollisesti maksimaalisessa tasatyöntösuorituksessa P3 (polviasento) on edullisempi kuin asento P2 (polvet sylissä) arvolla $p=0.011$. Tasapainon säilyttämisen kannalta Rectus Abdominus lihaksen aktivaatiossa on näiden asentojen suhteen eroa ($p=0.016$) P3:sen hyväksi.

Avainsanat: IPC, kelkkahiihto, lihasaktivaatio, istuma-asennot, luokittelu.

ABBREVIATIONS

ASIA	American Spinal Injury Association
D&W	Daniels and Worthingham
EMG	Electromyography
ICF	International Classification of Functioning, Disability and Health
IOC	International Olympic Committee
IPC	International Paralympic Committee
IPNSC	International Paralympic Nordic Skiing Committee
MMT	Manual Muscle Testing
MRC	Medical Research Council
MVC	Maximum Voluntary Contraction
NWAA	National Wheelchair Athletic Association
NWBA	National Wheelchair Basketball Association
ROM	Range Of Motion
WHO	World Health Organization

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1 INTRODUCTION

Paralympic sports are gaining more momentum in terms of publicity and professionalism. Sports for disabled persons are considered to have similar drivers as for able bodied persons including elite competitions – the Paralympic Games. As the impairments of disabled athletes are very individual by nature, sport specific classification processes are being utilized to create meaningful and high quality competition events.

The sport specific classification process is used to define how much the impairment limits the capabilities and performance of a Paralympic athlete. Classification of disabled athletes is an organizational structure and process that creates fair competition within a sport. Medical and functional parameters are used in classification assessments to allocate a sport class for the athlete. Percentage or other multiplier is then utilized in competitions to make the results comparable across the classes, since there in many cases are only few participants per a single class in a competition.

International Paralympic Committee (IPC) governs the Paralympic elite sports and drives for evidence based classification. Medical and functional – such as movement range – based class allocation include subjective assessment of the classifier. Collecting evidence via sport scientific process bring more information to classification process eliminating possibility of incorrect class allocation. IPC pursues towards the evidence based classification of impairments in all the sport events governed by it in order to enable an integrated classification systems. A holistic multidisciplinary approach including international co-operation between researching teams is a precondition for successful evidence based classification. (Tweedy and Vanlandewijck 2009; Beckman and Tweedy 2008).

Development of laboratory test set-up enable collection of data for the evidence based classification in constant environment. Biomechanical data about the joint range of movement (ROM), muscle electric activity (Electromyography, EMG) and force generation provide exact sport specific information about neuromuscular systems relevant to the sport.

This Master's Thesis is part of an IPC initiated scientific research project on Paralympic Nordic sit-skiing. Nordic skiing is a focus area of the Jyväskylä University’s Vuotech unit in Sotkamo Finland. The research project is governed jointly by University of Jyväskylä, University of Tübingen (Germany) and University of Saltzburg (Austria). Intent of this project is to define a laboratory test set up and to verify with able bodied test subjects that the test set-up bring valid information on the force generation and EMG of sit-skiers. Information could then be utilized to develop the classification process of the sit-skiers especially in cases where the allocation has room for interpretation due to subjective parameters.

In Nordic sit-skiing a key parameter for performance is the used sitting position. Position selection is done either due to limitations set by impairment or by personal preferences. Testing how the sitting position impacts the activity and performance of a skier defined the framework for the test set-up. Data about force generation and EMG in different sitting positions would not be relevant only for classification process development but could also bring beneficial input also to the athletes and their coaches for the training programs.

2 PARALYMPIC SPORT

The number of disabled athletes has been growing constantly in recent years, and disabled athletes nowadays participate virtually into every sport available. The same beneficial effects of physical exercise as for able bodied athletes also apply for the disabled ones. Evidence is growing that the more physically active disabled persons make less visit to doctors and are able to decrease the effect of disability into their lives. Movement to recognize and establish a structured governance model for sports on disabled persons started as rehabilitating activity for the injured veterans of Second World War. Sports was seen as a way to cope with the impairment and injuries received in the war. The veterans were still young people having similar ambitions to competitions as the able bodied athletes. During 1940s and 1950s in several countries in Europe and in US different organization were set up to run competitions, trainings and events for disabled athletes. (Vanlandewijck and Thompson 2011; Whyte et al. 2009; Pernot et al. 2011).

Paralympic athlete is the term used across the different sports to define a disabled person performing competitions. The term “Paralympic” comes from combination of “paraplegic” and “Olympics” and it was first time introduced in 1953. In 1988 Seoul Olympic games and following these games the term was incorporated into the name of the new governing body for the games, the International Paralympic Committee (IPC). IPC has since then taken the global role to collect the activities run by different disabled sport organizations under one global umbrella. This IPC governed framework is intended to raise the profile of Paralympic sports. (Vanlandewijck and Thompson 2011; IPC 2013).

Today IPC has been recognized the leading organization on governing the international Paralympic sports activities. The IPC vision is defined as “to enable Paralympic athletes to achieve sporting excellence and to inspire and excite the world”. The logo of IPC is described in figure 1. IPC organizes Summer and Winter Paralympic Games every 4th year aligned with Olympic games governed by International Olympic Committee (IOC). Popularity of the Paralympic Games are constantly growing, the 2012 London Summer Paralympic Games being the first to be sold out. The trend puts the sport for disabled into new context, not only to be used for rehabilitation but to be a right of every citizen. This brings Paralympic sports continuously closer to the able bodied sport in every aspects of sports and competitions, including professionalism level, rules, publicity, training and media coverage. (Vanlandewicjk 2006; Vanlandewijck and Thompson 2011).

Figure 1. Current official logo of IPC (IPC, 2013)

In Finland the Paralympic movement is governed by Suomen Paralympiakomitea (IPC Finland). IPC Finland is established in 1994, and it is a member of global IPC. IPC Finland is responsible for selecting the Finland representators to the Paralympic Games. It also ensures that the practices defined by IPC such as classifications are applied in the events and organizations operated in Finland. Logo of IPC Finland is described in the figure 2. (Suomen Paralympiakomitea 2013).

Figure 2. Official logo of IPC Finland. (Suomen Paralympiakomitea 2013)

2.1 Paralympic Winter Sports

The concept of International Winter Games for persons with disabilities was proposed by Sweden in 1974. The 1976 Örnsköldsvik Winter Olympic Games for the Disabled are considered to be the first official Paralympic Winter Games. Since then the Paralympic winter games have been organized in conjunction of the International Olympic Committee (IOC) hosted Winter Olympic Games. The latest Paralympic winter games were organized in March 2014 in Sots, Russia. (Vanlandewijck and Thompson 2011).

There are in six Paralympic winter sports hosted in the upcoming Winter Paralympic Games in Sots 2014: Alpine skiing, ice sledge hockey, biathlon, cross-country skiing, snowboarding (new) and wheelchair curling (has been included into the Paralympic Games since 2006). (Vanlandewijck and Thompson 2011; IPC, 2013).

2.2 Impairment type defines a Paralympic athlete

Today 10 major types of impairment have been defined in Paralympic sports: Vision impairment, impaired strength, impaired range of movement (ROM), limb deficiency, leg length difference, hypertonia, ataxia, athetosis, short stature and intellectual impairment. These parameters are used to validate if the athlete would fulfill requirement(s) to be eligible to participate into Paralympic sports events. Types of impairment can be summarized as biomechanical, visual and intellectual impairments which also form the baseline for organizing competitions. Impairment has to be permanent and not be impact of it should not be decreased due to physical training. (Tweedy and Vanlandewijck 2009).

Each of the Paralympic sport selects types of impairment valid to the sport and defines minimum disability criteria against them. For example in Paralympic Nordic skiing the leg and arm impairment and visual impairment are categorized. On wheelchair racing visual impairment is not categorized. Minimum disability criteria should define only the impairments that directly cause activity limitation on the particular sport. For example loss of the fingers may create challenges in strength training activities for a sprint runner but have no actual impact to running itself. Thus the impairment type would not be valid in defining eligibility to participate into Paralympic running events. (Tweedy and Vanlandewijck 2009; Vanlandewijck 2006).

3 CLASSIFICATION AND SPORT CLASSES

Disabled persons have different levels of impairment due to their disability. Classification is a critical aspect of the Paralympic sport since it determines who is and who is not eligible to compete in Paralympic Sport. As the role of the Paralympic sport is increasing, also the public visibility of it is increasing. Therefore the decisions determining eligibility into Paralympic sport are getting more important. Determining the minimum disability criteria, and furthermore a framework to classify the athletes based on their individual limitations, should be based on empirical evidence. (Vanlandewijck and Thompson 2011; DePauw 1988).

Classifications categorizes the competitors into Sport Classes based on their performance potential and relationship between the impairment and sport activity. Purpose of the classification is to ensure minimum disability criteria fulfilment and to minimize the impact of the disability on sport outcome. (Vanlandewijck 2006).

3.1 Characteristics of classification of disabled athletes

Each of the Paralympic sport has a target where the winning athlete is defined by the relevant skill for the particular sport in question - speed, power, endurance or something else - by the same factors that count for the success on the able bodied athletes. Each Paralympic sport defines clearly the impairment groups that it provides sports opportunities to as described in introduction chapter. (Tweedy and Vanlandewijck 2009).

Classification is a means of reduction the likelihood of one sided competition and in this way to promote participation into sport. Two types of classification are used in sport:

1. **Performance based classification** -such as classification of the national soccer teams into groups on World Cup based on their performance on qualifications.

2. **Selective classification** -based on certain adjustable attributes such as age, weight, sex or functional capabilities like ROM or strength limitations in case of disabled athletes.

On selective classification the athlete will compete in the same class regardless of performance as long as the class defining attribute is not changing over limits set by classification body. When defining the classes it is critical that within any given class the range of activity limitation should never be so large that athletes with least limitations get significant advantage over those with greatest limitation. For example tetraplegic and paraplegic athletes should not compete in a same class. (Tweedy and Vanlandewijck 2009; Beckman and Tweedy 2008).

Sport scientists face multiple challenges regarding athletes with disabilities, including the following (Vanlandewijck 2006):

a) Development of an evidence based sport specific classification system
b) Understanding of the causal mechanisms of sport injuries
c) Implementation of comprehensive sport counselling system
d) Understanding of disability-specific responses to exercise and their effect on training strategic
e) Understanding of the effect of “boosting” and the consequent implementation of an anti-doping education program.

3.2 Classification process and class allocation

Purpose of the classification process is to minimize the impact of impairments on the sport in question. Having the impairment itself is not sufficient but the impact of it on the sport must be proven. The criteria of grouping athletes by the degree of activity limitation resulting from the impairment are named **Sport Classes** that are specific to the sport and impairments categorized for it. Classification process validates that athletes are eligible to compete in a sport and how the athletes are grouped together for competition. (Tweedy and Vanlandewijck 2009).

When an athlete first starts competing he/she undergoes a classification process to define the Sport Class he/she belongs to. This process is conducted by a classification panel, a group of individuals authorized and certified by a Sport Federation Classification Process. IPC governs the global classification processes. The classification process is specific to the sport and includes typically (IPC 2013):

- Definition that the athlete has an eligible impairment for that sport
- physical and technical assessment to exam the degree of activity limitation
- the allocation of a sport class
- observation of performance in competition

Some impairments are dynamic by nature meaning that their impact on activities change over time. Therefore the athletes may undergo the classification process several times throughout their career. When the medical condition of an athlete changes, he/she needs to inform the sport classification panel and ask for re-assessment of the sport class. For international competition the classification needs to be done by International Classification

Panel and their decision overrules any previous classification decision taken by a national classification panel. (IPC 2013; Tweedy and Vanlandewijck 2009).

Classification processes are being continuously evaluated and developed using results from related sport science projects. For example the classification process used in wheelchair basketball was verified by Lira et al. (2010) by analyzing the correlation between aerobic and anaerobic performance and the sport class allocated. Correlation between the Wingate 30s sprint test results and sport classes was found to be determining in terms of relative and absolute peak and mean power being visible in peak VO_2 and VO_2 ventilator threshold values. Conclusions validated the targets set for the classification process. (Lira et al. 2010).

3.3 Functional classification

Functional classification determines parameters based on which the athletes are categorized into limited number of sport classes. Functional classification reviews the impairment impact to ROM, force generation or other variable specific to the sport. Functional classification is systematic and easy to apply methodological framework for the Sport Class allocation. It is the most widely used frame for a classification process. (Tweedy and Vanlandewijck 2009: Higgs 1990).

From statistical point of view the functional classification process requires that there should be significant differences in performance between classes and homogeneity within a class. To assess the functional class the classification bodies have defined specific sets of tests and parameters for class allocation. Competition should place those with similar degree of disability into same class based on the functional limitations the impairment causes. On the most extreme, this would for example with spinal cord injured athletes mean that for every level of spinal injury (42 when counted by spinal segments) there would be an own class to compete. (Higgs et al. 1990).

3.3.1 Manual muscle testing (MMT)

In functional classification ROM and muscle strength are key determining parameters. Manual Muscle testing (MMT) method to measure muscle strength for classification process is utilized by IPC defines following parameters to assess the muscle strength on impaired athletes (Tweedy et al. 2010):

1. Assessment should be limited to movements important to sport in question
2. A single technique for assessment of movement strength should be developed
3. Change the reference range of movement from standard anatomical range to maximum range used in the sport
4. Test techniques need to be adjusted for the sport

MMT methods are applied today in classification on 20 summer Paralympic governed by IPC. Two most recognized MMT methods are *Daniels and Worthingham (D&W)* and *Medical Research Council (MRC)*. Both of the methods utilize relative six point scale from 0 to 5 to grade muscle strength. Both describe the grades in relation to movement against gravity and manual resistance. In addition to these commonalities, the D&W method adds on this a descriptor for range of movement. (Tweedy et al. 2010; IPC 2013).

MMT methods can lead into different assessment scores and results. The methods of MMT used by classification team can alter therefore the final class allocation. Use of standardized framework such as D&W or MRC consistently over several years can eliminate potential source of inconsistency and it is important that the governing organization sets common guidelines to apply MMT on both national and global classification process. MMT methods should be used together with activity limitation based parameters to complement the functional classification process. (Tweedy et al. 2010)

IPC utilizes widely the MRC methods due to their wide deployment and ease of applicability. Compared to D&W methods the MRC methods are brief and simple whereas D&W instructions are more comprehensive. D&W methods utilization should be emphasized in the classification with following modifications as they are seen to increase the reliability of strength based classification in terms of force generation. (Tweedy et al. 2010; IPC 2013).

1. Select the right sport specific movements for assessment – internal hip rotation can be excluded on runners
2. Specify the movement testing techniques – selecting single technique based on biomechanical rationale increases reliability
3. Change the reference range of motion to suit the sport – full normal anatomical range does not apply, use maximum range of movement required in the sport as reference
4. Adjust the movement assessment techniques – customize the test set-up for example on test subject positioning and stabilization.

3.3.2 Classification outcome evaluation by performance

Large scale competition events provide good opportunities to study how well the classification processes is aligned with actual performance. IPC Paralympic Games represent the highest class event in the sports for the disabled so the games results are utilized in quantitative research on classification accuracy. The results can be considered to represent elite performances worldwide. Possibility for misclassification where the class does not support the performance is a lot debated phenomenon in Paralympic sports but found to be not that common in reality. For example in 1996 Atlanta Paralympic swimming games there were in total 6 classification appeals made and 3 misclassifications proven amongst 374 disabled swimmers. (Wu and Williams 1999; Higgs et al. 1990).

In terms of performance the classification process goals are twofold: to ensure clear difference in performance between the classes, and to ensure limited difference within a class. Higgs et al. (1990) studied results of 1982- 1987 International Stoke Mandeville Games (predecessor for IPC Paralympic Games) and Pan American Games on wheelchair track and field sports. The research group compared the results of male and female athletes by using statistical methods to test how well the class allocation reflected the results. In total 4698 performances were analyzed. The results showed that there would have been opportunities to reduce the number of sport classes used without seriously discriminating any athlete. New classification system would result into redistribution of athletes within each class. To confirm if the update of classification process based on performance would have been successful, the research group should wait for the results of the next similar games. (Higgs et al. 1990).

Abilities of Paralympic athletes are also determined by physiological parameters like cardiorespiratory fitness, anaerobic fitness and muscle-joint system coordination. Classification based on physiological parameters has had controversy as physiological performance in disabled persons has particularities compared with able bodied individuals. For example wheelchair athletes compensate their lower limb muscle loss through hypertrophy on upper limbs. Using performance levels to validate the functional classification poses therefore a risk of disadvantage due to the training and limited availability of heterogeneous group to verify how much the disabilities impact directly the physiological responses. For example wheelchair athletes have unique physiological responses during upper limb exercise as a result of vascular insufficiency of the lower limbs and adrenergic dysfunction. (Vanlandewijck & Thompson 2011; Lira et al. 2010).

Lira et al. (2010) demonstrated a correlation between aerobic and anaerobic performance measures against the sport classes on wheelchair basketball. According to the results the aerobic performance measures are aligned with functional capabilities and activity limitations used to classify the players. These findings support the suggestions from DePauw (1988) on similarities between able bodied and disabled athletes on performance evaluation. Responses that are in determining role on short duration activities like wheelchair basketball are though studied to very limited extent narrowing the options for wider scale conclusion definition. The impact of training and competition to the performance is not easy to be eliminated. (Lira et al. 2010; DePauw 1988).

3.3.3 Classification based on sport skills

In functional classification the assumption is that the degree of disability impacts to the performance of the sport. One aspect in the performance is the skill proficiency level that play important role especially in team sports where athletes form teams across Sport Classes. For fair and equitable competition for example on wheelchair basketball the classification based on disability should reflect to the skills of the players so that the teams' classification profiles could be produced. (Brasile 1986; Lira et al. 2010).

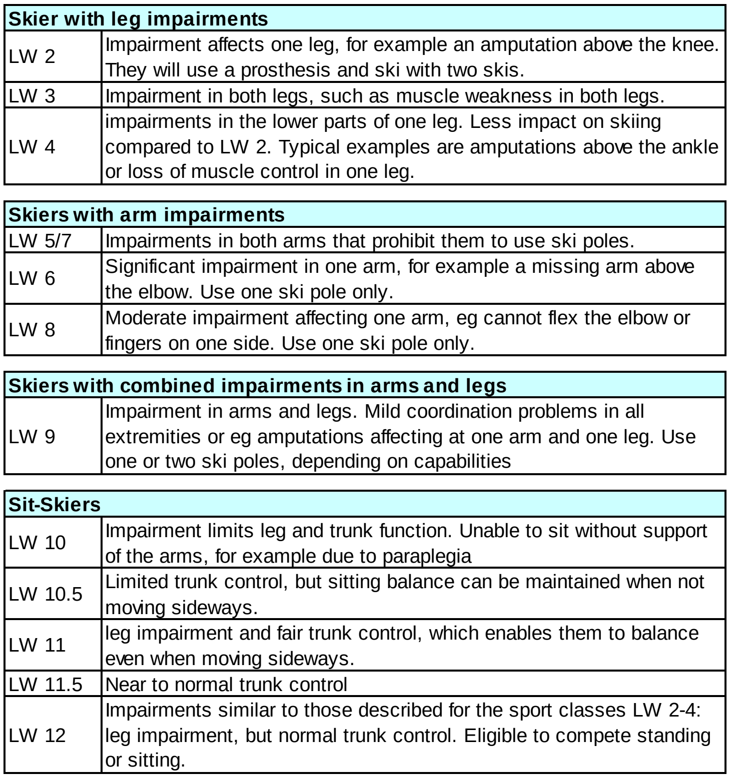
Correlation between the disability level and skills relevant in wheelchair basketball was analyzed by Brasile (1986). Wheelchair basketball players performed specific tests on skills such as speed, agility, shooting, catching and rebounding. The results were compared against the player's functionally assigned Sport Class (I-III). Classification system used was National Wheelchair Basketball Association (NWBA) classification system. The study revealed limitations in a simple three category based functional classification. The NWBA classification system did not support the players' skill level. For a classification system this kind of empirical results indicate that the classification system needs to be developed further. (Brasile 1986).

Results on tests such as pass for accuracy on non-dominant hand are also time context dependent and under influence of training. Stepwise forward regression analysis determined that classification levels, years of experience on wheelchair basketball and age contributed most to the overall skills. As an outcome Brasile (1986) suggests further studies either on combining classes II and III due to similar skill levels, or to divide the classes II and III even further towards more functionality based classification. Adapted skill specific tests where performance is tested on top of disability have limitations on global applicability and resistance to the training impact for classification, but they provide valuable input to the integration of sport classes for fair and equitable competitions. (Brasile 1986).

3.4 Classification in Nordic Skiing and Biathlon

In Nordic skiing and biathlon the relevant impairments for classification are leg or arm impairment and visual impairment. On the leg and arm impairment the skiers are divided first into standing skiers and sit-skiers. All of the Nordic skiing and biathlon classes belong into adapted sport event categories: they have been modified from the able bodied sport events to suit with disabled athletes. The Sport Classes in Nordic skiing are described below in the table 1. (Whythe et al. 2009; IPC 2013).

Table 1. Nordic Skiing and Biathlon Paralympic Sport Classes (IPC 2013)



Skier with leg impairments	
LW 2	Impairment affects one leg, for example an amputation above the knee. They will use a prosthesis and ski with two skis.
LW 3	Impairment in both legs, such as muscle weakness in both legs.
LW 4	impairments in the lower parts of one leg. Less impact on skiing compared to LW 2. Typical examples are amputations above the ankle or loss of muscle control in one leg.

Skiers with arm impairments	
LW 5/7	Impairments in both arms that prohibit them to use ski poles.
LW 6	Significant impairment in one arm, for example a missing arm above the elbow. Use one ski pole only.
LW 8	Moderate impairment affecting one arm, eg cannot flex the elbow or fingers on one side. Use one ski pole only.

Skiers with combined impairments in arms and legs	
LW 9	Impairment in arms and legs. Mild coordination problems in all extremities or eg amputations affecting at one arm and one leg. Use one or two ski poles, depending on capabilities

Sit-Skiers	
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	Impairments similar to those described for the sport classes LW 2-4: leg impairment, but normal trunk control. Eligible to compete standing or sitting.

With sit-skiers the definition of the Sport Class is seen as most challenging in between classes LW 10 and 10.5 and classes LW 11 and 11.5. Capability to maintain balance is the defining factor between classes LW 10 and 10.5 but class allocation leaves room for improvement in terms of athlete's actual performance. Capability to control trunk to maintain balance is in key position when defining if the athlete would belong into class 11 or 11.5. (Pernot et al. 2011).

3.5 Methods to classify a sit-skier's Sport Class

Methods to define the class for a sit-skier between LW10 and LW12 are based on IPC Classification Rules and Regulations. In November 2007 the general assembly of IPC approved the IPC classification code that includes comprehensive guidelines, policies and procedures for conducting classification. The code that includes also the Nordic Skiing Classification rules that are available at:

http://www.paralympic.org/sites/default/files/document/131004101850237_2013_10_04_IPC_Nordic_Skiing_Classification_Rules_and_Regulations_1.pdf.

These classification rules are regularly updated, the present one being released 4th October 2013. (Tweedy and Vanlandewijck 2009; IPC 2013).

3.5.1 **Physical/medical assessment**

Medical assessment is a key part of the classification process. It is conducted to ensure that the impairment of the athlete is permanent by nature and that the impairment gives eligibility to participate into Nordic skiing for disabled athletes. IPC Nordic Skiing Classification Rules require that allocation of a class for a sit-skier is defined from both physical and from technical point of view. The physical evaluation can be performed only by qualified classifier obtaining needed medical education. The main frameworks used for physical/medical assessment in the Nordic skiing are World Health Organization's International Classification of Functioning, Disability and Health (WHO ICF) and American Spinal Injury Association (ASIA) impairment classification. (Vanlandewijck and Thomson 2011; Snyder et al. 2008).

Disablement models provide a common language and a baseline for developing a sport specific classification methods. They also provide an effective conceptual framework for refocusing health care interventions. WHO ICF is the disablement framework used by IPC as a baseline for medical assessment. ICF includes two main dimensions to the framework as lists: a list of body functions and structure, and a list of domains of activity and participation. As the functionality and impairment is individual and occurs always in a context, the ICF includes also environmental factors. The framework is applicable to all people and described both positive and negative functionalities. (Snyder et al. 2008; IPC 2013).

ASIA released its first guideline to classify the spinal cord injuries in 1982. Classification of spinal injury applies to sit-ski athletes outside amputees or athletes with lower limb deformity. ASIA classification is based on neurological responses like touching or pinching selected parts of the skin. It also includes evaluation of the strength of the muscles controlling key motions of the body including hip flexion, shoulder shrug, elbow flexion, wrist extension and elbow extension. Using these parameters the spinal injury is classified into five different categories (A-E) on ASIA impairment scale. (Vanlandewijck and Thompson 2011; Tweedy and Vanlandewijck 2009).

3.5.2 Technical/functional assessment

The **technical/functional** assessment for sit-skiers includes muscle activity tests, sensitivity tests and coordination tests. With functional assessment the main factors determining the Sport Class focus on how much does the impairment of a person impact upon sport specific activities and performance. A test setup named as **test-table-test** was introduced in 1985 for the muscle activity and balance maintenance testing of sitting athletes. It is used as functional test for the sitting ability and trunk stability. Test-table-test utilizes a specific board with sit-skiers as described in the figure 4. (IPC 2013; Pernot et al. 2011; Tweedy and Vanlandewijck 2009).

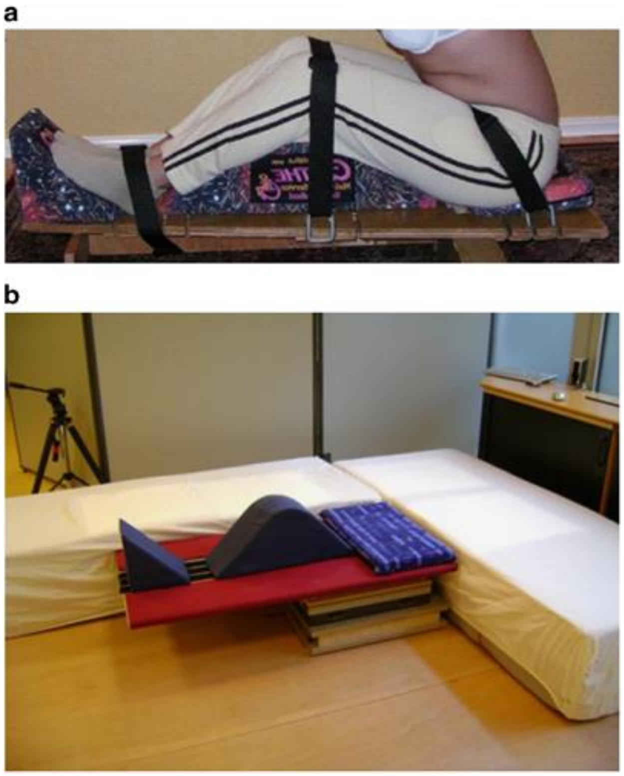


Figure 4. Test-table-test used in IPC sit-skier classification (Pernot et al. 2011).

Test-table-test has in total four different tests: 45 degree hip flexion (forward leaning), 45 degree backward inclination, lifting a ball above head and a maximum trunk rotation range. In each of tests the athlete is assigned certain number of points based on the functional capability and test performance. For example in the forward leaning test the points would be given as:

Score 0: No function: The athlete can lean forward but loses balance before 45°

Score 1: Weak function: The athlete can lean forward but not go up against gravity

Score 2: Fair function: The athlete can lean forward and come up with using the head and upper part of the trunk from 45° and above

Score 3: Normal function: The athlete straightens up normally

The test table test focuses on functional limitations of key muscles and joints contributing to sit-skiing. It defines the sitting capability level for a disabled athlete. The scoring does not take into account the muscle strength itself. MMT methods like static isometric force production on upper limbs are utilized to create grading system that also take into account the force generation capabilities of the athlete. This complements the functional assessment of the sit-skiers. (Tweedy et al. 2010; Pernot et al. 2011).

3.6 Allocation of Sport Classes LW10-12 (sit-skiers)

IPC uses the ASIA classification standard to define impact of the spinal cord injury to the Sport Class. The ASIA standard includes functional parameters on sensory and motor levels, zone of partial preservation, score on ASIA Impairment Scale and evaluation of the completeness of the injury. ASIA classification standard applicability was tested in study by Cohen et al. (1998). ASIA was seen as a defining classification method on severe spinal cord injuries like tetraplegia. On patients with incomplete paraplegia the ASIA classification method provided different results leaving room for interpretation on the correct class. (Cohen et al. 1998; Pernot et al. 2011).

Test-table-test is in a key role in determining the Sport Class an athlete belongs into. Validity of the test-table-test for the functional classification was tested by Pernot et al. (2011) by mounting the test-table-test board on top of a force plate. Test subjects performed reaching forward, reaching lateral right and left sides moves on the board with target to maintain the balance. Movement results were compared with the force plate forces. Outcome of the study gave strong positive correlation between the movement and force plate results in terms of center of pressure displacement. Test-table-test was proven to be accurate for the functional classification but one of the findings was that the accuracy is less clear between classes LW 10 and LW 10.5. (Pernot et al. 2011).

As an end result of medical and functional classification the sit-ski athlete gets a single score indicating the class he/she belongs into. Cohen et al. (1998) study conclude that the pure functional classification system is not an evidence based but leaves room for discussion, especially on the challenging cases between LW 10 and LW 10.5 and between LW 11 and LW 11.5. Objections and protests of both athletes and coaches are raised regularly in sports for the disabled, including the sit-skiing. (Cohen et al. 1998; Pernot et al. 2011).

3.7 Functional classification process challenges in wheelchair racing

Validity of the functional classification system can be questioned from measurement weighting and measurement aggregation perspectives. Tweedy & Vanlandewijck (2009) revisit these perspectives in context of wheelchair racing highlighting the challenges involved in validating a functional classification process. The wheelchair racing classes are defined in terms of loss of strength as: (Tweedy and Vanlandewijck 2009):

T51: Equivalent activity limitation to a person with complete cord injury at cord level C5-6

T52: Equivalent activity limitation to a person with complete cord injury at cord level C7-8

T53: Equivalent activity limitation to a person with complete cord injury at cord level T1-7

T54: Equivalent activity limitation to a person with complete cord injury at cord level T8-S4

Based on the above profiles for the classes, an athlete with complete cord injury on T2 would entail diagnostic tests and evaluations of strength using MMT and the resulting class would be T53. Classification process for a person with a C6 incomplete injury (e.g. with some functionality on abdominal and lower spinal muscles but limitations on arm strength) is more complicated. The outcome could be either T52 (if the disadvantage of the arm strength limitation is considered greater than advantage of superior trunk strength), T53 (if the disadvantage of the arm strength limitation is considered equal to advantage of superior trunk strength) or T54 (if the disadvantage of the arm strength limitation is considered to be less compared to the advantage of superior trunk strength). (Tweedy and Vanlandewijck 2009; Tweedy et al. 2011).

Scientific evidence from research projects are being used to define the sport specific "impairment scores" that could be used to determine the correct class in multidimensional cases by weighting the result with a framework score. This is a method for overcoming the weighting measurement challenge. For the wheelchair racing case above a framework could be based on defining arm and trunk muscle role for the event performance by examining several athletes with different disability levels. This would be used to overcome the measurement weighting challenge of functional classification. Similar impairment score set-up was introduced by Pernot et al. (2011) in context of sit skiers and test-table-test. (Tweedy and Vanlandewijck 2009; Pernot et al. 2011).

Measurement aggregation challenge can be demonstrated when the classification process includes two or more different impairment types. A person with a complete spinal cord injury at T2 and right elbow extension deficit would by default belong into class T53. He/she could be classified into T52 in case the disadvantage of elbow extension limitation is same or more as the bilateral arm weakness of other athletes in this class, or again into T53 in case the disadvantage of elbow extension limitation is minor. In this case the evidence based decision making requires knowledge of the relative importance of impaired elbow to the wheelchair racing and means to summarize the impact in terms of joint movement limitations (degrees) and strength (relative score). (Tweedy and Vanlandewijck 2009).

3.8 Combination of sit-ski race results across Sport Classes

When the number of classes in a given sport are defined, it is important to understand the distribution of athletes per class. In some classes the number of classified athletes can be small. The goal of an integrated classification system is to enable each competitor, even those with the most severe disability to compete in a fair manner with other athletes that would have similar degree of disability. (Gehlsen and Karpuk 1992; Pernot et al. 2011).

The number of skiers attending to a competition on each of the Sport Classes described in table 1 can be very limited. Having a separate event for each of the classes would not bring out a valid race event. Therefore the results of skiers belonging into different sport classes are being integrated together using a weighting system in a similar manner as described in chapter 3.7 in context of wheelchair racing. Each sport class has an own multiplier that is used for balance the end result so that the results between classes become comparable. In Nordic Skiing the IPC has three combined medal classes: ‘locomotor skiing’, ‘sit-skiing’ and ‘visually impaired’. Final results of the all of the sit-skiers are multiplied by a percentage based on the estimated impact of the disability to the result. The system is an adjusted formula that is used to determine overall each of the competitor relative to each other. This way the athletes from different classes can fairly compete against each other in the same race despite of Sport Class. (Pernot et al. 2011; IPC 2013; Tweedy and Vanlandewijck 2009).

The percentage system used in Nordic sit-skiing is based on adjusted time formula where the finishing time is defined from the actual time by multiplying it with a class specific percentage score. The percentages are being evaluated per season by IPNSC (International Paralympic Nordic Skiing Committee) and are being published in Internet on IPC official website. The IPC Nordic Skiing Percentages for 2012-2014 can be found here (IPC 2013):

http://www.paralympic.org/sites/default/files/document/130124162220086_IPC+Nordic+Skiing+Percentages2012-14.pdf

The table 2 below presents the percentages being applied for 2012-2014 for sit skiers.

Table 2. Percentages to combine sit skiing results on season 201-2014 (IPC 2013)

Class	Percentage
LW 10	86 %
LW 10,5	90 %
LW 11	94 %
LW 11,5	97 %
LW 12	100 %

Based on the table 2 the final time for LW 10 sit skier would be 21:30 in case the actual time would be 25:00 (25:00 * 0,86).

3.9 Integrated evidence based classification process

Integrated evidence based classification combines medical and functional assessment outcomes with scientific results. It requires extensive field testing and research to define in an unambiguous manner the determining parameters for class allocation, especially in complicated multi-impairment cases as highlighted by Tweedy & Vanlandewijck (2009) with wheelchair racing in chapter 3.7. Integrated classification system is being taken into use across the sports under IPC including swimming, wheelchair racing and sit skiing. (Richter et al. 1992; Tweedy and Vanlandewijck 2009).

Evidence based classification requires process related research work. It is critical for the researchers to use research design that confirms the classification process rather than evaluates the resulting class itself. The process focus takes into account measures for impairment level and activity limitation. Impairments related to co-ordination, ROM and strength need to be evaluated on how much they limit activation on movements relevant to the sport in question. After developing the measures and examining relevant size of group of athletes, it is possible to develop a regression equation for class allocation based on statistical multivariate analysis. The regression equation could then be used as a baseline for an athlete to obtain an impairment score used to define the sport class. This score would take into account the activity limitation and enable to overcome weighting and aggregation challenges described in chapter 3.7. (Backman and Tweedy 2008; Tweedy and Vanlandewijck 2009).

3.9.1 Applying evidence based classification in swimming

Gehlsen & Karpuk (1992) demonstrated that in paraplegic swimming the functional classification used by National Wheelchair Athletic Association (NWAA) is applicable to classes with significant differences in terms of impairment but with classes close to each other, where the conclusion of the final class leaves room for interpretation for the classifier, the differences are not that clear. In paraplegic swimming the Classes V and VI were noted being challenging to differentiate in terms of mean speed measured from 50 and 100 meter swimming events. (Gehlsen and Karpuk 1992).

Limitations identified by Gehlsen & Karpuk (1992) were analyzed further by Richter et al. (1992) to clarify if the NWAA functional classification system on swimming would work as a baseline for competition and how to develop the current system towards more integrated evidence based classification. The functional classification on swimming was based on points allocated on body parts involved on swimming propulsion and defines their role to the end result. For example on breaststroke 55% of the performance would be on leg propulsion and 45% of arm propulsion. Classifiers utilized these parameters on different manner and moved the athletes from a class to another also based on their performance on competitions. This may be enough on recreational sports whereas with elite athletes lead into a situation where the athlete might get disadvantage by taken into higher class just because of training efforts. The results of the study stated that applying only functional criteria is not enough. (Gehlen and Karpuk 1992; Richter et al. 1992).

Wu & Williams (1999) build on Richter et al. (1992) in defining the limitations of functional classification in swimming and challenges of developing it. As international elite

Paralympic Games are only organized once in every four year, it takes four years to validate a classification system modification with large enough number of data points. Several studies were made based on 1992 Barcelona games results and the functional classification system was again revisited. This highlights one major problem on classification research: observations of the classifiers about the games results lead to new classification process development, and consequently several versions of the classification systems have been used since first introduced. This makes comparisons of the results and standings between the games challenging. (Wu and Williams 1999; Richter 1992).

Wu & Williams (1999) criticize the arguments of Richter (1992) questioning the validity of the results in terms of empirical study and ability to influence on classification process development. Wu & Williams (1999) state that the focus should be on performance outcome of individuals instead of the biomechanical analysis of the swimming. Research of the classification methods of disabled sports is in early phase and test set-ups are very much context specific. Research group can therefore find arguments to define the test set either for the performance equity or activity limitation focus. (Wu and Williams 1992; Richter 1992; Vanlandewijck and Thompson 2011).

3.9.2 Impairment measurement challenges

Contradicting results from Wu & Williams (1999) and Richter (1992) on swimming demonstrate the challenges related to collecting and measuring evidence for integrated classification process. Limited number of test subjects and contextuality of the test set-up create challenges to collect reliable information about the role of impairment for the sport: (Wu and Williams 1999; Richter 1992; Tweedy and Vanlandewicjk 2009):

1. **Identifying intentional misrepresentation of abilities**. Some athletes may try to obtain more favorable classification by intentionally misrepresenting their abilities. For this the IPC Classification Code contains severe sanctions up to lifetime ban from Paralympic sports. Developing evidence based methods to identify intentional misinterpretations is important for athletes, coaches, administrators and other stakeholder in Paralympic sports.
2. **Training responsiveness of impairment measures**. Complete training resistance of classification systems cannot be guaranteed even on evidence based classification. It is vital that athletes who have positively influenced their impairment (for example a spinal cord injured athlete by training of the trunk muscles) do not get competitive disadvantage by being classified into less impaired class.

In order to overcome the impact of training the classification process has to include a set of tests that enable classifiers to classify athletes regardless of training impact. Backman & Tweedy (2008) validated a test set used on Paralympic runners for their training impact evaluation. The test set included sport independent tests like standing broad jump, four bounds for distance, 10 meter speed skip, running on a place and split jumps. The study was conducted on able bodied persons to verify the test set before being proposed as input for IPC classification process. As a conclusion the usage of sport independent parameters provide objective insight to the level of impairment without distortion of sport specific training. (Backman and Tweedy 2008).

Results from a study on able bodied showed good reliability and normal performance ranges for each test. The tests emphasizing strength and power (standing broad jump and four bounds) were well in line with the actual performance of disabled athletes. The coordination focused tests like running in place or split jumps showed lower predictive impact. This was hypothesized to be because able bodied athletes had a threshold value of coordination enabling them to run or jump quickly. With disabled persons these tests could have been more determining. As a conclusion the verification of a test set up used in classification is doable with able bodied persons bearing in mind the possible limitations of the test applicability. (Backman and Tweedy 2008).

3.9.3 Integrated classification development based on competition results

Studies and research projects on integrated classification process development have aimed to analyze classification outcomes in games to determine effectiveness of the classification systems. As the research projects have challenges described in the previous chapter the results can be considered to have following limitations in terms of wider applicability (Wu and Williams 1999; Backman and Tweedy 2008):

- Focus only on the functional classification systems and there are multiple of them to follow (e.g. NWAA classification vs. IPC classification on wheelchair racing)
- Limited availability of data on athletes with spinal cord injuries vs other impairments
- Very few participants with very severe disabilities

Regardless of the limitations the studies provide good methodological frameworks on the test set-up development for the evidence based classification. Target of integrated classification is to enable combining the sports classes in competitions. Combination of the classes increases the number of competitors per class. This can be problematic for a single event because it increases the potential for differences between competitors within a class and increases risk of misallocation. (Wu and Williams 1999; Tweedy and Vanlandewijck 2009).

A classification method can be considered as successful in case the medal distribution and advancing in competitions follows the distributions similar to impairment group sizes. Development of the swimming classification process between 1992 and 1996 games seems to be successful against this target. Distortion of cerebral palsy and spinal cord injured athletes being underrepresented in 1992 games (in terms of gold medals won) was fixed when examining the results of 1996 games. Continuous evaluation of the classification process results against elite competition results enable development of integrated classification process. (Wu and Williams 1999; Gehlsen and Karpuk 1992).

4 MUSCLE ACTIVATION IN SIT-SKIING

Sit-skiing is based on double poling skiing technique. Muscles of upper limbs, trunk, abdomens and hip are in key role in force generation. To increase accuracy of allocation of the sport class the biomechanics of sit-skiing need to be understood. Measuring the force generation and EMG in sit-skiing bring factual information about differences of impairment levels to performance of a sit skier. Measurements conducted in laboratory environment limit the impact of external parameters to the study results increasing level of conformance of the results for classification.

4.1 Biomechanical characteristics of sit-skiing and wheelchair racing

Biomechanics on sit-skiing focus on seated double poling exercise where the force is being produced by poling with both arms in parallel and the skier is sitting on a sledge. Sitting position on the sledge can vary. This is from biomechanics point of view closely aligned to able-bodied double poling skiing in terms of upper body muscle activation and joint ROM. Double poling is an economic technique with increasing popularity also amongst the able bodied skiers. (Bjerkefors et al. 2013).

4.1.1 Muscle activation in double poling

Holmberg et al. (2005) and Halonen (2013) define the key muscles in the double poling in activation order to be Rectus Abdominis, Obliques Externus Abdominis, Teres Major, Hip extension muscles, Latissimus Dorsii, Triceps Brachii, Vastus Lateralis, Vastus Medialis, Biceps Femoris and Flexor Carpi Ulnaris. In addition to these muscles also the muscles on legs are being utilized. Muscles have different roles in different phases of double poling in terms of activation level and timing. (Holmberg et al. 2005; Halonen 2013).

Role of the muscular system pre-activation in double poling was demonstrated by Lindinger et al. (2009) on upper body EMG role for double poling. Results were further applied by Halonen (2013) to confirm the EMG size and timing in the double poling. Increased electronic muscle pre-activity is seen as a preparatory action to accumulate the muscle-tendon complex into different kinds of movements. Muscle pre-activity increases the sensitivity of muscle spindels. This can be seen as EMG before the actual activity like movement. Pre-activation of the muscular system is an important factor for the timing of the force generation and for the accuracy of the response for a stimulus. A well pre-activated system increase the capacity for storing elastic energy in the muscle-tendon complex. (Lindinger et al. 2009; Halonen 2013).

Upper body muscle EMG is aligned with produced velocity. Measuring the EMG on the active muscles during double poling force generation provides a framework that can be used to reflect the velocities achievable, when the EMG results are normalized against the maximum EMG the muscle can generate. (Lindinger et al. 2009; Holmberg et al. 2005).

4.1.2 Impact of sitting position to force generation

Hip and trunk muscles play a central role in the sit-skiing biomechanics in force generation and in maintaining balance. Changing the tracks using trunk and hip assistance, trunk power during climbing, trunk stability and control during hill descent, and trunk control in curves are the key events on sit-skiing where the athletes' capabilities or limitations to use these muscles have a determining role for the performance. EMG quantity and timing can define what are the key muscles in balance maintenance and in which order they are recruited to stabilize the body on external stimulus. (Pernot et al. 2011; Shemmell et al. 2010).

Shemmell et al. (2010) demonstrated the role of involuntary stretch reflex to maintain limb stability. Involuntary stretch reflex can be seen as muscle EMG activity in 50-100ms after perturbation. Timing of the latency depends on the muscle measured and type of reflex. Short latency reflex (monosynaptic reflex) occur around 30-50ms whereas long latency reflex (polysynaptic reflex)) timing is around 50-100ms. Fastest voluntary reaction is seen after 90-100ms of the stimulus. Long latency reflex can be modulated by the test subject. Therefore the long latency reflex amplitude can be used also to illustrate how muscle responses are adapting to respond to the perturbation stimulus. (Shemmell et al. 2010).

Sitting position has an impact to the force generation capabilities on sitting sports as was demonstrated by Masset et al. (1992) and Vanlandewick et al. (2011) studies on biomechanical analysis of wheelchair propulsion and impact of sitting position to force generation. Masse et al. (1992) studied the biomechanics by filming the test subject performing wheelchair rolling on constant 60% of maximum velocity with raw EMG being recorded from Biceps Brachii, Triceps Brachii, Pectoralis Major, Deltoid Anterior and Deltoid Posterior muscles. Vanlandewijck et al. (2011) focused on the acceleration in different sitting positions. Used position alter the athlete's pattern of propulsion and consequently affect the performance. One of the key findings of the study was that the upper body muscle EMG had a correlation with the sitting position used. Sitting positions are specific to sport so the results could not be extended as such to sit skiing but the dependency between EMG and sitting position give input to the test set-up for sit skiing. (Masse et al. 1992; Vanlandewijck et al. 2011).

Used equipment impacts to the pushing technique and joint ROM. Key joint ROM is in many sports a determining factor for classification. When the athletes are otherwise equal, those with greater active ROM will be placed in less impaired class. One of the key findings of the Goosey & Campbell (1998) was that the joint ROM had a direct impact to the wheelchair propulsion economy. Sitting position impacts the ROM creating a positive correlation between the position and propulsion economy, especially when the speed is increasing. (Goosey and Campbell 1998, Crespo-Ruiz et al. 2011).

Impact of the ROM in wheelchair basketball and the role in classification was studied by Crespo-Ruiz et al. (2011). The classification process for wheelchair basketball competition utilizes skill based proficiency as illustrated by Brasile (1990) in chapter 3.3.3 and is based on observations of classifiers. Kinematic analysis would act as development input towards evidence based classification. (Vanlandewijck et al. 2011; Crespo-Ruiz et al. 2011; Brasile 1990).

Like Goosey & Campbell (1998), Crespo-Ruiz et al. (2011) studied the key movements of upper limb joints when test subjects performed selected activities such as pushing, pivoting, shooting and passing. Upper limb joint ROM is in key role in wheelchair sports. The results of the study validated the hypothesis that biomechanical analysis is applicable to define sport class specific motion characteristics and supports the classification process. (Crespo-Ruiz et al. 2011; Goosey and Campbell 1998).

Vanlandwijck et al. (2011) focuses on the biomechanical differences between the sitting positions and reason for differences between positions in acceleration. The positions studied are described in figure 5. (Vanlandewijck et al. 2011).

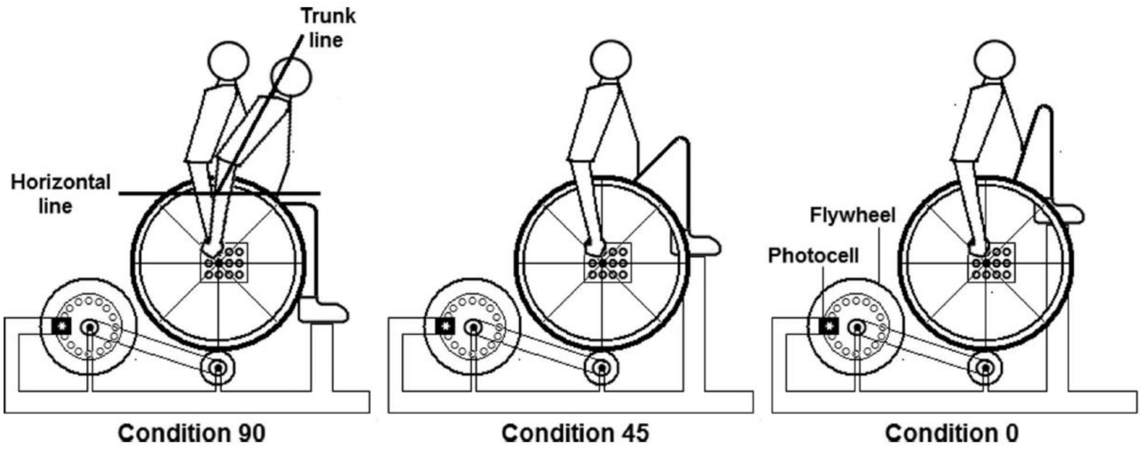


Figure 5. Wheelchair seating positions studied. (Vanlandewijck et al. 2011).

Sitting stability of athletes with spinal cord injuries have limited capabilities to utilize trunk, pelvis and hip muscles. These limitations are addressed either by strapping around pelvis and trunk or by adopting the sitting position. Key reason is the perceived positive impact of these actions to performance. In general the athletes with higher spinal cord injuries and more significant seating stability reduction use relatively deeper seating position – such as Condition 0 on the figure 5 - with more acute angle on the hips. (Vanlandewijck et al. 2011).

Deeper sitting position limits the range of trunk movement due to altering the length of abdominal muscles and placing pelvis into posterior tilt. In wheelchair racing this limits the capabilities to position the shoulder optimally with respect to handrim of the wheelchair. Position of the shoulder joint movement has impact to the hand contacting the rim. Rim contact and shoulder movement is seen by Goosey & Campbell (1998) to be in key position in terms of economy of the wheelchair propulsion. Limitation caused by the deep sitting position to the shoulder movement would decrease also the propulsion economy and performance, which was also a validated hypothesis of the Vanlandewijck et al. (2011) study. (Vanlandwijck et al. 2011; Goosey and Campbell 1998).

In addition to the shoulder angle against the rim, the altering of the sitting position changes the average trunk position and trunk active ROM. From performance point of view Conditions 90 and Conditions 45 (figure 5) were seen as similar. In Condition 0 the performance was lower. The compromised performance in Condition 0 was defined to be due to significantly limited trunk ROM and more upright position for the wheelchair rim propulsion. Trunk ROM was seen to be very important in force generation during the wheelchair first push from standstill state. Rectus Abdominus muscle was highly active in the fast acceleration phase driving the force generation. The main reason for adoption of the deep sitting position (and for using straps to limit the trunk ROM) was impaired trunk function (Vanlandewijck et al. 2011).

Wheelchair racing propulsion efficiency depends on the experience level of the test subject. Therefore the results from wheelchair studies done on able-bodied subjects need to be put in context where the experience on wheelchairs is limited compared to athletes that are using the wheelchair on their daily life. Lenton et al. (2008) compared experienced and non-experienced wheelchair users and concluded that the main contributor to the efficiency is on co-ordination capabilities and more effective transfer of force between the hand and the rim. Effect of continuous practice leads to development of more optimal coordination and hence improved propulsion technique. (Lenton et al. 2008).

4.2 Usage of ergometers to simulate skiing

Ergometers are being used in sport science to stabilize the research environment and to produce valid data for example on biomechanical characteristics of the event in question. Wheelchair sport events such as track and field, basketball and rugby, have been studied more extensively than winter sports. (Thompson and Vanlandewijck 2011).

Correlation between tests conducted in laboratory against the tests done on field in Nordic skiing, wheelchair racing, wheelchair tennis and wheelchair basketball were investigated by Bernardi et al. (2011). Comparison between wheelchair basketball players to wheelchair track and field athletes were in the focus of Coutts (1990) study. Bernardi et al. (2011) found dependencies between aerobic performance measures like maximum heart rate and VO_{2max} between field and laboratory tests. Amongst the sports investigated the Nordic skiers and track & field wheelchair racers had the largest aerobic capacity both in laboratory and in field conditions. Coutts (1990) investigated the biomechanical correlations between environments on wheelchair propulsion on maximum velocity and acceleration. Results between laboratory and field conditions were aligned. Physical wheelchair hand rim diameter was identified as key sport specific differentiator for velocity and acceleration. (Bernardi et al. 2011: Coutts 1990).

In cyclic sports such as Nordic skiing the skiing velocity is derived from the distance the body travels during each of complete cycle of movement and the rate or the number of times the body moves through a complete cycle in 1 second. These parameters can be tracked on field by recording the skiing and also in laboratory using ski ergometers. Ski ergometers are based on similar flywheel and rope mechanism as rowing ergometers. Halonen (2013) and Forbes et al. (2010) validated the ski ergometer test applicability to simulate Nordic skiing. Halonen (2013) demonstrated that the ergometer is aligned well with skiing on snow in terms of absolute and relational power output whereas Forbes et al. (2010) validated the positive correlation in terms of cardiorespiratory response. Forbes et al. (2010) concluded that double poling results in ski ergometer were aligned with field conditions on elite Nordic sit-skiers. However in the ergometer test the subjects recorded significantly higher heart rate and lactate values. A possible reason for this was more constant nature of muscle activation on ergometer compared to field conditions, which is also one of the proposed reasons found by Halonen (2013) for the power output differences. (Forbes et al. 2010; Halonen 2013).

The test set-up of Forbes et al. (2010) in the study included usage of a modified double poling ergometer with wheelchair as illustrated in figure 6.

Figure 6. Modified double poling ergometer (Forbes et al. 2010)

Positive connection between the double poling ergometer and field test results verified that the ergometer can be applied with seated athletes. The major limitation in the study was the small sample size due to uniqueness of the population. This means an increase in likelihood to find differences between variables when in fact there is no difference or to find differences on test conditions when in fact there is no difference. (Forbes et al. 2010).

5 PURPOSE OF THE STUDY

Purpose of this study was to define if a custom made sit-ski ergometer would provide to be a suitable test set-up for bringing information on force generation and muscle electronic activation (EMG) on double poling and on balance maintenance activities. Furthermore the differences between four main sitting positions are to be analyzed. As both sit skiing and wheelchair racing are cyclic sports, the findings from Masse et al. (1992) and Vanlandewijck (2011) about role of sitting position impact to force generation are applicable to the sit-skiing. The findings were introduced in chapter 4.1.2. (Masse et al. 1992; Vanlandewijck 2011).

Information on force generation and EMG should be proven to be an accurate enough framework so that the test set-up could be applied to the development of classification process of the sit-skiers. Therefore the study aims to provide insights to complement the IPC functional and technical assessment methods described in the chapter 3.5.2. Capabilities to operate trunk and hip muscles are considered to be in determining position for class allocation. (Pernot et al. 2011).

5.1 Identify the differences between sitting positions

Hypothesis is that there are differences between sitting positions in sit-skiing and that those differences can be identified in a laboratory environment via EMG. The focus of the study was on verification of the test set-up and the tests were done with able bodied skiers to homogenize the set-up. The test set-up verification process is aligned with the results from

Backman & Tweedy (1998) where test set-up was verified on able bodied subjects to be accurate with results' limited applicability in wider context. (Backman and Tweedy 1998).

Positive connection between laboratory and field condition tests found by Bernardi et al. (2011) and Coutts (1990) enable operating the test protocol in a laboratory environment. The test protocol was defined to measure following parameters on a custom made sit-ski ergometer in different sitting positions: maximum velocity and force generation on double poling, EMG, acceleration and joint movement angles (radius). (Bernardi et al. 2011; Coutts 1990).

5.2 Identify key muscles active in force generation and balance maintenance

Applicability of the sit-ski ergometer to simulate the double pole skiing process in laboratory conditions has been confirmed by Halonen (2013) showing that EMG and force output on double pole skiing on ski ergometer is well aligned with skiing on real snow. Muscle activation order was the same, however there were differences identified in the force generation and EMG amplitude. It can be expected that the similar test set-up would also be applicable into sit-skiing when upper body movement is comparable to the regular double poling. Forbes et al. (2010) test setup on wheelchair was chosen as another adaptation reference where ergometers and seated equipment were used in one test set-up. (Halonen 2013; Forbes et al. 2010).

Maintaining the balance during skiing is very important for the sit skiers. Depending on the level of impairment and the sitting position, the muscles used for balancing the posture are different and they operate on different activation levels. Balance test was conducted using a perturbation platform built from a motor and a force plate and the sit-ski seat attached on top of it. This part of the test set-up was defined to illustrate muscle activation during skiing on field conditions, for example in curves and downhill. As described by Holmberg et al. (2005) and Lindinger et al. (2009), EMG can be used to identify key muscles activated for the balance maintenance and what is their activation timing during the action. According to Shemmell et al (2010) the latency of the EMG can be used to define reflex responses to the balance maintenance for further muscle and joint stiffness analysis. (Holmberg et al. 2005; Lindinger et al. 2009; Shemmell et al 2010).

Hip, elbow, wrist and shoulder joints have different ROM on perturbation tests in different sitting positions. Different sitting positions and different range of movements change the kinematics of the activity as was confirmed by Goosey & Campbell (1998). Comparing the ROM against the EMG between the positions can give indication on muscle activation to maintain position during the skiing for example on curves. Data on ROM was recorded during this test set-up but the analysis is excluded from the scope of this study. Therefore the detailed results are not presented in this thesis. The ROM test is discussed only as a contextual element. (Goosey and Campbell 1998).

Force generation on sit-ski ergometer combined with ROM analysis follows the recommendations presented by Tweedy et al. (2010) for MMT as it takes into account ROM parameters from D&W muscle strength assessment method. Modifications proposed by Tweedy et al. in chapter 3.3.1 have been taken into account in the test protocol definition. The test set-up is defined to focus on the main muscles and joints defining the impact of th impairment so that the results could be utilized further in classification process development. (Tweedy et al. 2010, Pernot et al. 2011).

6 METHODS

6.1 Test subjects and preparations for the test

The test protocol was executed in Vuokatti, Finland 7th – 10th of October 2013. The ski ergometer test set-up was build indoors into Vuokatti Snowpolis test station gym. In total 9 volunteered test persons were selected amongst the students of Sotkamo Sport High School via email request. The focus group was the students specialized into Nordic skiing and actively competing on international or national level. Each of the participants was explained the test procedure and possible risks involved into the test. Test subjects filled in a written consent that they are physically fit to perform the test in the given time. The test persons were instructed not to drink alcohol or coffee before the test and to avoid smoking. Characteristics of the participants are defined in table 3.

Table 3. Test subject height, weight and age.

subj #	Height (cm)	Weight (cm)	age (y)
1	176	72	23
2	175	65,2	19
3	184	76,3	19
4	173	69,1	18
5	175	60,9	18
6	184	71,9	18
7	178	69,7	19
8	177	73,9	18
9	179	72	25
Average	**177,9**	**70,1**	**19,7**

Test subjects had experience on skiing and use of double poling ergometer. This is expected to increase the level of conformance of the results on double poling. However the test subjects did not have previous experience about sit skis, which needs to be taken into account on result. On wheelchair racing the lack of experience was defined to be a main differentiator on results between able bodied and disabled athletes. Vandlandewijck et al. (2001) introduced multiple studies highlighting similar differences in terms of efficiency, kinematics and force generation. Lenton et al. (2008) also concluded upon the importance of experience. The level of test subjects' skill on the test set up is an important contextual matter for a test. (Vanlandewijck et al. 2001; Lenton et al. 2008).

Information on table 3 clarifies that the selected test persons form a homogeneous group of young males with average age of 19.7 years. This supports the purpose of the study of verified the test setup as it eliminates the question of too diverse group of test persons that might lead into speculations of accuracy of the results. The sample size of 9 is relatively small and has to be taken into consideration when defining wider scale applicability of the results. Measurement information recording and data collection was done in anonymity with respect to the test subjects' privacy. Data was stored to the research group members' personal computers that were password protected.

6.2 Test equipment and environment

Test set-up for sit skiing was built on Concept 2 SkiErgo ski ergometer (Concept2 Inc, Morrisville, Vermont, USA) with a custom made seat that was fixed on a force platform. Seat was designed to align with the sledges used by sit skiers. The seat is adjustable so that the test subject could perform the test in four different positions. Usage of the ergometer for the double poling simulation was aligned with the test set up of Forbes et al. (2010) study on the differences between laboratory and field conditions on sit skiers cardiorespiratory responses. Figure 7 below presents the ergometer test platform. One can identify similarities with Forbes et al. (2010) test set up by comparing with figure 6 from chapter 4.2. Utilization of the force plate in the test set-up was applied from Pernot et al. (2011) validation study on the test-table-test. (Forbes et al. 2010; Pernot et al. 1998).

Figure 7. Sit-ski ergometer and perturbation platform

6.2.1 Custom made sit ski seat and ergometer

The sit-ski seat used was custom made by Jyväskylä University. The seat was placed in front of the ski ergometer (called as SkiErgo in this thesis from now on). Test subject was to pull down the SkiErgo ropes to simulate the double poling trajectory on sit-skiing. SkiErgo was fixed on wall. The poling resistance could be adjusted as air resistance on scale 1 to 10 where 1 is the lowest resistance. Force transducers (Jyväskylä University, Finland) were attached to the ropes of the SkiErgo. For this study the resistance was set to 7.5 for all of the test persons and positions used.

Building of a custom made seat instead of using a real sit-ski seat was chosen for two reasons:

a) Able-bodied skiers do not benefit from using an own seat
b) The real seats are tailored for the sit skiers, no standardized seats available.

This approach differs from the Goosey & Campbell (1998) recommendation to utilize test subjects' own seats. With able bodied subjects this was considered not to bias the results. The test-set up enables changing the seat to another one for example if the equipment would be applied for disabled athletes.

The force plate and the seat were mounted on a perturbation platform that could be moved into one dimension by an electronic motor. Rapid movement of the seat illustrates perturbation and furthermore provides information about the activation of muscles in situations where the balance is being altered by an external stimulus. The test set-up with a test person is illustrated in figure 8.

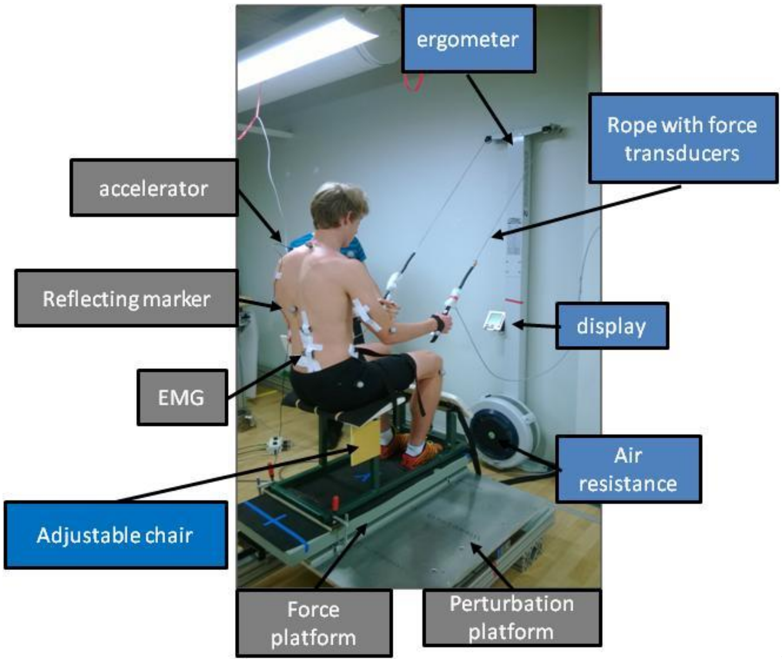


Figure 8. Test set-up overview with a test person

Before engaging to the test protocol eight (8) bipolar electrodes were attached on test subject's skin to record EMG, as illustrated in Figure 8. In addition of the EMG electrodes an accelerator sensor (Vernier Low-g Accelerometer, Vernier Software and Technologies, Oregon, USA) was attached to the shoulder of the test subject. The accelerator sensor recorded information about the body trunk movement during the tests. Accelerator signal time alignment with perturbation signal and EMG signals provides information about muscle activation timing when the body was moved. In addition to EMG electrodes also reflective markers were placed on the test subject for joint ROM. The ROM data analysis was excluded from the scope of this study.

6.2.2 Four different positions on sit skiing

Depending on the level of impairment or personal preferences, there are four main positions being used by sit skiers. Positions as part of the test set-up are illustrated below in figure 9.

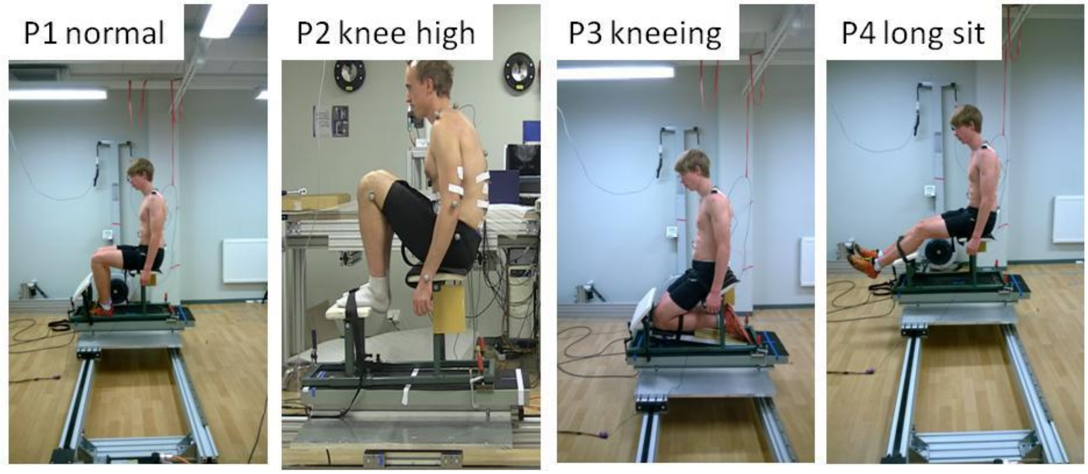


Figure 9. Sitting positions used in the study.

Force generation, balance and motion tests were performed in all four positions in random order to exclude the impact of the order of the positions used in the protocol to the results.

6.3 Test protocol

The test protocol consisted of three main phases.

1. Recording of maximum EMG that the test subject could produce on a force chair and on floor (MVC, maximum voluntary contraction). This was done to obtain reference for normalized EMG in main study phases.
2. Measuring the velocity and EMG on double poling with the SkiErgo to clarify differences between the sitting positions
3. Balance tests on perturbation platform to understand role of the trunk and hip muscles in balance maintenance

Each of the test subjects went through the following tests in the phases 2 and 3 in each of the four positions:

- Maximum velocity, try 1
- Maximum velocity, try 2 (only in the first position)
- Constant velocity (75% of max)
- Perturbation 1: Anterior - Posterior (6 times in both directions)
- Perturbation 2: Medial - Lateral (6 times in both directions)

6.3.1 EMG measurement preparation

Muscle electric activity as EMG was measured from following muscles**.** The selection of the muscles to analyze was adopted from the reference studies on wheelchair propulsion and on double poling conducted by Masse et al. (1992), Lindinger et al. (2009) and Holmberg et al. (2005):

- **Abdominal muscles**: Rectus Abdominus (RECab), External Abdominal Obliques (OBL)
- **Back muscles**: Erector Spinae (high) (ESH), Erector Spinae (low) (ESL)
- **Hip flexor muscles**: Rectus Femoris (RECf)
- **Hip extensor muscles**: Gluteus Maximus (GLU), Biceps Femoris (BICf)
- **Arm muscles**: Triceps Brachii (Long head) (TRI)

Abbreviations in capital letters (e.g. ESL) will be used in the text onwards. The placement of the electrodes is illustrated in figure 10.

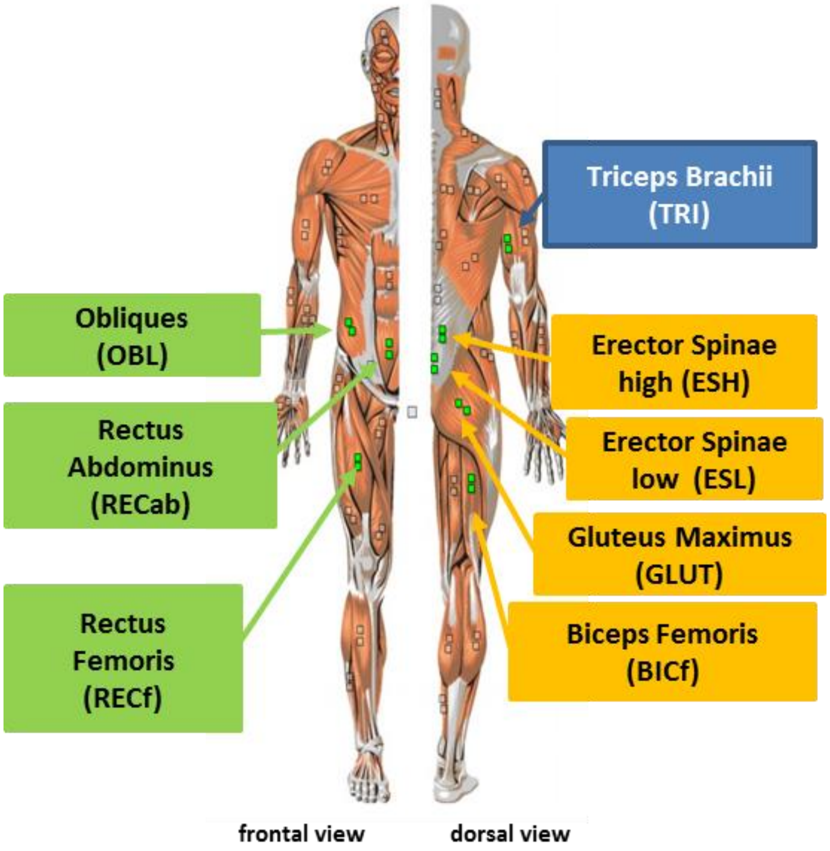


Figure 10. Placement of bi-polar electrodes in the muscles

EMG activity was recorded using bi-polar surface-electrode. One bi-polar electrode was attached to each of the muscles where the EMG activity was recorded. The distance between the electrode ends was 2 cm. Placing the electrodes on the muscles was done according to SENIAM instructions. First the skin hairs were removed from skin using a disposable razor. Then the skin was rubbed using fine sandpaper to make it more electricity conducting. Skin was disinfected with Neo Amisept fluid. Electrodes remained on the places attached throughout the test protocol and their placement was secured by taping the electrodes, wires and transmitter unit on to the skin.

Each of the bipolar electrodes was connected to Noraxon TeleMyo 2400R transceiver (Noraxon Inc, Scottsdale, Arizona, USA). Transceivers had wireless connection to TeleMyo DTS belt receiver. Each of the transceivers had own channel configured into the receiver. Test subjects performed the tests in short or long running thighs without shirt or shoes. In total performing the test protocol took two hours per subject and it was done on individual basis.

6.3.2 Phase 1: Maximum EMG

The maximum EMG was recorded as a reference point for the EMG produced in the actual tests. Normalized EMG gives better contextual information about the muscle electric activity than the absolute values. For the EMG recording the Telemyo DTS belt receiver was connected to TeleMyo 2400R G2 data consolidator (Noraxon Inc, Scottsdale, Arizona, USA) using a WiFi connection. From the G2 data consolidator the raw EMG signal was transferred to CED 1401 AD analog to digital converter (CED, Cambridge, UK) and then to PC to be visualized and recorded using Spike 2 software (CED, Cambridge, UK). The base level in Spike 2 was set to 0 when no muscle activation was perceived.

Maximum EMG for RECf, BICf, TRI, RECab and OBL were recorded using a force measurement seat (Jyväskylä University, Finland). Maximum EMG was recorded as a static force production as maximum voluntary contraction (MVC). Test subject was fixed to the force measurement seat using straps and instructed to produce the maximum force against the resistance when commanded. For each of the muscles the procedure was done twice on the seat. The force measurement seat is presented in figure 11.

Figure 11. Force measurement seat used for MVC EMG.

Maximum EMG for GLU, ESH and ESL were recorded the test subject laying on the floor on his chest. Test assistant was holding either the leg or the back of the test subject. On command he performed a maximum force production against the resistance provided by the assistant. On the tests conducted in the seat the force produced was recorded from the sensors on the leg extension and arm extension pads in the chair.

6.3.3 Phase 2: Maximum velocity and force generation on SkiErgo

In each of the four sitting positions (see figure 9) the test subject executed first a maximum double poling velocity test. The test subject was instructed to pull down the SkiErgo ropes as fast as possible to achieve maximum velocity (minutes / 500 meters). Test instructor followed the velocity development from the SkiErgo display and when velocity stagnated and there was no acceleration, he called the test subject to stop. In the first of the positions tested the test subject performed the maximum velocity test twice. This part of the double poling test provided information about differences of positions in context of maximum velocity to be achieved.

In order to make comparisons between sitting positions in terms of ROM and EMG it is important to record data on constant speed for a limited number of poling cycles. Based on the maximum velocity the test instructors calculated 75% velocity using Microsoft Excel 2003 PC software (Microsoft Corporation, Redmond, Washington, USA). The test subject then performed 15-20 pulls of SkiErgo on this constant 75% of maximum velocity.

Vicon Nexus 1.7.1 Software Suite (Vicon Motion Systems Ltd, Oxford, UK) was used to capture the Pole forces ($\text{Pole}_{\text{left}}$, $\text{Pole}_{\text{right}}$) from the force transducers mounted into the SkiErgo handles. Force transducer analog signals were converted into digital format using CED 1401 AD signal translator.

The EMG signals were captured in the Vicon software connected to TeleMyo 2400R G2 data consolidator. This enabled the research group’s all key data to be recorded using a single computer set-up. In Vicon the sensor delay was set to 312 ms, sensitivity into 1000 ms/kg and gain value to 10V.

6.3.4 Phase 3: Balance tests on perturbation platform

To analyse muscles active on balance maintenance the test platform was moved from a starting position either forward or backward using an electro-mechanical computer controlled motor. This is referred further as a perturbation platform. The platform was custom assembled by Jyväskylä University Vuotech unit. The motor used was Bosch Rexroth 3-phase synchronous pm-motor type MSK060C-0300-NN-M1-UG1_NNNN. (Bosch Rexroth AG, Germany). It was controlled by a power steering unit: Indradrive HCS typ: HCS2.1E-W0012 (Bosch Rexroth AG, Germany). The perturbation platform is presented in figure 7 as part of the overall test set-up.

Power steering unit of the motor was connected to PC where the power signal initiating stimulus was given by Indraworks 12V06 software. (Bosch Rexroth AG, Germany). User interface for Indraworks to give the backward and forward stimulus was custom made by Jyväskylä University Vuotech unit on LabVIEW software environment (National Instruments, Austin, Texas, USA). User interface was controlled from the same PC that recorded the data to Vicon. When the movement was triggered from the LabVIEW software, the platform moved on speed of 50 cm/s either forward or backward with acceleration of 50cm/s^2. Amplitude of the movement (length) was not constant but dependent on how long the trigger signal was kept on. The balance tests were conducted in both anterior-posterior and medial-lateral directions. The test set-up with a test subject prepared for anterior-posterior balance test is illustrated on figure 12.

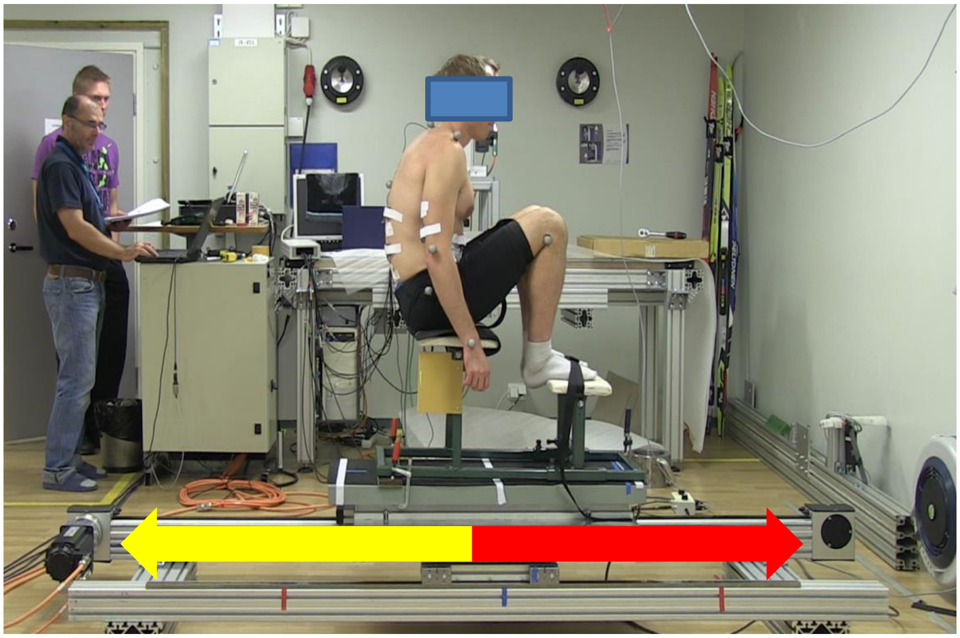


Figure 12. Test subject prepared for anterior-posterior dimensional perturbation test.

Forward/backward and left/right movements were elicited in a randomized way so that the perturbation stimulus was not predictable. Time between the movements was changed and also the length of the movement. Subject could not anticipate the distance of the stimulus or the direction of it. Task of the subject was to keep the sitting position as stable as possible yet not to stress the muscles continuously. The test subject was told to receive in total 12 stimuluses' per position. In anterior-posterior dimension this would mean six movements forward and six backward in a randomized order. Balance tests were conducted in all four positions so in total a test subject received 4 * (12 + 12) stimuluses'. EMG was recorded in all of the positions. The data analysis focuses on the anterior-posterior dimension only.

6.4 Data collection and analysis

Data processing was conducted during November 2013 – January 2014 in Vuokatti using PCs equipped with Vicon Nexus 1.7.1 software and Noraxon MR-XP Master 1.08 software (Noraxon Inc, Scottsdale, Arizona, USA). Data processing included multiple phases where the information was exported and imported between the processing softwares'. Role of the Vicon software was to act as a central data collection point whereas Noraxon was the primary analysis tool. Selective parts of all of the data recorded are discussed in the scope of this master's thesis.

6.4.1 SkiErgo and perturbation platform test EMG analysis

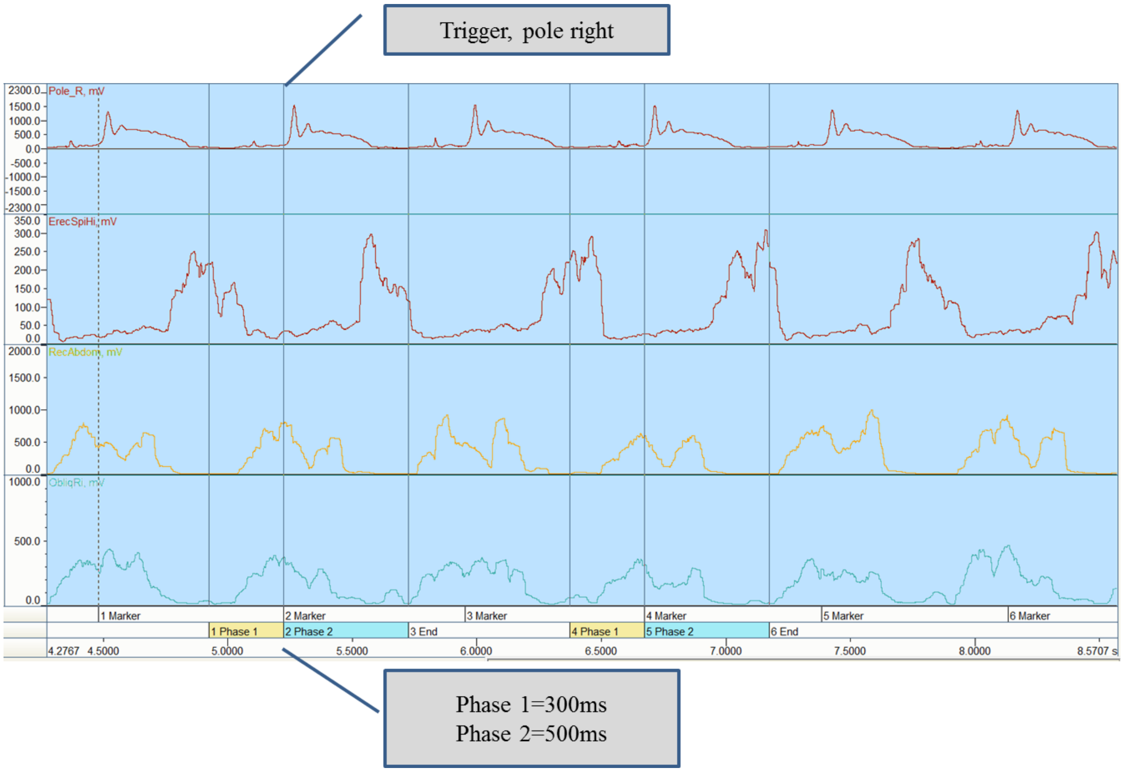
The recorded data in Phase 2 and Phase 3 described in chapter 6.3 was outputted from the Vicon software in .c3d format to Noraxon to analyse the EMG and force signals in terms of peak value, mean value, area value and timing against the trigger time. Trigger time represents the start of the data analysis time window. Pole force signal was used as trigger in SkiErgo test and electronic motor stimulus was used in perturbation platform test.

A personal record folder was created for each test subject in Noraxon and the relevant .c3d files were imported into it. Maximum speed and perturbation platform test data analysis on anterior-posterior dimension (backward/forward) collected information on each position on:

- Acceleration (based on the accelerometer signal)
- Pole forces (POLE _L and POLE_R)
- EMG (mVs) per each of the muscle with bipolar electrode.

On SkiErgo test the EMG recording was conducted in two phases on Noraxon: Phase 1 represents 300ms window before the actual pulling of the ergometer rope starts. This phase defines the muscle pre-activation EMG quantity and timing. Lindinger et al. (2009) demonstrated the importance of pre-activation EMG for the stretch-shortening cycle in double poling skiing. This provided the baseline for analyzing the EMG in two phases. (Lindinger et al. 2009).

Right pole force channel ($\text{Pole}_{\text{right}}$) was selected to be the trigger and starting point of the Phase 2 in the SkiErgo test, which was set as 500ms from the start of the pulling to define the muscles active in the actual pulling of the ropes. Figure 13 presents the Noraxon screenshot with the phases 1 and 2 represented over time.


Trigger, pole right

Phase 1=300ms
Phase 2=500ms

Figure 13. Data windows: Phase 1 and Phase 2 in Noraxon

Figure 14 presents the Noraxon analysis of a data gathered during a perturbation test in one position. In the balance tests the movement was done in a random order so in Noraxon analysis the directions backwards and forwards had to be separated. This can be seen as separate FRW (forward) and BWD (backward) analysis results on the figure 14 following trigger signal on channel #8. The trigger signal is based on the electronic motor movement.

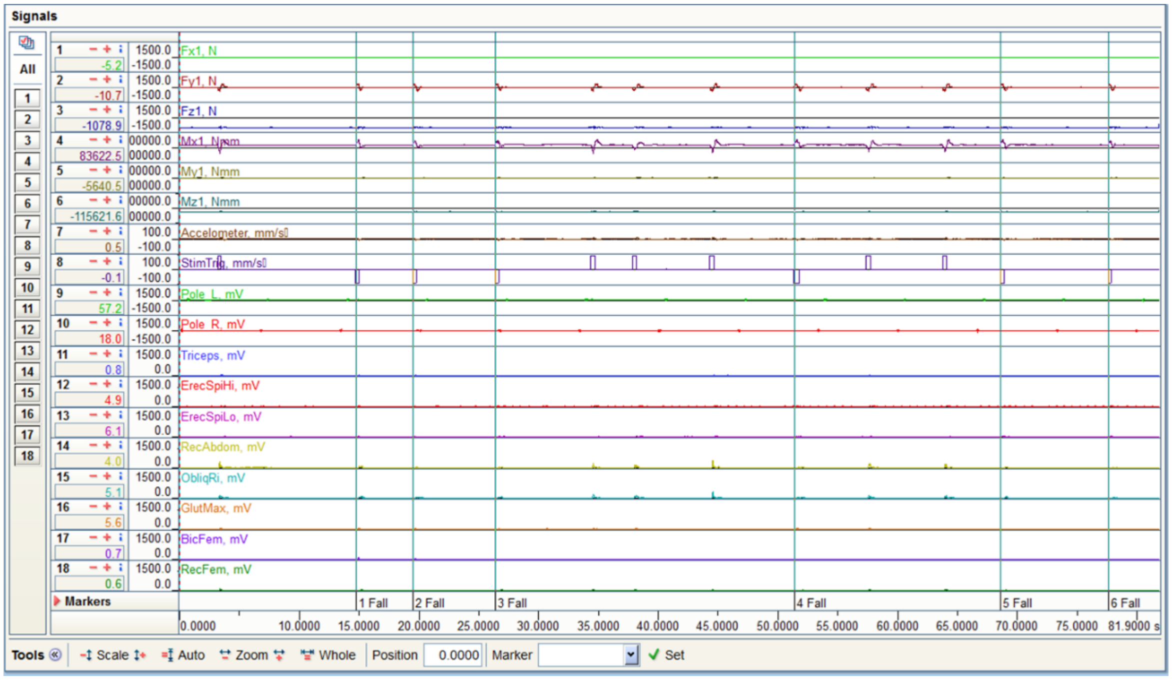


Figure 14. 18 channels recorded during a perturbation test

Each analysis record contains the EMG data of all the muscles having the electrodes attached. In the balance tests focus was on the trunk muscles' EMG, aligned with the findings of Vanlandewijck et al. (2011) about the role of trunk and abdominal muscle EMG. (Vanlandewijck et al. 2011).

6.4.2 **Analysis of the maximum EMG**

Analysis of the maximum EMG on MVC as described on chapter 6.3.2 was done using the same Noraxon software as with the SkiErgo and perturbation platform tests. The Spike2 records were first multiplied by 1000 in Microsoft Excel. Spike recorded the EMG values as µVs whereas Vicon used mVs. The modified records were saved in .txt format and imported into the Noraxon. Max EMG was defined as mean value from the two MVC performances. The maximum EMG was visualised as below in the figure 15.

All of the EMG data were processed on Noraxon software. The raw EMG signal bias was removed by zeroing the mean. Then the signal was full-wave rectified and filtered to obtain linear EMG data.

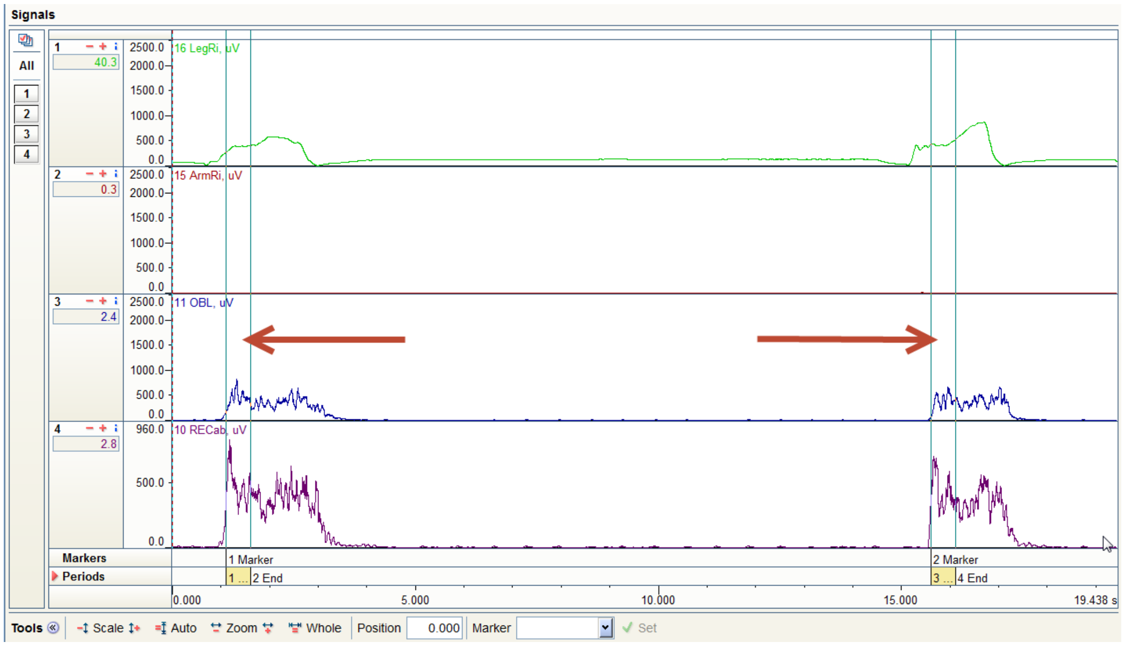


Figure 15. Maximum EMG values in Noraxon, recorded from abdominal muscles and filtered. (OBL and RECab)

In the data analysis the markers were set to analyze mean, peak and area values of the EMG for 500 ms after the marker (Phase 2). These areas are highlighted with red arrows on figure 15. Table 5 illustrates the EMG data collected in SkiErgo test analysed in Noraxon.

Table 5. Extraction of the maximum EMG analysis

Subject	Muscle	Parameter	Muscle (µV)	Leg (µV)	Arm (µV)
SE	RECTF	Mean, uV	278	1593	99,4
SE	RECTF	Peak, uV	322	1696	114
SE	RECTF	Area, uV*s	139	796	49,7
SE	GLU	Mean, uV	143		
SE	GLU	Peak, uV	182		
SE	GLU	Area, uV*s	71,7		
SE	OBL	Mean, uV	379	183	0,514
SE	OBL	Peak, uV	620	198	0,624
SE	OBL	Area, uV*s	190	91,5	0,257
SE	RECAB	Mean, uV	879	183	0,514
SE	RECAB	Peak, uV	1292	198	0,624
SE	RECAB	Area, uV*s	439	91,5	0,257

“Muscle” column in the table presents the muscle where the EMG value is recorded. Muscle values represent the EMG of the muscle in question (peak, mean and area). Leg and Arm columns provide information on the amount of force the test subject produced against the leg extension and arm extension pads on the chair. For GLU, ESL and ESH these values were empty since the test subject was not in the chair when muscle activation was recorded but the tests were done on the floor.

6.4.3 EMG activation timing: reflex or reaction

On perturbation platform the timing of the EMG was analyzed against the motor trigger signal in order to illustrate when then muscles activate against the platform movement. Different muscles have different activation latencies on the stimulus. Figure 16 is a snapshot illustrating the differences between timings of muscle activation. Latency measurement was divided into two phases separated by a red line. Red line represents the trigger signal that is visible in the channel “StimTrig”.

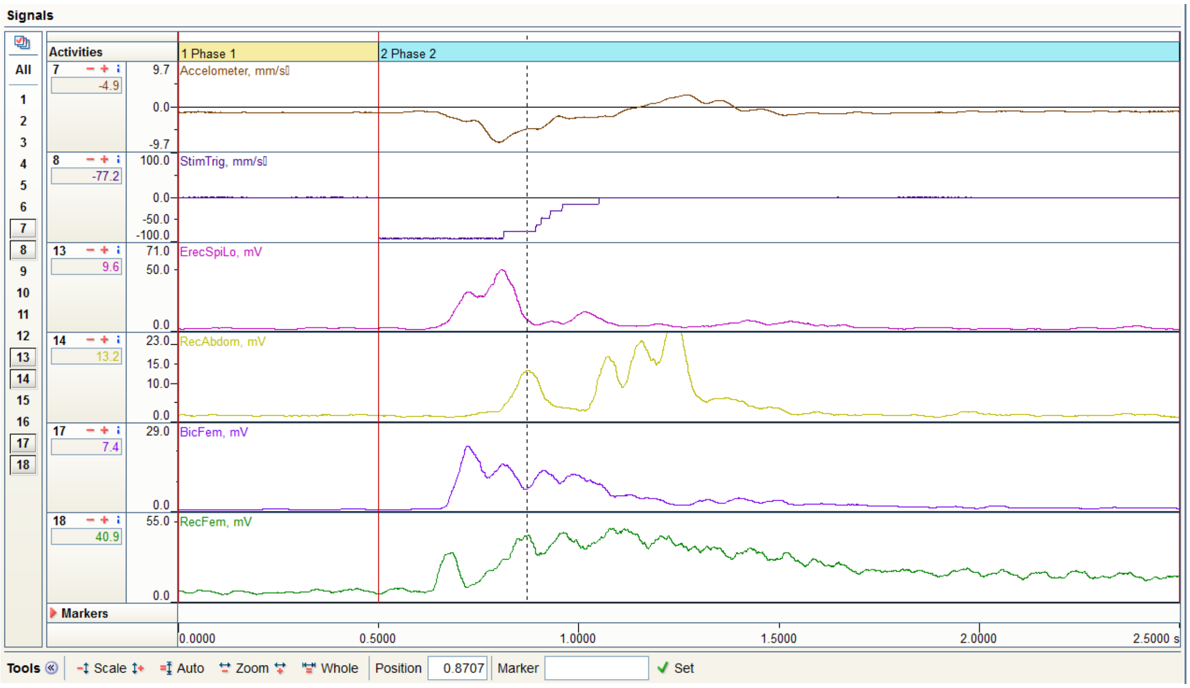


Figure 16. EMG activation timing on Noraxon: Phase 1= preactivation, Phase 2= activation after perturbation, Channel 7= accelerometer, Channel 8= perturbation stimulus

Actual movement of the trunk is presented in Channel 7 “Accelerometer”. It is measured from the accelerometer taped on the shoulder of the test subject. Accelerometer has own latency against the trigger stimulus that was not calculated. The start time accelerometer against the trigger stimulus was analyzed separately for all of the data records as the time interval between the movements was not constant. In figure 16 the latency of accelerometer is around 200ms. Once the supervisor releases the motor on/off switch, the stimulus trigger returns to the origin, which is visible as stair-shape curve of the Channel 8 “StimTrig” signal.

EMG activation latency was measured against the stimulus trigger and calculated from the first peak value. In order for the first activation to be categorized as a reflex rather than a reaction, the latency should be less that 200 ms so that it could be defined as a polysynaptic long latency reflex as described in chapter 4.1.2. From the beginning of the Phase 2 it can be seen that the RECf (the lowest channel) had first a small activation EMG peak that is perceived to be a reflex to the stimulus. The highest peak EMG comes later as the test subject’s voluntary reaction to maintain balance against the sudden movement.

6.5 Statistical analysis on SPSS

The Noraxon analysis records were collected on Excel files like presented on table 5. All the records were checked for statistical correlations in order to identify differences between sitting positions in terms of speed, EMG and force generation. Due to the small group of test subjects, only descriptive analyses has been made. The statistical correlations were analysed using SPSS 20.0 pc software (SPSS Inc, Chicago, Illinois, USA). The .xls files from Noraxon were imported into SPSS software. Statistical significance value was set as $P < 0.05$. One way Anova test was applied to confirm the identified differences or commonalities between sitting positions and muscle EMGs.

Following files were analysed in SPSS for this thesis:

1. Maximum speed produced per position on SkiErgo
2. Muscle EMG on SkiErgo test
3. Muscle EMG on perturbation test on anterior/posterior dimension

One way Anova test with Bonferroni post hoc test was used to identify if there are statistically significant differences between sitting positions. This would enable concluding that one position or a muscle has significantly different role in the test in question. One way Anova was applied to both SkiErgo and perturbation platform tests. On the one way Anova the statistical significance value (sig) needs to be less than 0, 05 ($p<0, 05$) in order for the difference to be statistically significant.

Linear model and Pairwise comparison tests in the SPSS were applied to confirm the role of selected muscles in SkiErgo and perturbation platform tests. In these tests the EMG of the muscle in question was compared across any other muscle in all positions to confirm the role of it.

Independent samples t-test was used in perturbation platform test to compare if the values on anterior-posterior movement differ on direction (backward vs forward). Independent samples t-test was selected for this case as movement between directions do not share interdependencies. On the independent t-test the significance value (sig) needs again to be less than 0.05 ($p < 0.05$) for statistically verified conclusions.

.

7 RESULTS

7.1 Data analyzed

Analyzed data included performances of nine test subjects in SkiErgo and perturbation platform tests. Results were clarified from the analyzed data to define if there are differences between sitting positions in terms of:

- Maximum speed (m/s) that the test subject can produce in each position
- Maximum forward taking force component per position from pole forces
- Mean EMG in double poling
- Mean EMG in perturbation platform test
- Role of muscle activation timing –latency- in the perturbation platform test
- EMG activity level between SkiErgo and perturbation platform tests

Results are represented as SPSS bar charts where the bars represent measured variable like EMG, speed or time. The results are categorized according to sitting position. Error bars on the graphs represent the standard deviation of the results, i.e. the range between the smallest and largest record. On EMG the Phase 2 represents first 500ms from the start and Phase 1 preactivation, as described in figure 16. EMG values in all of the results are represented as normalized to MVC (MVC_N), i.e. as percentage of maximum EMG. Normalization of the EMG against the maximum EMG make the results comparable in sit-skiing in terms of whether the same results would be shown on field conditions. According to Halonen (2013) the EMG results on double poling are lower on EMG compared to skiing on snow, but normalization against MVC eliminates this difference. (Halonen 2013).

TRI is the muscle which represents high EMG quantity for forward propulsion in Nordic skiing double poling as identified by Holmberg et al. (2005) and Halonen (2013). Same dominant role of TRI applies also to sit-ski double poling. In selected results the focus therefore put to trunk and hip muscles as operational capabilities of these muscles are seen to be in pivotal positions for sport classes LW 10.5 and LW 11.5 (see table 1) allocations. (Pernot et al. 2011; IPC 2013; Holmberg et al. 2005, Halonen 2013).

7.2 Speed, muscle activation and force generation in Ski Ergo test

Figure 17 presents the mean value of maximal speed the test subjects were able to achiebe in each of the positions. Figure 17 indicates that a sit-skier is able to ski fastest either on P1 or in P3. Achievable maximum speed remained slowest on P2 where the skier is sitting knees high. The standard deviation represented as error bars on the figure 17 is low increasing the confidence level of the test results.

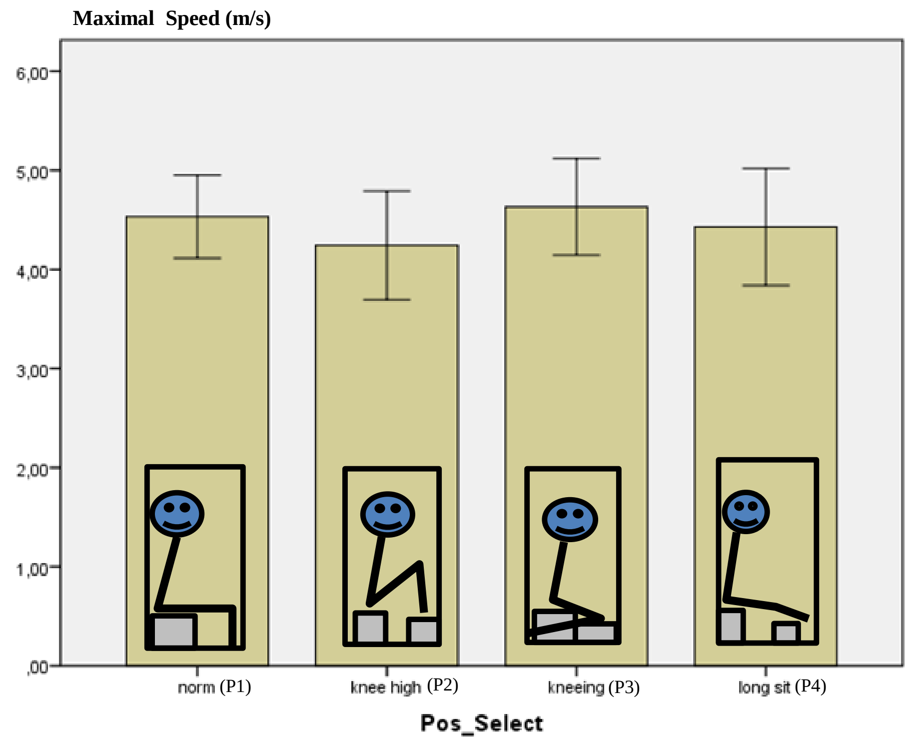
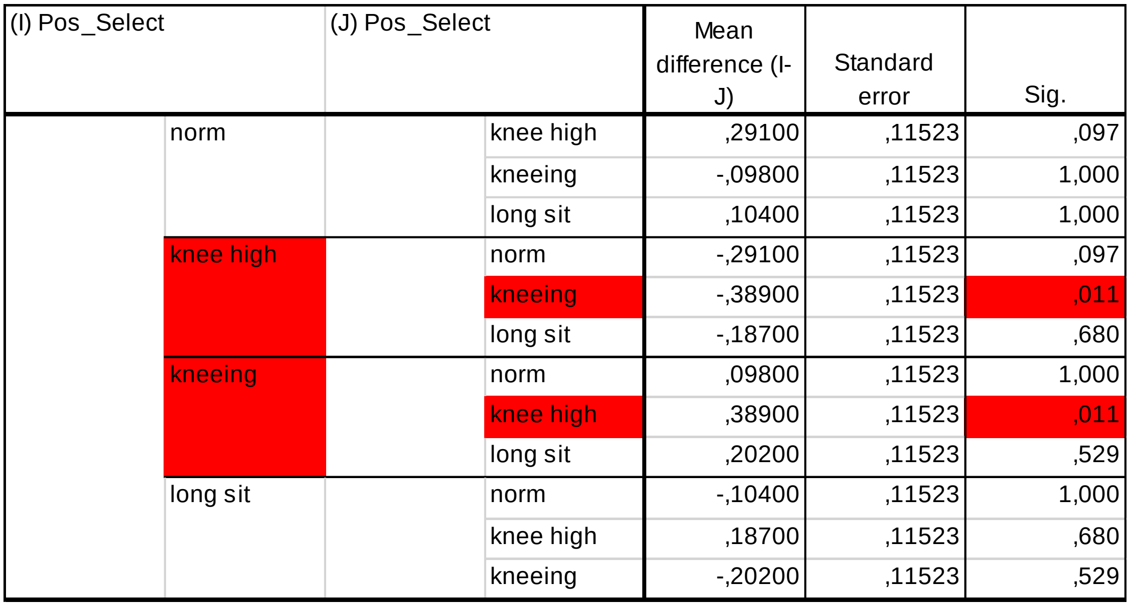


Figure 17. Maximal speed per sitting position

Table 6 presents the one way Anova test with Bonferroni post hoc test on the maximal achievable speed per position with focus on the comparisons where statistical difference can be seen.

Table 6. One-way Anova test results on maximal speed per position



(I) Pos_Select		(J) Pos_Select		Mean difference (I-J)	Standard error	Sig.
	norm		knee high	,29100	,11523	,097
			kneeing	-,09800	,11523	1,000
			long sit	,10400	,11523	1,000
	knee high		norm	-,29100	,11523	,097
			kneeing	-,38900	,11523	,011
			long sit	-,18700	,11523	,680
	kneeing		norm	,09800	,11523	1,000
			knee high	,38900	,11523	,011
			long sit	,20200	,11523	,529
	long sit		norm	-,10400	,11523	1,000
			knee high	,18700	,11523	,680
			kneeing	-,20200	,11523	,529

In table 6 the statistical difference can be found between positions P2 and P3 with significance factor P=0.011. This indicates that in P3 the skier can achieve significantly higher speed than in P2. In other comparisons no statistical difference was found.

EMG on Phase 2 (500 ms from start, using right pole force as trigger event) is selected here to represent muscle activation during pulling. Figure 18 presents the Phase 2 mean EMG in each of the positions in SkiErgo test as normalized to MVC (MVC_N). Standard deviation on these results - as in all of the following on EMG- is very high, for example in P2 EMG is ranging from -10% to 90%. Main reason for this is small sample size.

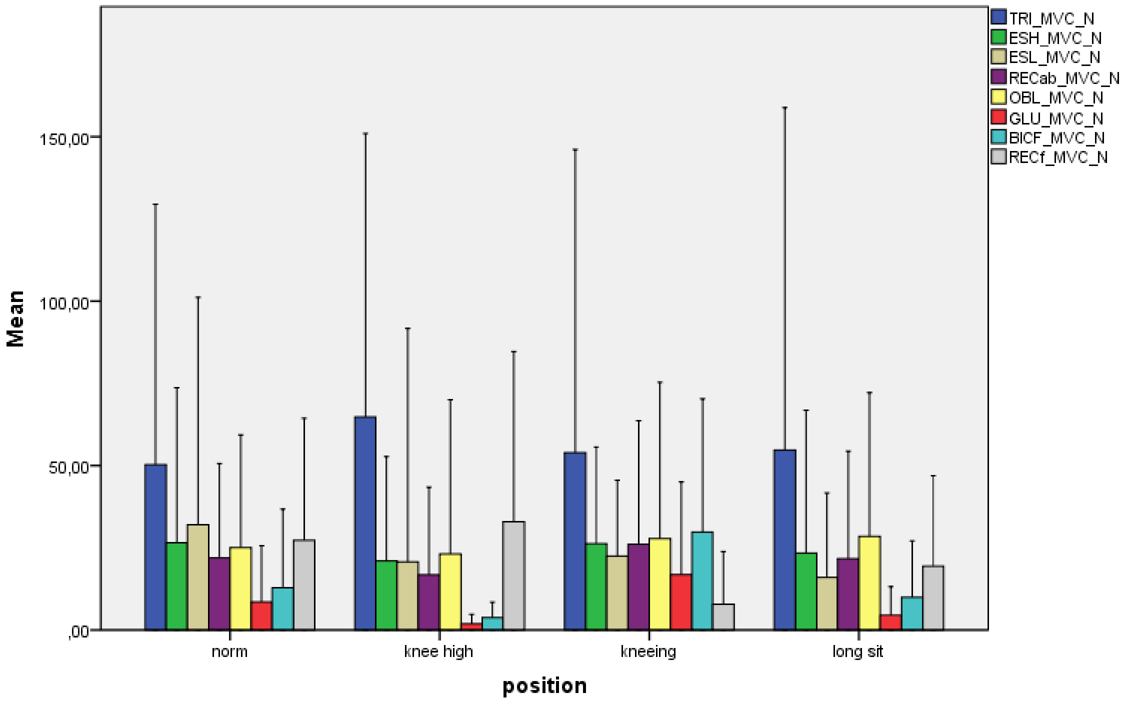
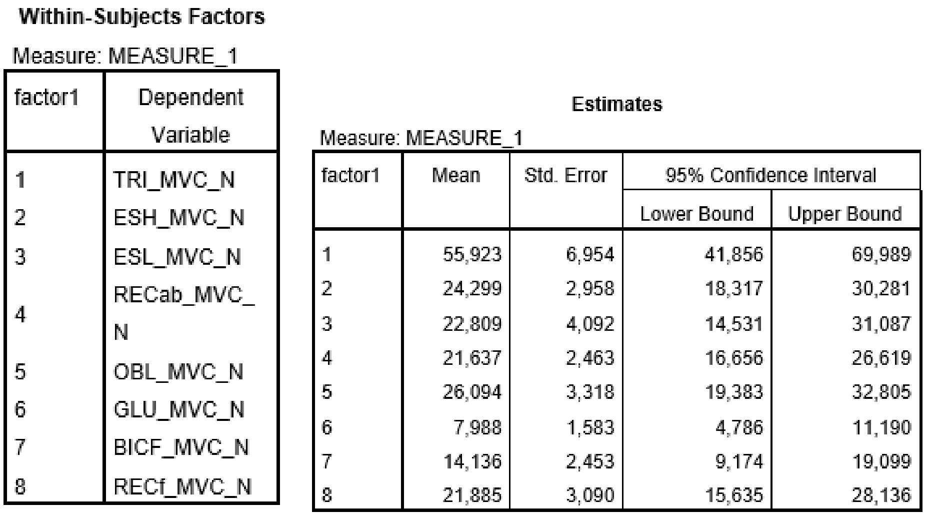


Figure 18. Mean EMG on Phase 2 SkiErgo test per muscle per position

Figure 18 indicates that TRI is the most active muscle in the double poling but there is no significant difference between TRI mean EMG between the positions. Linear model and pairwise comparison of the mean EMG max values of each muscle confirm the role of TRI compared to other muscle in all of the positions. Results of the pairwise comparison are presented in the table 7 where TRI mean EMG is represented as #1 (Within-Subject Factors -section). Results concluded that there are no statistically significant difference between the other muscles involved. TRI EMG values on double poling are 55.9% of max EMG whereas the other muscles measured remain on level of 20% (Estimates -section).

Table 7. Linear model results of mean EMG per muscle across positions



Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	TRI_MVC_N
2	ESH_MVC_N
3	ESL_MVC_N
4	RECab_MVC_N
5	OBL_MVC_N
6	GLU_MVC_N
7	BICF_MVC_N
8	RECf_MVC_N

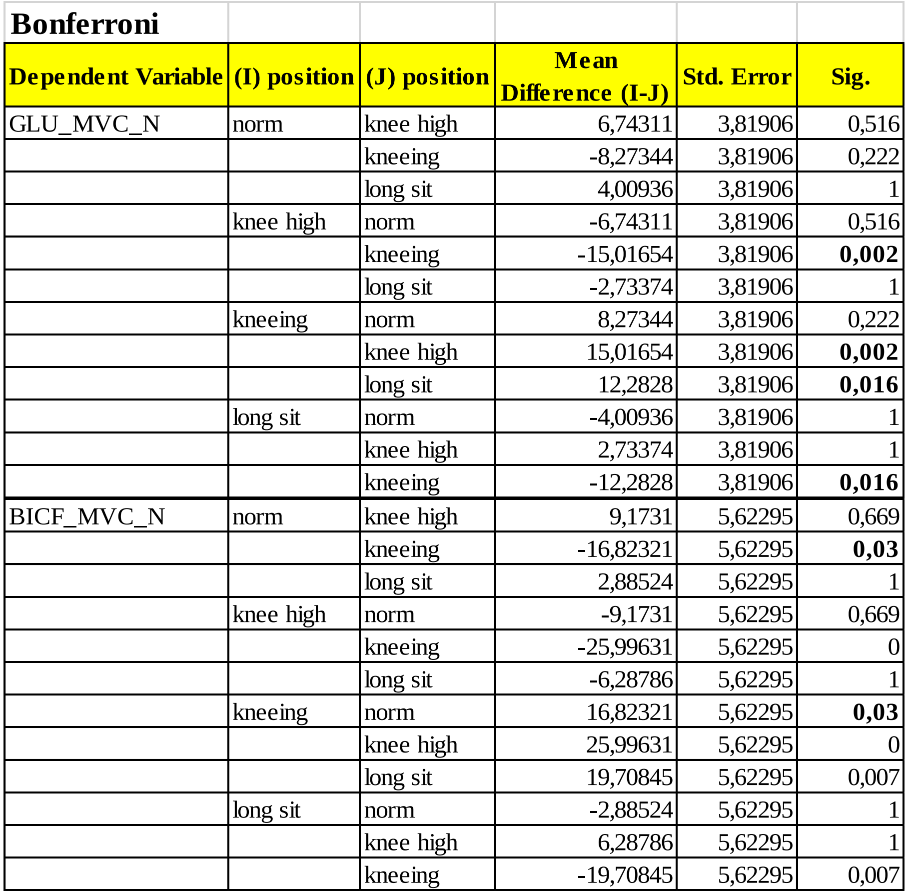
Estimates

Measure: MEASURE_1

factor1	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	55,923	6,954	41,856	69,989
2	24,299	2,958	18,317	30,281
3	22,809	4,092	14,531	31,087
4	21,637	2,463	16,656	26,619
5	26,094	3,318	19,383	32,805
6	7,988	1,583	4,786	11,190
7	14,136	2,453	9,174	19,099
8	21,885	3,090	15,635	28,136

Difference between positions becomes best visible on the hip and trunk muscles. Results of one way Anova concluded that statistically significant difference between sitting positions on EMG can be found on GLU (p=0.002) and BICf (p=0.000). A Bonferroni post hoc test was applied to clarify details of the differences. Table 8 summarizes the key findings from the Bonferroni post hoc test applied on GLU and BICf.

Table 8. Bonferroni test results on SkiErgo test EMG on GLU and BICf



Bonferroni					
Dependent Variable	**(I) position**	**(J) position**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**
GLU_MVC_N	norm	knee high	6,74311	3,81906	0,516
		kneeing	-8,27344	3,81906	0,222
		long sit	4,00936	3,81906	1
	knee high	norm	-6,74311	3,81906	0,516
		kneeing	-15,01654	3,81906	**0,002**
		long sit	-2,73374	3,81906	1
	kneeing	norm	8,27344	3,81906	0,222
		knee high	15,01654	3,81906	**0,002**
		long sit	12,2828	3,81906	**0,016**
	long sit	norm	-4,00936	3,81906	1
		knee high	2,73374	3,81906	1
		kneeing	-12,2828	3,81906	**0,016**
BICF_MVC_N	norm	knee high	9,1731	5,62295	0,669
		kneeing	-16,82321	5,62295	**0,03**
		long sit	2,88524	5,62295	1
	knee high	norm	-9,1731	5,62295	0,669
		kneeing	-25,99631	5,62295	0
		long sit	-6,28786	5,62295	1
	kneeing	norm	16,82321	5,62295	**0,03**
		knee high	25,99631	5,62295	0
		long sit	19,70845	5,62295	0,007
	long sit	norm	-2,88524	5,62295	1
		knee high	6,28786	5,62295	1
		kneeing	-19,70845	5,62295	0,007

Bolded numbers on Column “Sig” represent statistically significant difference ($p < 0.05$) that can be found on GLU EMG in P3 compared to P2 and P4 (p=0.03), P3 having higher EMG value against P2 and P4. On BICf the difference on EMG is significant between P1 and P3, P3 having higher value. On other comparisons the difference was not significant so the data is excluded from this presentation.

Figure 19 focuses the on the hip and trunk muscle EMG in a consolidated view by grouping the muscles. In the figure 19 the hip muscles are RECf, GLU and BICf. Trunk muscles include RECab, OBL, ESH and ESL. The results show that EMG values are highest on P1 and P3, which is aligned with findings on speed per position in figure 17. However the difference is not big. Trunk muscles are in dominant role only in P1 compared to hip muscles indicating that on the positions P2, P3 and P4 if the sit skier has capabilities to operate RECf, GLU and BICf, it may provide advantage in terms of higher EMG.

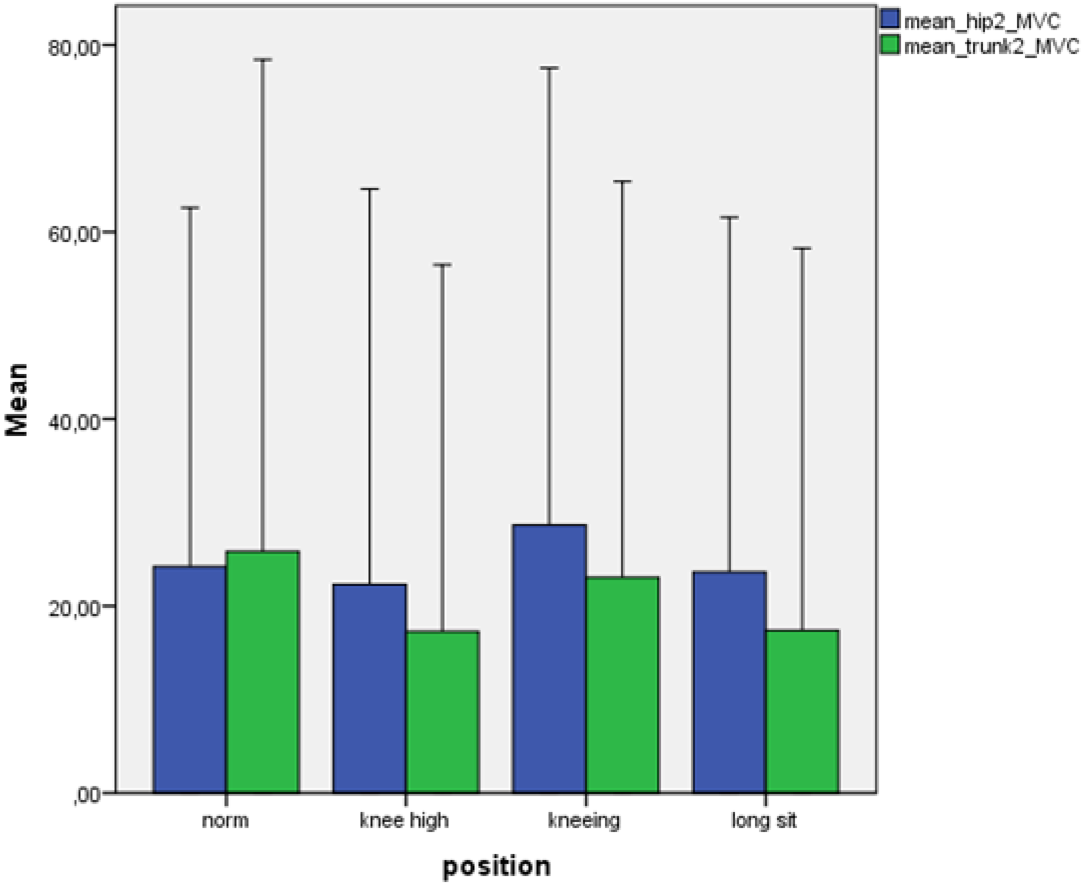


Figure 19. Sum mean EMG of trunk and hip muscles per position

Figure 20 presents force generation in each of the positions measured from the pole forces as mean value during Phase 2. From the Force components Fy represents the force vector that is taking the skier forward and thus is seen as most relevant component in this context. Since the timing trigger was adjusted to the right pole, only the right pole values were selected to illustrate the force generation capability differences between positions.

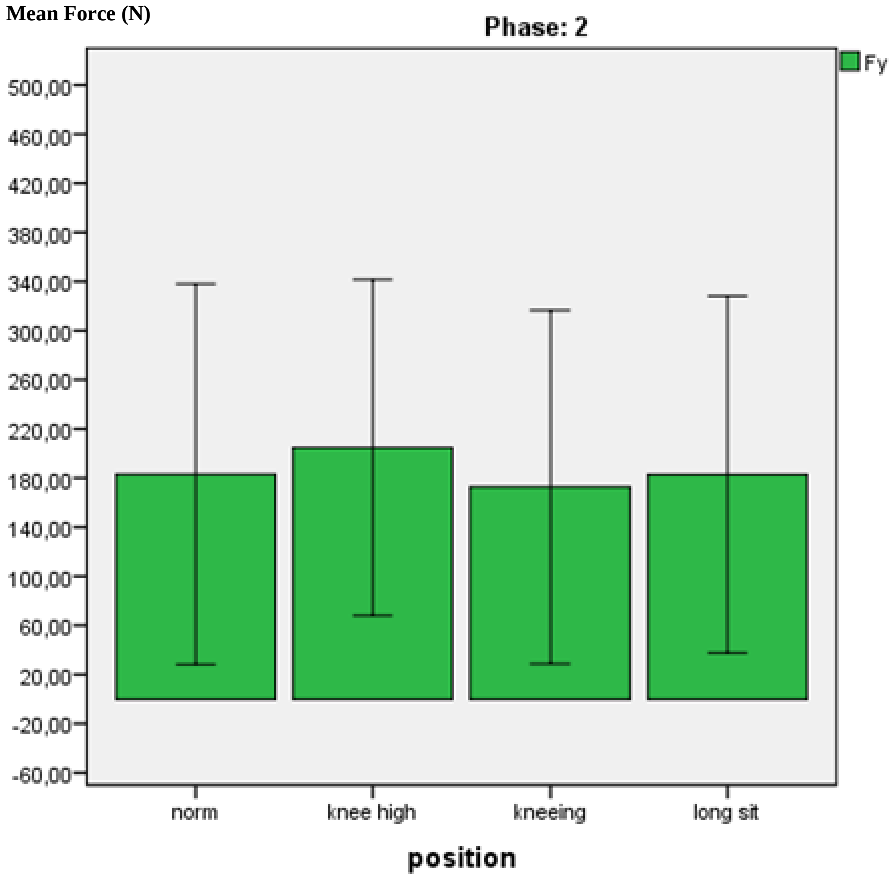


Figure 20. Forward taking force components per position

Figure 20 presents that there is no significant difference between positions in terms of forward taking force generation even though EMG and maximum speed were different.

7.3 Balance maintenance on perturbation platform test

In perturbation platform test the EMG was analyzed separately on forward and backward movement directions since different muscles were active in maintaining balance depending on if the machine moved the test subject forward or backward. The analysis window is same Phase 2 as with SkiErgo test. In this test the trigger was set by the machine signal which can be seen as channel 8 on figure 16 in chapter 6.4.3. Figure 21 represents the mean EMG values per muscle in the perturbation test divided first by position and separated then by movement direction.

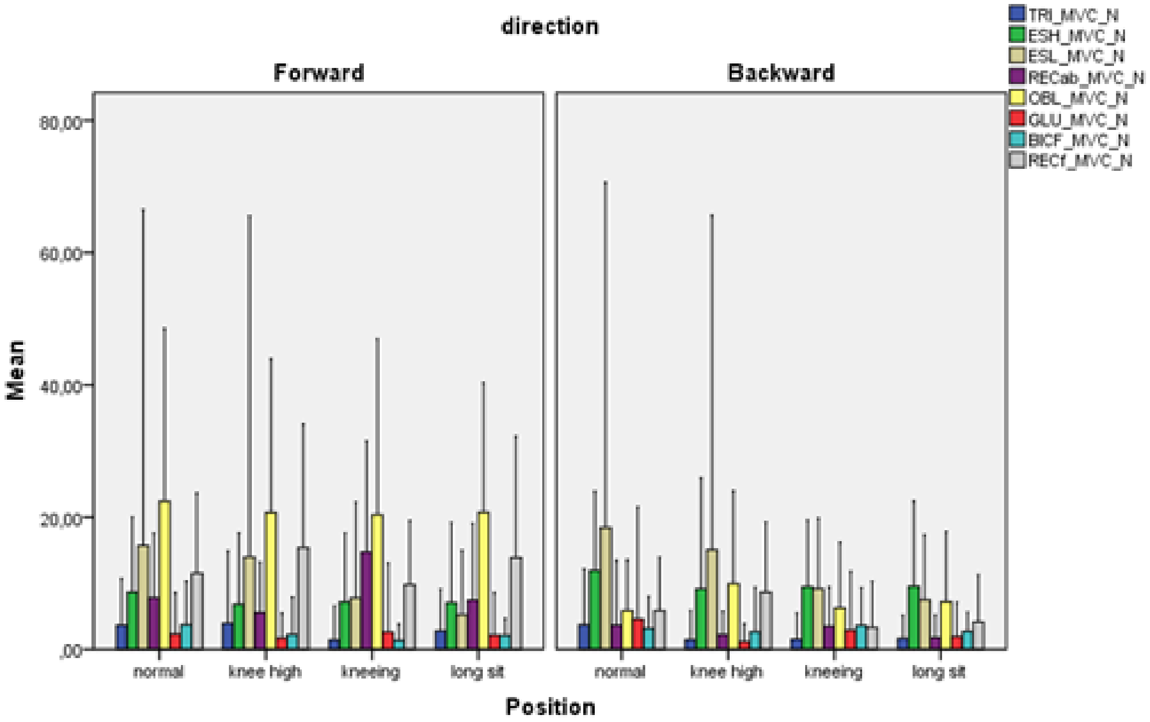


Figure 21. Mean Peak EMG values per position of all muscles

In P1 and P2 there are some data points involved that significantly increases the standard deviation of the results. Regardless of that, figure 21 indicates that the muscles on trunk and abdominal side are in key role in the balance maintenance. Based on this, the further analysis of perturbation platform test is focusing on following muscles: **ESH, ESL, RECab and Obl**. Figure 22 represents a focused view to the same mean EMG values for these muscles.

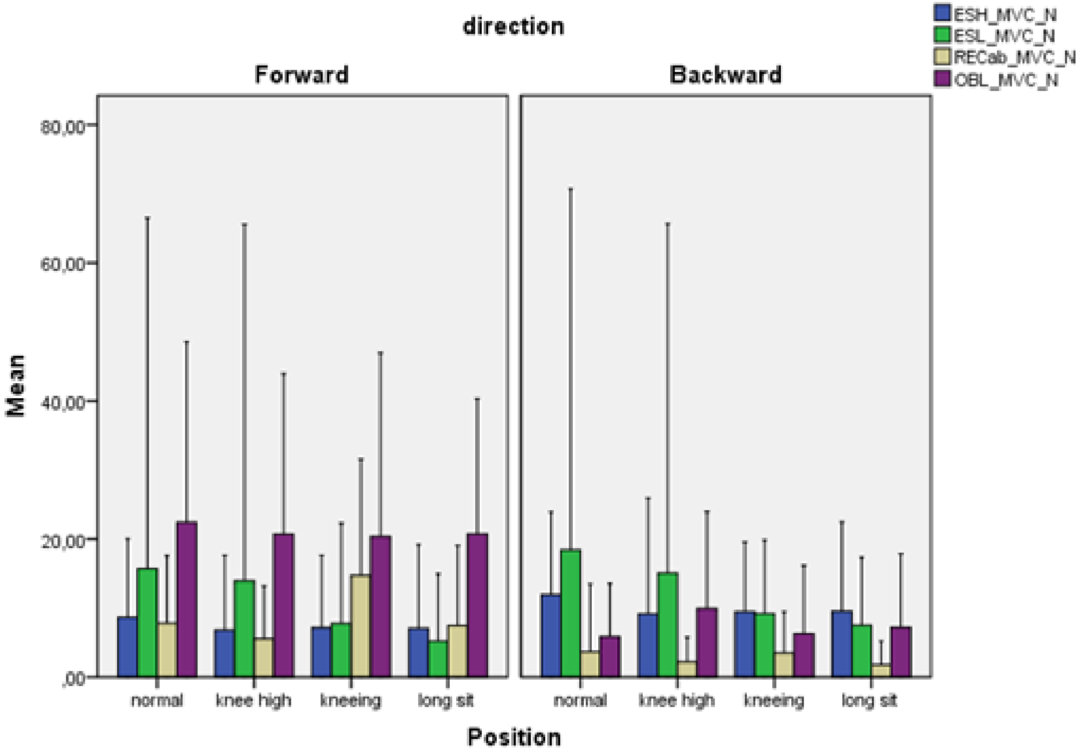
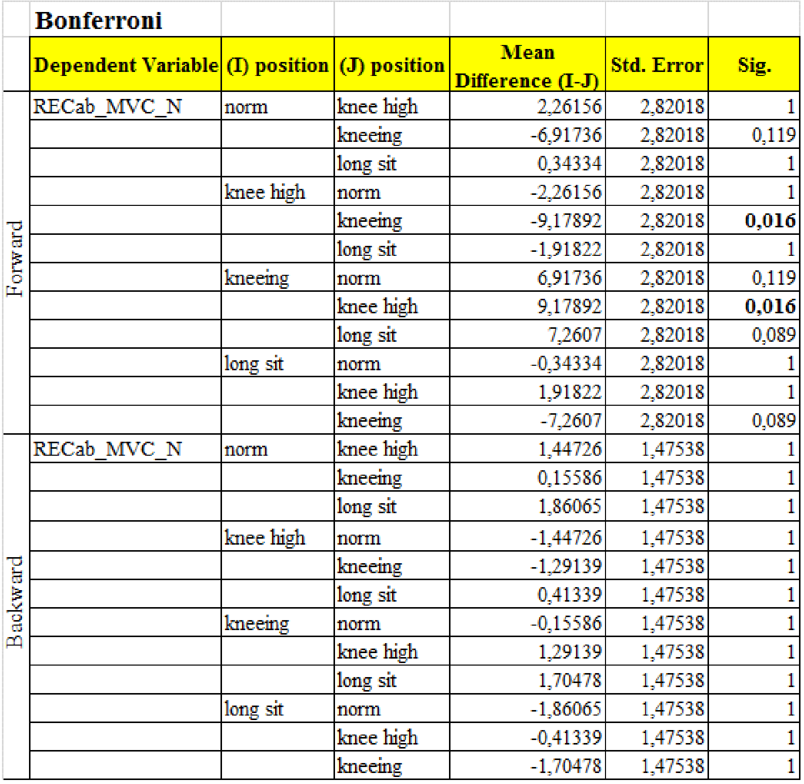


Figure 22. Mean EMG values per position of all muscles

Figure 22 shows OBL as the most active muscle when test subject is moved forward. On forward movement the trunk moves backwards and abdominal muscles straighten the trunk up. On backward movement the similar role is seen on ESL but not as clearly as on OBL on forward movement. ESL data included the highest standard deviation decreasing the conformance level of the records. One-way Anova test with Bonferroni post hoc test was conducted also on perturbation test data. The results were split according to movement direction since the muscles active varied based on direction. Table 9 presents the Bonferroni test results on RECab, which was the only muscle where the One-way Anova brought up statistically significant difference with P=0.016.

Table 9. Bonferroni test results on SkiErgo test EMG on RECab



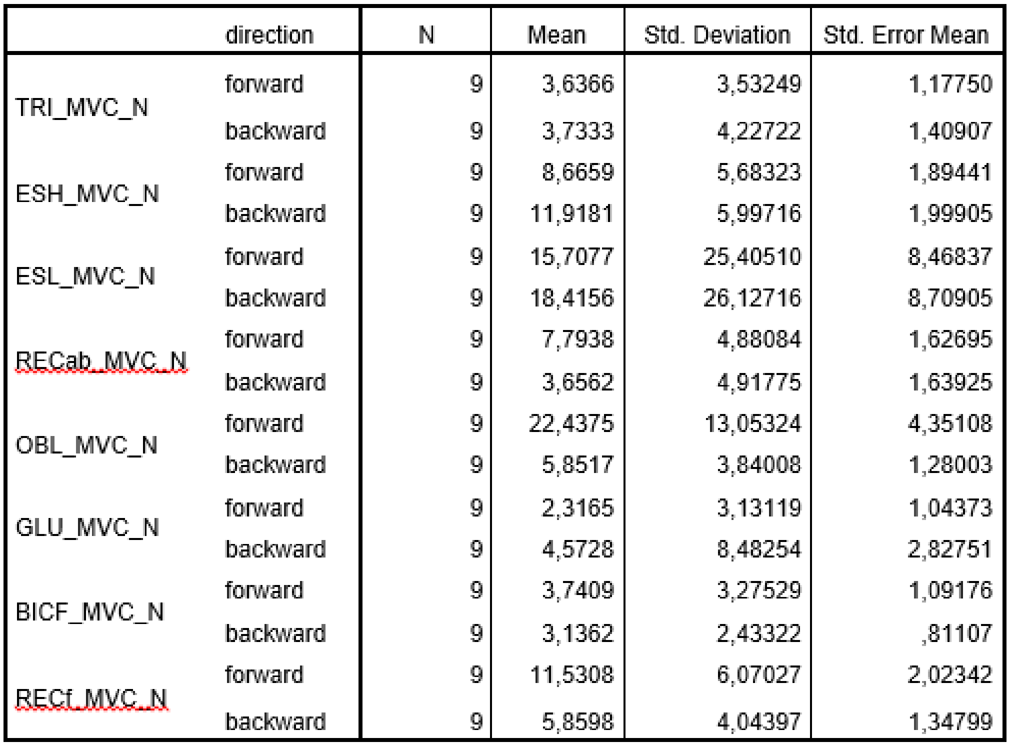
Bonferroni

	Dependent Variable	(I) position	(J) position	Mean Difference (I-J)	Std. Error	Sig.
Forward	RECab_MVC_N	norm	knee high	2,26156	2,82018	1
			kneeing	-6,91736	2,82018	0,119
			long sit	0,34334	2,82018	1
		knee high	norm	-2,26156	2,82018	1
			kneeing	-9,17892	2,82018	**0,016**
			long sit	-1,91822	2,82018	1
		kneeing	norm	6,91736	2,82018	0,119
			knee high	9,17892	2,82018	**0,016**
			long sit	7,2607	2,82018	0,089
		long sit	norm	-0,34334	2,82018	1
			knee high	1,91822	2,82018	1
			kneeing	-7,2607	2,82018	0,089
Backward	RECab_MVC_N	norm	knee high	1,44726	1,47538	1
			kneeing	0,15586	1,47538	1
			long sit	1,86065	1,47538	1
		knee high	norm	-1,44726	1,47538	1
			kneeing	-1,29139	1,47538	1
			long sit	0,41339	1,47538	1
		kneeing	norm	-0,15586	1,47538	1
			knee high	1,29139	1,47538	1
			long sit	1,70478	1,47538	1
		long sit	norm	-1,86065	1,47538	1
			knee high	-0,41339	1,47538	1
			kneeing	-1,70478	1,47538	1

Table 9 concludes that only in forward direction the RECab EMG has a statistically significant difference (p=0.016). This difference applies only between P3 and P2, P3 having higher value. On all other comparisons between other positions and other muscles there was no statistically significant difference identified, regardless of the movement direction.

The role of OBL muscle on the balance maintenance on forward direction was verified by applying an independent samples t-test. P1 was selected as reference point to analyze the difference between the backward and forward movements. EMG values per muscle used as the t-test reference are first represented in the table 10.

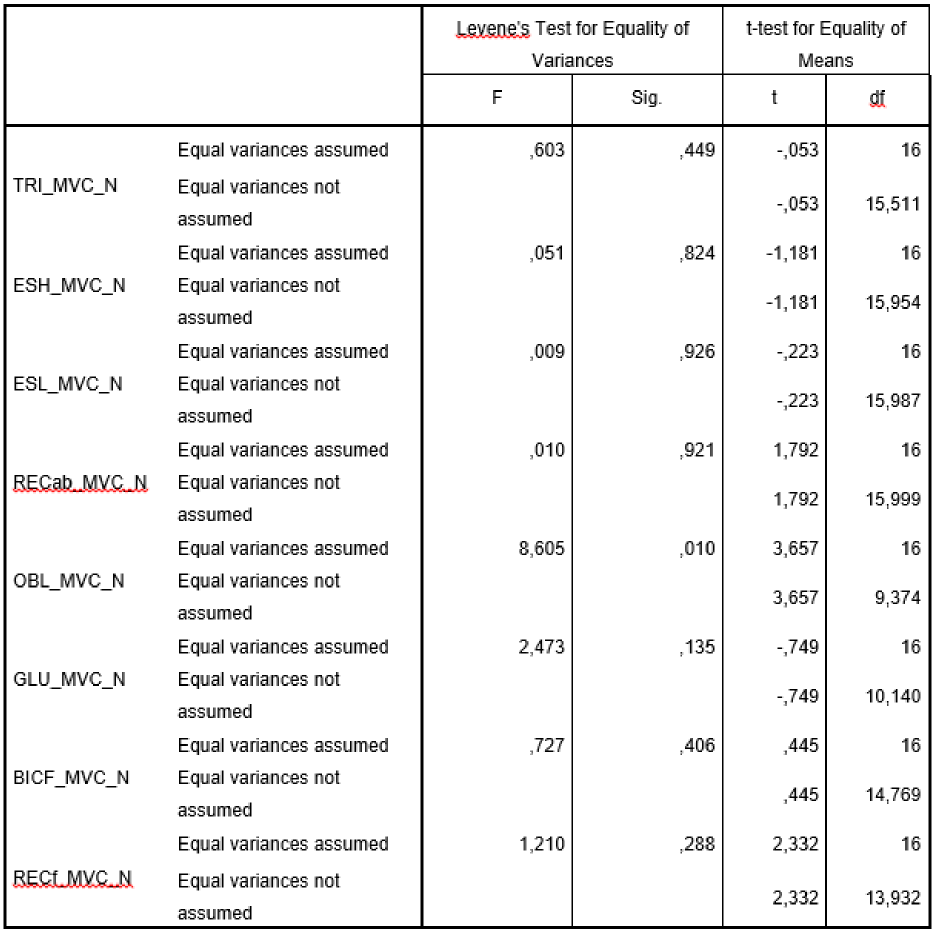
Table 10. Mean EMG values per muscle per direction



	direction	N	Mean	Std. Deviation	Std. Error Mean
TRI_MVC_N	forward	9	3,6366	3,53249	1,17750
	backward	9	3,7333	4,22722	1,40907
ESH_MVC_N	forward	9	8,6659	5,68323	1,89441
	backward	9	11,9181	5,99716	1,99905
ESL_MVC_N	forward	9	15,7077	25,40510	8,46837
	backward	9	18,4156	26,12716	8,70905
RECab_MVC_N	forward	9	7,7938	4,88084	1,62695
	backward	9	3,6562	4,91775	1,63925
OBL_MVC_N	forward	9	22,4375	13,05324	4,35108
	backward	9	5,8517	3,84008	1,28003
GLU_MVC_N	forward	9	2,3165	3,13119	1,04373
	backward	9	4,5728	8,48254	2,82751
BICF_MVC_N	forward	9	3,7409	3,27529	1,09176
	backward	9	3,1362	2,43322	,81107
RECf_MVC_N	forward	9	11,5308	6,07027	2,02342
	backward	9	5,8598	4,04397	1,34799

Table 10 presents that OBL has the highest EMG value of 22,4 % of MVC EMG on forward direction. Independent samples t-test makes comparisons between the directions based on the values on the table 9. Table 11 presents the results of the t-test where again the statistically significant difference is presented as $p < 0.05$ on column “Sig.”

Table 11. T-test results on EMG per muscle on normal sitting position



		Levene's Test for Equality of Variances		t-test for Equality of Means	
		F	Sig.	t	df
TRI_MVC_N	Equal variances assumed	,603	,449	-,053	16
	Equal variances not assumed			-,053	15,511
ESH_MVC_N	Equal variances assumed	,051	,824	-1,181	16
	Equal variances not assumed			-1,181	15,954
ESL_MVC_N	Equal variances assumed	,009	,926	-,223	16
	Equal variances not assumed			-,223	15,987
RECab_MVC_N	Equal variances assumed	,010	,921	1,792	16
	Equal variances not assumed			1,792	15,999
OBL_MVC_N	Equal variances assumed	8,605	,010	3,657	16
	Equal variances not assumed			3,657	9,374
GLU_MVC_N	Equal variances assumed	2,473	,135	-,749	16
	Equal variances not assumed			-,749	10,140
BICF_MVC_N	Equal variances assumed	,727	,406	,445	16
	Equal variances not assumed			,445	14,769
RECf_MVC_N	Equal variances assumed	1,210	,288	2,332	16
	Equal variances not assumed			2,332	13,932

Based on the data in the table 11 a conclusion can be made that OBL is the only muscle in normal sitting position whose role change significantly when the direction of the movement is changing. OBL activity is significantly higher when the movements is on forward direction. For the other muscles in terms of EMG there is no significant difference if the movement is forwards or backwards.

7.4 EMG comparison between perturbation platform and SkiErgo tests

Comparing the EMG between the perturbation platform and SkiErgo tests provides information about individual muscle EMG difference between the tests conducted. Figure 23 represents the muscle activation on perturbation platform and SkiErgo tests. The graphs are the same as in Figures 21 and 18.

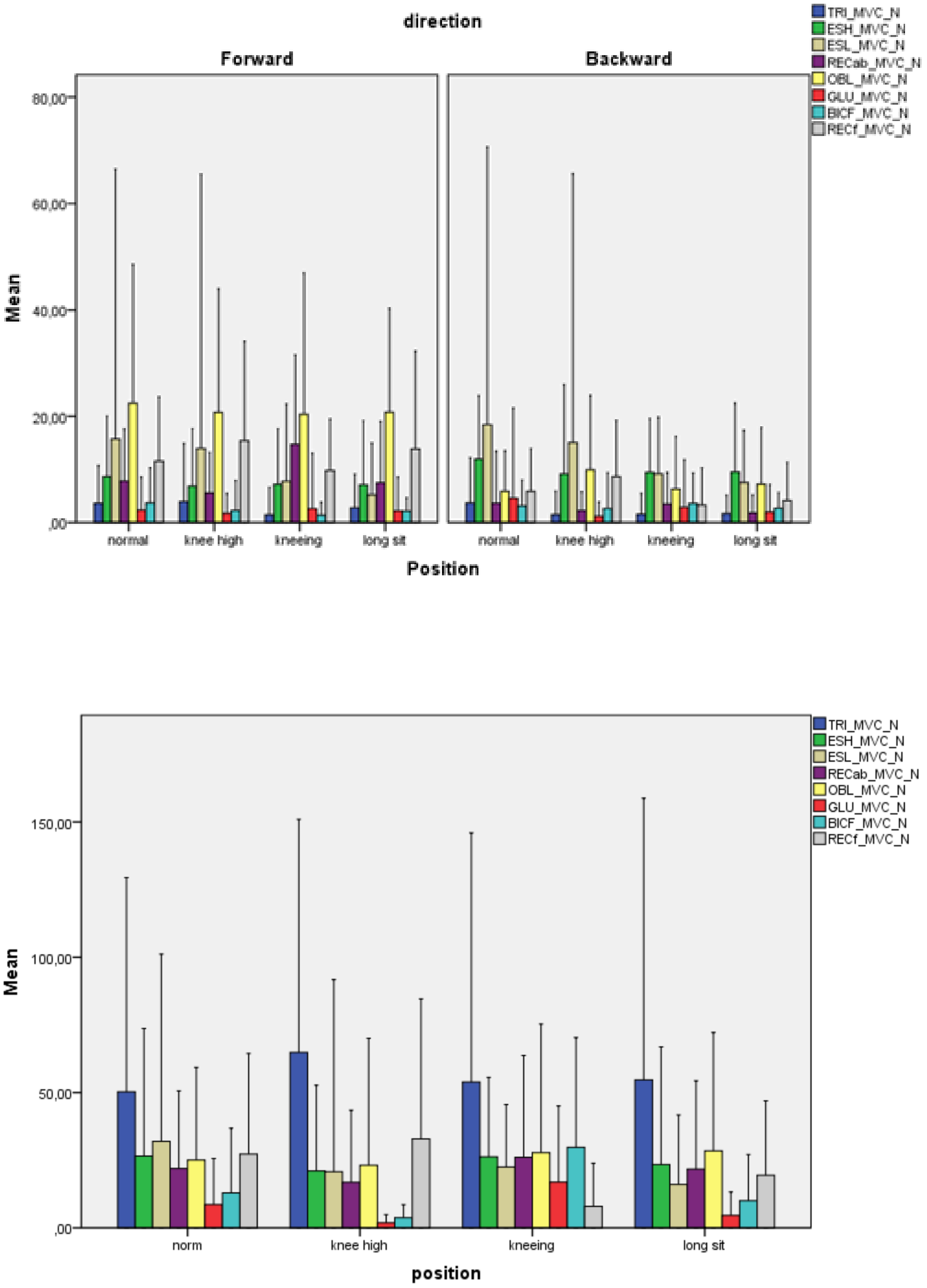


Figure 23. EMG on perturbation platform test vs SkiErgo test

Muscular activity in general is higher on SkiErgo test where the EMG range varies between 20% and 100% of MVC. Exceptional cases are TRI that is in dominant role in all positions and GLU and BICf on P2 where their ROM is limited.

The variation range on perturbation platform test is smaller, between 3% and 23% of MVC EMG. In the perturbation platform test OBL, ESL and ESH create most EMG, around 20% of the MVC depending on direction. On the SkiErgo test the EMG of these muscles ranges between 40-60% of the MVC. As a conclusion of figure 23 it can be seen that EMG values are higher on SkiErgo tests. The most likely reason is that the muscles are being consciously activated for force generation in the SkiErgo test.

7.5 EMG activation timing on perturbation platform test

The key hip and trunk muscles were analyzed to clarify the latency timing, and if the latency would be a reflex or a conscious reaction to the stimulus. Figure 24 below represents the average latency times on RECab, RECf, BiCf and ESL muscles. If the latency time is lower than 200 ms, then the activation can be considered as a reflex. 200 ms threshold value takes into account also the latency between trunk movement and the machine signal. On higher activation timing values the activation is considered to be a result of a conscious reaction to the stimulus.

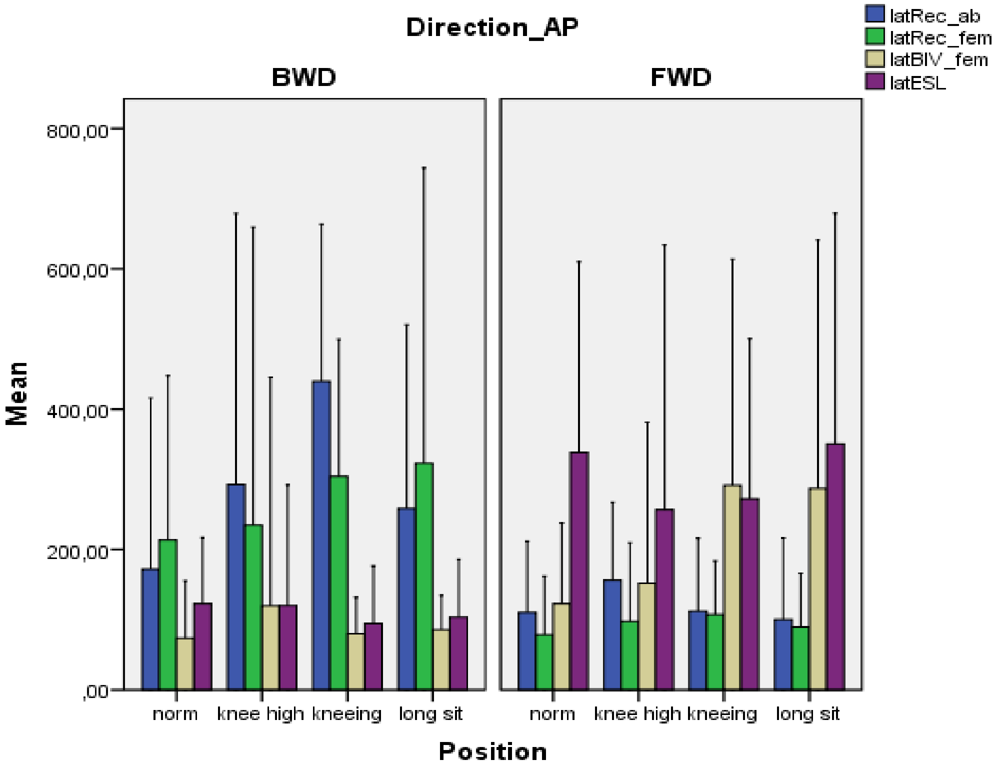


Figure 24. Average EMG latency per position

Based on the figure 24 it can be concluded that on forward movement the RECab and RECf activation timing is caused by a polysynaptic long latency reflex. On backward movement BICf and ESL activation is also likely to be due to reflex. Interesting finding is that BICf activation timing on forward direction differs between sitting positions. Here P3 and P4 have the longest latency. Similar difference is seen on RECab timing on backward direction in P2. RECf demonstrated also highest pre-activation EMG (Phase 1, Figure 16) from the muscles recorded indicating that the test subject contracts the RECf before the stimulus in order to be ready to react for the coming movement.

8 DISCUSSION

The objective of this study was to verify if the defined test set-up provides accurate enough results on EMG and speed on SkiErgo double poling and perturbation platform tests so that it could be furthermore applied with disabled athletes belonging to Nordic sit ski sport classes LW 10, 10.5, 11 and 11.5. Functional classification system leave room for interpretation for example on classes 10 and 10.5 where according to the definition (table 1) in chapter 3.4 the difference is mainly identified by capability to maintain stability. (IPC 2013; Pernot et al. 2011).

Cohen et al. (1998) concluded that ASIA classification standard had limitations when applied to the athletes with incomplete impairments. Therefore the classification process should not be based on the medical diagnosis only but would benefit from information provided by scientific research. Differences between the sitting positions were analyzed in terms of maximal speed and force generation in SkiErgo double poling and EMG in SkiErgo and perturbation platform tests to complement the medical assessment. In this area the purpose of the study was to verify that the defined test set is able to create data about the positions' key characteristics so that those can be taken into account on disabled athletes. (Cohen et al. 1998).

8.1 Maximum speed and EMG in different positions in SkiErgo test

On chapter 7.2 the position where the maximum speed could be achieved was defined to be P3 or P1. P2 was concluded to be the position where achieving the highest speed is most challenging. Statistical difference was found on table 6 between P3 and P2 indicating that skiers utilizing these positions have high possibility for difference in performance level. This should be taken into account when allocating classes and combining the athletes from different classes into common race events. On P2 the range of movement of GLU and RECf was limited. This can be seen as a reason for limiting force generation and is visible as lower EMG activity on figure 18. This limited ROM of hip muscles also limit the maximal speed. As these muscles are not contributing into the force generation, the achievable speed level remains lower. This finding of P2 being the weakest position against P3 is aligned with Vanlandewijck et al. (2011) conclusion on wheelchair racer’s lower performance on Condition 0 (deep sitting) in chapter 4.1.2 compared to the other positions illustrated in figure 5. Condition 0 in that study is similar to P2 in this one. (Vanlandewijck et al. 2011).

EMG of hip and trunk muscles (figure 19) also indicate that P3 and P1 are positions with most EMG on double poling. The limited amount of data points creates high standard deviation decreasing the conformance level of the data. The test set-up provides right information but the number of test subjects needs to be higher when seeking for wider applicability of the results. Furthermore the test set-up was specified for the sit-skiing and cannot be as such applied to other sports. The results may be biased on training impact. Sport independent tests are recommended to be included into the complete test set to limit the training impact as described in the chapter 3.9.2. (Backman and Tweedy 2008).

Based on the maximal speed and max EMG values, P3 seems to be the optimum position for double poling. Consumption of O_2 was not measured in this study in context of several minutes’ long constant speed poling activity, so the advantage of the P3 is confirmed only on short term sprints and against P2. Adding the cardiorespiratory parameters into the test protocol would enable comparison between positions also in terms of performance efficiency: in which position the test subject produces most power compared to energy consumption. This would enable reflecting the results against the findings of Halonen

(2013) on double poling physiological parameters between sit skiers and regular skiers. (Halonen 2013).

Forward taking force components would need more detailed analysis than conducted in this study. Findings presented on figure 20 indicate no significant difference between the forward taking force components per position. Analyzing all of the force vectors in context of the center of gravity would bring more insights on how the pole forces are contributing to forward taking force generation. This would be needed information to adjust the test set-up and measurements if applied on the field conditions.

8.2 Role of trunk muscles in balance maintenance

In case the disabled athlete cannot trunk or hip muscles, the class allocation would be pointing more towards LW 10.5 than LW 10 when following the IPC classification process. This would be due to the limited capability to maintain balance. From the trunk and hip muscles RECab, RECfem, OBL, ESH and ESL are in key position to maintain balance, as defined by Pernot et al. (2011). On Figure 21 the EMG of OBL and ESL is higher than RECab and RECfem on the anterior-posterior dimension promoting the role of these muscles especially in forward taking movement. These results are aligned with Pernot et al. (2011) conclusions on confirming the test-table-test applicability for the sit-skier functional classification. Therefore it can be stated that the test set-up used in this project provides correct information on perturbation test and it is able to separate the muscle EMG information so that the key muscles can be defined. (Pernot et al. 2011; IPC 2013).

Interesting finding on this study is that only the role of OBL changes significantly when the movement direction changes. When the platform is moved forward the trunk moves backwards and OBL activates to restore the balance. It can be suggested that role of OBL on disabled athletes is examined in further details both in laboratory and field conditions. One opportunity for application of the findings would be to build a scoring system based on the trunk muscle EMG to overcome the measurement weighting challenge illustrated in chapter 3.7. (Tweedy and Vanlandewijck 2009).

Timing wise the role of RECab, RECf and ESL in maintaining balance in anterior-posterior perturbation test came up as the clearest evidence. Sudden move of the platform backwards produced a reflex in less than 150ms from the trigger signal in RECf. This signal is seen as a peak on top of the muscle first activation EMG in figure 16 and can be seen as a polysynaptic reflex. The movement of the body had a delay of approximately 100 ms compared to the given stimulus. The reflex impulse timing states that RECf is activated before the test subject is making conscious effort to maintain the sitting position after the shake. Reflex timing differs between the positions as described in figure 24. This can be due to test subject's adaptation to the perturbation stimulus. Shemmell et al. (2010) introduce that the long latency reflexes could be mediated to some extent. The test set-up can be applied to collect information on the disabled athletes for reflex responses but the order on which the test subject performed the perturbation test can impact the EMG latency. The subject gets more familiar with the stimulus during the test process and can therefore anticipate another one to come. Muscle pre-activity could be studied further to indicate the anticipation. The impact of order was randomized in the test but cannot be completely excluded due to small number of test subjects. (Shemmell et al. 2010; Lindinger et al. 2009).

Balance maintenance and sitting capabilities are important also in other disabled sports such as wheelchair basketball, wheelchair tennis or wheelchair hockey. Adapting the perturbation platform test to other sports can provide more evidence to develop the classification methods and enable more equal integration of the Sport Class also for example on wheel chair racing. Vanlandewicjk et al. (2011) demonstrated similar biomechanical characteristics on the movement (propulsion vs double poling) and sitting positions (conditions 0/45/90 vs P1/P2/P3/P4) that could be utilized as another reference study when the test set-up is modified to be used in another sport. (Vanlandewicjk et al. 2011).

8.3 Difference between sitting positions on perturbation test

One of the main purposes of the study was to understand if there are differences between sitting positions on perturbation platform test. Based on the results in chapter 7.4 there was no statistically significant difference identified between sitting positions and EMG activation with exception of RECab on P3 and P2. With the limited number of healthy test subjects the test set-up therefore did not conclude on wider scale if maintaining balance in one position is requiring more muscle activation that in another. Repeating the test set-up with real disabled athletes might provide alternative results when the sit ski is more familiar to the test subjects and some of the key trunk and hip muscles may be inoperative due to impairment. It is also suggested that the EMG measurement should focus on the trunk area muscles in the upcoming related studies. Also other muscles in that area are suggested to be taken into scope of measurement.

The study showed that maintaining balance on the P1 and P2 required higher muscle activation rate than P3 or P4. This is because on P1 and P2 the center of gravity of the test subject is higher and therefore maintaining balance on sudden movements is more difficult. This assumption was not thoroughly confirmed as the center of gravity was not calculated and thus evidence on this is missing. This is proposed to be taken into scope of future related studies.

Sitting position EMG differences on disabled athletes would give indication for the classifiers on the capabilities of the athlete to operate trunk and hip muscles. This can be applied into the development of the classification process. For example balance maintenance test score framework as described in chapter 3.5.2 could be revisited to gear the classification process towards more evidence based set-up.

8.4 Applicability of the test set-up on disabled athletes

This study was done with able bodied subjects. Experienced real disabled sit ski athletes obtain fully mature sit ski ergometer skills on double poling. Joint ROM and muscle EMG are different, depending on the operational capabilities of lower limb and trunk muscles. Also the deviation between results is expected to be lower with test subjects having extensive experience on usage of a sit ski.

As an example the hip joint ROM during the perturbation test on able bodied may be different compared to paraplegic athletes whose abdominal strength has decreased due to extended period of time in wheelchair. Crespo-Ruiz et al. (2011) propose that the wheelchair propulsion kinematic analysis results could be applied also outside Paralympic sports, for example to older people having spinal cord injury and thus using wheelchair on daily basis. With sit-skiers we do not see that as a feasible extension field of the results due to sit-ski being a very sport specific equipment. Comparing the results of this sit ski study with a study on real disabled athletes would provide more information on differences or similarities in between. (Crespo-Ruiz et al. 2011).

Repeating the test protocol with disabled athletes would support the sit skiers’ classification process development and sitting position selection. Functional classification process limitations highlighted by Tweedy & Vanlandewijck (2009) are applicable also in sit-skiing. Challenges become more complex to analyze in terms of impact when there are multiple parallel impairment involved. Test-set up applied from Vanlandewijck et al. (2011) about different sitting positions for wheelchair propulsion was confirmed to be applicable to use also with disabled athletes. Sport specific adaptations on sit-skiing were conducted as the positions used are different. (Tweedy and Vanlandewijck 2009; Vanlandewicjk et al. 2011).

Bjerkefors et al. (2013) study on double poling ergometer performance on spinal cord injured versus able bodied test subjects included measurements on the kinematics and force production data about the sit skiing. The test set-up of the study together with the test set-up from Forbes et al. (2010) provided a reference point with insight on how to utilize ergometers on laboratory environment with force plates and how to define recording of the kinematic data on joint movement. (Bjerkefors et al. 2013; Forbes et al. 2010).

The test set-up itself confirmed to provide relevant information about the difference between sitting positions in terms of force generation on double poling, and in terms of EMG on double poling and anterior-posterior perturbation platform tests. When the test set up is applied to the disabled athletes the number of test subjects should be increased. The test set-up should be tuned on perturbation platform to focus more on spinal (ESH, ESL) and abdominal (OBL) muscle activation as those are seen to be in determining role in the balance maintenance. Timing of the EMG response on disabled athletes should be analyzed in context of the impairment. Short and long latency reflex timing can be different due to different limb and muscle stiffness compared to able bodied athletes. In the following tests the timing of the perturbation stimulus against the movement of body should be analyzed in more detail so that the verified delay in time could be taken into account when determining muscles with reflexes. (Shemmell et al. 2010).

Applying the test set up for disabled sit-skiers would serve as scientific input to develop the Nordic Skiing classification system on IPC governed events. Classification systems based on functional parameters have limitations as demonstrated by Brasile (1986) with wheelchair basketball players on NWBA classification system and skill proficiency. In addition to the classification process, information on differences between the sitting positions would also serve as input for the coaches and athletes. (Brasile 1986)

8.5 Future research topics

The test set-up was done in a stable laboratory environment. Related studies, like Vanlandewijck et al. (2001) and Halonen (2013), conclude that in laboratory environments the force generation and EMG activities differ as values from field conditions. It is therefore reasonable to assume that force generation, EMG and joint ROM would be different when similar test would be conducted on real snow. The inertial forces applying to the sit ski are neglected in the ergometer but need to be taken into account on field conditions. (Vanlandewijck 2001; Halonen 2013).

The project collected joint movement information (ROM) using motion cameras, markers and Vicon software. Analyzing the ROM data from the SkiErgo and perturbation platform tests would complement the information portfolio on the biomechanics of the sit-skiing and be a natural continuation point for this research project. Kinematics of these joints on wheelchair racing were discussed by Vanlandewicjk et al. (2001) and the same joints play key role also in sit skiing. Comparing the sit-ski ROM data against the wheelchair racing data would bring out biomechanical similarities and differences between these sports. In case of multidimensional disabilities where for example trunk muscles' and one upper limb muscles' force generation capabilities are limited, the measurement aggregation challenge introduced in chapter 3.7 could be overcame by combining the ROM and EMG analysis outcome. (Vanlandewijck et al. 2001; Tweedy and Vanlandewijck 2009).

The data collected during these test could be further elaborated to build mathematical models on sit skiing to support testing and coaching. Vanlandewijck et al. (2001) discuss this modelling aspect of biomechanics on wheelchair propulsion. Creation of a mathematic model on sit-skiing would benefit from insights on constraints on force generation and relationship between effective force generation and motion efficiency. Mathematic modelling of the sit-ski biomechanics could enable performance optimization and support the training activities for example by identifying how the double poling phases align with generation EMG. Increased understanding of the neuromuscular system on double poling would also bring information on force generation strategies during sit skiing. (Vanlandewijck 2001).

Mathematical model on sit-skiing biomechanics could be used to develop ergometer training programs that would prevent the sit-skiers from shoulder injuries that are common in wheelchair and sit ski sports due to overloading of upper limbs and trunk. The training could better take into account the asymmetries between anterior and posterior musculature force generation that is caused by daily usage of wheelchair. (Bjerkefors et al. 2013).

MVC tests were conducted to get Maximum EMG as a reference for the EMG on SkiErgo tests. Analyzing the maximum force generation data and applying the MVC tests to disabled persons would bring input how to apply the MMT methods to sit-skiing classification process. This would enable piloting the MMT methods described in chapter 3.3.1 also with Nordic sit-skiers. (Tweedy et al. 2010).

Modification of the test set up so that the skiers' own sit-skis could be mounted on top of the perturbation platform would enable studying of the performance level or economy of sit-skiing. This would exclude the possible errors or limited maximum speed results caused by an unfit test seat. Studying the impact of the equipment and their evolution on sit-skiing would also provide an interesting overview to the sport technology. Most technological research on sport for the disabled has been conducted in the area of wheelchair design. Sit ski design advantages or disadvantages should be studied further.

Participation into sport is considered to improve individual's self-esteem or self-concept, especially on disabled individuals. Sport psychology and sport sociology aspects on the Nordic skiing for disabled would provide another viewpoint to its role in wider context. Topics such as society's perceptions and awareness to the sit skiing or athlete's motivational factors could provide more information for the Paralympic movement and training development.

8.6 Conclusions

The study provided insights to the differences between sitting positions in terms of achievable maximal speed and force generation on SkiErgo test. P3 was concluded to have advantage over P2 in double poling. The results of better performance on P3 and P1 positions against other positions need to be evaluated in context of small sample size. On the perturbation platform test there was no statistically significant difference on anterior-posterior dimension. To understand the difference between positions the analysis has to be taken on individual muscle level where role of RECab, OBL and ESH differ between sitting positions and movement direction when measured as EMG.

The test-set up was verified for recording EMG data on different muscles on force generation and balance maintenance tests and can be applied to disabled athletes. The EMG recording and analyzing should focus more on the trunk and hip area muscle behavior. The hypothesis of the test set-up can be considered partially confirmed. The additional data collected during the test on able bodied persons can be analyzed to complement the findings on this thesis before applying the test to disabled athletes or experimenting the test set-up in field conditions. Classification process development proposals can be provided when the test set-up has been conducted with disabled athletes and information about trunk and hip muscle operational capabilities is available on real subjects.

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