PERFORMANCE DETERMINANTS 
AND CLASSIFICATION IN PARACANOE
Performance determinants and classification in paracanoe

Johanna Rosén
To all athletes, coaches, team leaders and classifiers involved in paracanoe; this thesis would not have been possible without your support.
Abstract

Valid classification systems are vital for Paralympic sports in order to minimise the impact of impairment on sports performance. To achieve valid classification, each sport must develop evidence-based classification systems by examining the impact of impairment on key performance determinants. The two disciplines included in the sport para-canoe, para kayak and para va’a, have both recently implemented new evidence-based classification systems. The aim of this thesis was to examine the impact of impairment on key performance determinants in para va’a and para kayak. Additional aims were to examine the reliability of the para va’a classification system and the validity of the para kayak classification system.

Ten non-impaired va’a athletes and 44 para va’a athletes with; trunk and leg impairment (TL), bilateral leg impairment (BL) and unilateral leg impairment (UL) participated in study I. Paddling force and three-dimensional (3D) kinematics of the upper limbs, trunk and lower limbs were collected during paddling on an ergometer. Correlations between paddling forces and joint angles, and differences between groups were examined. Significant positive correlations between paddling force and; maximal trunk flexion, trunk flexion range of motion (ROM), trunk and pelvis rotation ROM, hip flexion ROM and knee and ankle flexion ROM at the paddle side were seen. The results also showed that the TL athletes demonstrated less paddling force and trunk flexion compared to the BL and UL athletes. Furthermore, even though differences were seen between the BL and UL athletes in knee and ankle flexion ROM, no differences in paddling force were seen. The results indicated that athletes with bilateral and unilateral leg impairment can compete in the same class if the athletes have full trunk function. The results from this study provided important evidence for the development of the evidence-based classification system for para va’a.

Study II examined the inter-rater reliability (IRR) of the new evidence-based classification system for para va’a. Three international classifier teams, each comprised of a medical and technical classifier, classified 12 para va’a athletes using the new trunk, leg and on-water classification test batteries and class allocation. Each classifier team classified each athlete once, thus all athletes were classified three times. The results showed no discrepancies between the classifier teams in class allocation, indicating excellent IRR. Additionally, each classification test battery also showed excellent IRR and only
minor discrepancies were seen between classifier teams in individual tests. The study indicate that the new evidence-based classification system is reliable in terms of IRR.

Ten elite non-impaired kayak athletes and 41 para kayak athletes classified into one of the three classes included in the new evidence-based classification system for para kayak; KL1, KL2 and KL3, participated in study III. Differences between the groups in paddling output and 3D joint angles concerning the upper and lower limbs and the trunk as well as correlations between these joint angles and paddling output were examined. The results showed differences in power output between all classes. Additionally, the KL3 and KL2 athletes could sit more forward flexed with the trunk than the KL1 athletes, and the KL3 athletes had larger knee and ankle ROMs than the KL2 and KL1 athletes. These differences were in accordance with the class descriptions in the new classification system for para-kayak. In addition, significant positive correlations were observed between power output and; maximal shoulder and trunk flexion, trunk and pelvis rotation ROM, and hip, knee, and ankle flexion ROM demonstrating the importance of trunk and leg movement for paddling performance. No significant positive correlations between power output and any of the joint angles were seen for the KL1 and KL3 classes indicating that the classes are valid. A significant positive correlation between power output and hip and knee flexion ROM was however seen in the KL2 class indicating that more research is needed on the impact of impairment on performance.

In study IV differences in kinematic and kinetic performance variables in 11 KL3 athletes with above knee amputation (AK) and 6 KL3 athletes with below knee amputation (BK) were examined. Differences between the amputated (A) and the non-amputated (NA) sides were also examined. 3D kinematics of the trunk, legs and paddle as well as forces at the footrest, seat and paddle were measured. Significant differences between the groups were only observed at the hip joint in flexion ROM, flexion and extension angular velocity and flexion moment where the BK athletes exhibited significantly greater values. Differences between the sides were seen in hip flexion moment and in posterior force and anterior/posterior centre of pressure displacement at the seat. The differences between the groups in hip joint variables did however not result in significant differences between the groups in paddle performance variables. The results indicate that AK and BK athletes may be able to compete in the same class.

This thesis has described how athletes with different impairment differ in key performance determinants for para va’a and para kayak. The results of the thesis also gave indications of that the new evidence-based classification system for para va’a is reliable concerning IRR and that the new evidence-based classification system for para kayak is valid regarding the KL1 and KL3 classes. Future studies examining the impact of impairment on paddling performance and the validity of the systems should preferably be conducted on water to further increase the ecological validity of the studies.
List of scientific papers

This thesis is based on the following studies, referred to in the thesis by their Roman numerals:


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<td>2D</td>
<td>Two-dimensional</td>
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<tr>
<td>3D</td>
<td>Three-dimensional</td>
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<tr>
<td>A</td>
<td>Amputated side</td>
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<tr>
<td>AK</td>
<td>Above knee amputation</td>
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<td>BH</td>
<td>Bottom hand side</td>
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<tr>
<td>BK</td>
<td>Below knee amputation</td>
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<td>BL</td>
<td>Bilateral leg impairment</td>
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<td>COP</td>
<td>Centre of pressure</td>
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<td>GCS</td>
<td>Global coordinate system</td>
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<td>ICC</td>
<td>Intraclass correlation coefficient</td>
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<td>ICF</td>
<td>International Canoe Federation</td>
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<td>IPC</td>
<td>International Paralympic Committee</td>
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<td>IRR</td>
<td>Inter-rater reliability</td>
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<td>IVF</td>
<td>International Va’a Federation</td>
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<td>K1</td>
<td>One person kayak</td>
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<td>KL1</td>
<td>Kayak level 1</td>
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<td>KL2</td>
<td>Kayak level 2</td>
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<tr>
<td>KL3</td>
<td>Kayak level 3</td>
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<tr>
<td>MIC</td>
<td>Minimal impairment criteria</td>
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<tr>
<td>MMT</td>
<td>Manual muscle test</td>
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<tr>
<td>NA</td>
<td>Non-amputated side</td>
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<tr>
<td>ROM</td>
<td>Range of motion</td>
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<tr>
<td>SCI</td>
<td>Spinal cord injury</td>
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<tr>
<td>SCS</td>
<td>Segment coordinate system</td>
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<td>TH</td>
<td>Top hand side</td>
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<td>TL</td>
<td>Trunk and leg impairment</td>
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<td>UL</td>
<td>Unilateral leg impairment</td>
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<td>V1</td>
<td>One person va’a</td>
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<td>Va’a level 2</td>
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<td>VL3</td>
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1 Introduction

Sport for persons with an impairment, also known as para sport, has its origins from World War II where soldiers who were injured were rehabilitated using physical activity and sport (Legg, 2018). The Paralympic Games are the parallel games to the Olympic Games in which athletes with physical, intellectual and visual impairment compete. A common factor for all Paralympic sports is that it is mandatory that athletes partake in classification. Classification entails dividing athletes with similar types of impairments into classes in which they compete. Classification systems enable athletes to compete on a similar level with other athletes and reduce the likelihood of predictable competition. An invalid system is a significant threat to Paralympic sport since a predictable competition where a person with a less severe impairment constantly succeeds, discourages participation in sport for persons with impairment (Beckman et al., 2014; Tweedy & Vanlandewijck, 2011). In order to increase the chance of having valid classification systems, the International Paralympic Committee (IPC) have in their classification code specified that sports should develop sport-specific classification systems which should be based upon multidisciplinary research and focus on the relationship between impairment and key performance determinants (IPC, 2015). This is also a requirement for a specific sport to be included in the Paralympic Games. Examining the performance of elite para athletes therefore not only provides valuable information of which factors can increase performance, but also provides input for creating evidence-based classification systems.

Paracanoe is a sport that involves canoe or kayaking for people with impairments and debuted as an international elite level sport in 2009 (Edwards et al., 2019). It consists of two disciplines, para va’a and para kayak. In 2015 the IPC accepted a new evidence-based classification system for para kayak which resulted in para kayak being included in the Paralympic Games in Rio de Janeiro 2016. A new evidence-based classification system for para va’a was created during the time of this PhD programme of study and was accepted by the IPC in 2018. Para va’a debuted in the Paralympic Games in Tokyo 2021.

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1 Paralympic sport refers to elite level sports contested at the Paralympic Games by athletes with impairment (Legg, 2018).
Because paracanoe is a relatively new competitive sport, no research had been published on elite paracanoe athletes prior to the studies included in this thesis. The overall aim of this thesis was to examine the impact of impairment on key performance determinants in para va’a and para kayak during paddling on ergometers. This would provide evidence for the creation of the evidence-based classification system for para va’a and increase the knowledge about the new evidence-based classification system for para-kayak. Additionally, the aim was also to examine the reliability of the new classification system for para va’a and the validity of the new classification system for para kayak.
2 Background

2.1 Paralympic sport

During World War II soldiers who obtained a spinal cord injury (SCI) had a good chance of surviving due to better evacuation techniques and the invention of penicillin (Legg, 2018). Since more soldiers survived, there was a need for rehabilitation of these injured soldiers in order to enhance independence and improve inclusion into society. The Stoke Mandeville Hospital in Great Britain therefore opened a SCI centre under the lead of neurosurgeon Sir Ludwig Guttmann. Sir Ludwig Guttmann used sports and physical activity as rehabilitation methods for soldiers who had acquired a SCI during the war (Legg, 2018). In 1948, on the same day as the opening of the Olympic Games, Sir Ludwig Guttmann hosted the Stoke Mandeville Games where British soldiers with SCI competed in archery. These games became very popular and soon became an international event as more countries wanted to join. In 1960 the Stoke Mandeville Games were held in Rome shortly after and at the same venues as the recently concluded Olympic Games. 400 athletes from 23 countries participated (Legg, 2018) and these Games are often referred to as the birth of the Paralympic Games and the Paralympic Movement. The word “Paralympic” originates from the Greek preposition “para” (beside or alongside) and the word “Olympic”. The Paralympic Games are therefore intended to be parallel Games to the Olympic Games to illustrate that the two movements exist beside each other (IPC, 2021; Legg, 2018). Since 1988, both the summer and winter Paralympic Games have been held right after the Olympic Games and at the same venues. In 1989, the IPC was founded as an international non-profit organisation to act as the global governing body of the Paralympic Movement (IPC, 2021). Every bid for the Olympic Games must now include a bid to host the Paralympic Games, which is regulated by an agreement between the IPC and the International Olympic Committee (Legg, 2018). The interest in the Paralympic Games has increased markedly during recent years and has millions of spectators and billions of TV viewers (IPC, 2019). In 2021, there were 22 summer sports and six winter sports included in the Paralympic Games (Table 1). The 2020 Paralympic Games were held in Tokyo in 2021 due to the Covid-19 pandemic.
Table 1. List of the summer and winter sports included in the Paralympic Games in 2021 and 2022.

<table>
<thead>
<tr>
<th>Paralympic Summer sports</th>
<th>Paralympic Winter sports</th>
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<tr>
<td>Archery</td>
<td>Alpine</td>
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<td>Athletics</td>
<td>Biathlon</td>
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<td>Badminton</td>
<td>Cross-country skiing</td>
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<td>Boccia</td>
<td>Ice hockey</td>
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<td>Canoe</td>
<td>Snowboard</td>
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<td>Cycling</td>
<td>Wheelchair curling</td>
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<td>Equestrian</td>
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<td>Football 5-a-side</td>
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<td>Goalball</td>
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<td>Judo</td>
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<td>Powerlifting</td>
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<td>Shooting</td>
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<td>Sitting volleyball</td>
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<td>Swimming</td>
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<td>Table tennis</td>
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<tr>
<td>Taekwondo</td>
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<td>Triathlon</td>
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<td>Wheelchair basketball</td>
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<td>Wheelchair fencing</td>
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<td>Wheelchair rugby</td>
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<td>Wheelchair rugby</td>
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<td>Wheelchair tennis</td>
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2.2 Classification in Paralympic sport

In order to achieve fair competition, classification has been a part of the Paralympic movement since its beginning. Classification in para sport entails deciding who is eligible to compete and dividing para athletes into groups by the degree of activity limitation resulting from the impairment. Classification is an integral part of para sport and aims to minimise the impact of the impairment on athletes’ performance (Tweedy & Vanlandewijck, 2011).

When the Paralympic movement first started, classification was based on medical evaluation and did not place emphasis on assessing the impact of the impairments on the sporting activity (IPC, 2015). This type of system grouped athletes with similar
medical diagnoses in the same class regardless of which sport they competed in. Conceptually, this meant for example that athletes with an amputation above the elbow competed in the same class in swimming as they would in long distance running, even though the impairment would have a larger impact on swimming performance than on long distance running performance.

As the Paralympic movement grew, athletes with a larger variety of impairments began participating and the focus on competition rather than rehabilitation increased. Medical classification systems were therefore no longer plausible, and the development of functional classification systems began (Legg, 2018; Tweedy & Vanlandewijck, 2011). In the functional classification systems, the impact of impairments on sports performance was assessed rather than the medical diagnosis (Tweedy & Vanlandewijck, 2011). These functional classification systems were however strongly based on the opinions of classifiers with medical background or expert knowledge within the sport, and not on concrete scientific evidence. In the 2007 classification code the IPC wrote that sports should develop evidence-based classification systems that are based upon multidisciplinary research (IPC, 2007). Having classification systems based on evidence increases the chance of achieving valid systems of classification. A valid classification system aims to ensure that athletes who succeed in Paralympic sport do so because they have the most favourable anthropometric, physiological and psychological attributes and have enhanced them through training and diet and not because their impairment is less severe than their competitors’ (Beckman et al., 2014; Tweedy et al., 2014; Tweedy & Vanlandewijck, 2011).

In 2011 a position stand was published which described the scientific principles underpinning classification in Paralympic sport (Tweedy & Vanlandewick, 2011). This also defined the term evidence-based classification systems and provided guidelines how to achieve evidence-based classification (Tweedy & Vanlandewick, 2011). The purpose of evidence-based classification was stated as “promote participation in sport by people with disabilities by minimising the impact of eligible types of impairment on the outcome of competition” (Tweedy & Vanlandewick, 2011, p.265). Impairments that were eligible for classification in Paralympic sport were defined: visual impairment, intellectual impairment, and physical impairment. The eligible types of physical impairment were also defined: impaired muscle power, impaired passive range of motion (ROM), hypertonia, ataxia, athetosis, limb deficiency, leg length difference and short stature (Tweedy & Vanlandewijck, 2011). This means that for example an athlete with a hearing impairment or an athlete who has a medical condition which primarily causes pain, such as for example fibromyalgia, are not eligible to compete in Paralympic sports. Additionally, each sport is required to define which impairment types are eligible for that specific sport. This means that for example an athlete with short stature cannot compete in all of the 28 Paralympic sports. To compete in boccia or wheelchair
rugby for instance, the eligible impairment types are impaired muscle power, athetosis, hypertonia, ataxia, impaired passive ROM or limb deficiency. In paracanoe only athletes with impaired muscle power, impaired passive ROM and limb deficiency are eligible. In addition to having an eligible impairment, the impairment needs to be severe enough to have an impact on the performance in the sport and discipline the athlete wants to compete in. This is termed the minimal impairment criteria (MIC) and is different between sports due to different key performance determinants and different impairments having different impacts on performance (Tweedy et al., 2014; Tweedy & Vanlandewijck, 2011).

2.3 Evidence-based classification research

In the newest version of the Paralympic classification code from 2015, it states that the “International Sports Federations must develop sport-specific classification systems through multidisciplinary research. Such research must be evidence-based and focus on the relationship between impairment and key performance determinants” (IPC, 2015, p. 11). Tweedy et al. (2014) described a stepwise process consisting of three steps for the development of evidence-based classification. This was further developed by Tweedy et al. (2016) and now consists of five steps:

1. Identify the impairment type/s to be classified.
2. Develop theoretical model of the determinants of sports performance.
3a. Develop valid measures of impairment/s (i.e., specific to the impairment; quantitative; reliable; precise; parsimonious; training resistant; and ratio scaled).
4. Assess the relative strength of association between valid measures of impairment and sports performance.
5. Use outcomes from step 4 to determine MIC, number of classes and class profiles.

Since the decision to make classification systems based upon research compulsory, sport specific classification research has been conducted in numerous Paralympic sports including for example wheelchair rugby (Altmann et al., 2013, 2016, 2017; Mason et al., 2020), swimming (Burkett et al., 2018; Hogarth et al., 2018, 2019a, 2019b, 2020; Nicholson et al., 2018; Payton et al., 2020), Nordic skiing (Rosso et al., 2016, 2019; Pernot et al., 2011), and athletics (Beckman et al., 2016; Connick et al., 2015; Vanlandewijck et al., 2011).
The classification research has adopted many different approaches, yet most have included one or more of the above-mentioned steps. The research has especially been focused upon developing valid measures of impairment and the relation between measures of impairment and sports performance.

2.3.1 Reliability and validity of classification tests and systems

It is important that the classification systems are reliable and valid. If classifiers are classifying athletes with similar impairments inconsistently due to unreliable and invalid classification tests or if the athlete with less impairment always wins, then the credibility of the classifiers and the classification system becomes flawed. Examining the reliability and validity of the classification tests and systems is therefore important since it is vital that the athletes are placed in the correct class for a fair competition.

Inter-rater reliability (IRR) of classification tests has been examined in multiple sports. Altmann et al. (2013) examined the IRR of a revised classification system for trunk impairment in wheelchair rugby. The IRR was shown to be adequate for the trunk impairment test with an overall Fleiss Kappa of 0.76 in a first session and of 0.75 in a second session after the descriptions of tests had been improved from the first session. In para Nordic skiing, the test-table-test used for assessing trunk impairment in sit-skiing athletes has also demonstrated an overall good IRR (Pernot et al., 2011). A disagreement in class allocation was observed in 4 out of 33 athletes but a Spearman rank correlation coefficient of 0.95 was seen (Pernot et al., 2011) which corresponds to an overall Fleiss Kappa of 0.8 according to Altmann et al. (2013). In swimming, the inter- and intra-rater reliability has been examined of a test battery that could potentially be used as a measure of impairment for athletes with impaired passive ROM (Nicholson et al., 2018). The study found that the test battery had good to excellent reliability in non-impaired participants.

The validity of new classification tests, methods or classes have also been examined throughout different sports. In wheelchair rugby the validity of the trunk impairment classification system (Altmann et al., 2016) and the validity of an isometric strength test battery measuring arm strength impairment (Mason et al., 2020) have been studied. The validity of the trunk impairment classification system was studied by examining its relation to objective instrumented measures of impairment which consisted of trunk muscle strength and of static and dynamic sitting balance performed in a chair mounted on a force plate (Altmann et al., 2016). The new trunk classification system had an adequate validity in athletes with severe and moderate neuromusculoskeletal trunk impairment but the authors concluded that more research is needed to establish validity for athletes with mild to moderate trunk impairment. The isometric strength test battery for measuring arm strength impairment was shown to be valid as it could differentiate between
people without impairment and wheelchair rugby athletes with arm impairment (Mason et al., 2020). Similarly, in para swimming, Hogarth et al. (2019a) have examined the validity of isometric strength measurements for classification of para athletes with impaired strength. As in the study by Mason et al. (2020), the study indicated that the isometric strength test battery could differentiate non-impaired participants from para swimmers. These studies are important because it is vital to have tests which can differentiate non-impaired persons from para athletes, which is also important for establishing MIC. The studies did however not examine whether the test batteries could differentiate para athletes with different strength resulting from the impairment which is of importance for class allocation. The test-table-test used for classification of sit-skiing athletes has not only been examined for IRR, but also for validity (Pernot., 2011). The test apparatus that is used during the test-table-test was placed upon a force plate to measure centre of pressure (COP) in order to test for validity. The test exhibited high correlations with the COP displacement except for in two classes concluding that further refinement of the test-table-test may be warranted (Pernot et., 2011).

The validity of a whole class has also been examined in wheelchair tennis. Cavedon et al. (2014) examined differences in kinematic performance variables in open class wheelchair tennis players when divided into own constructed groups based on level of impairment. The results showed that there were differences between the groups in key performance determinants such as post impact ball velocity after the first and second serves. Furthermore, a correlation between both the post impact velocities and shoulder angle after impact and group was also found. These results indicate that the open class in wheelchair tennis is not a valid class.

2.3.2 Relationship between measures of impairment and performance

The relation between impairment and performance has also been examined in different para sports. In wheelchair rugby, the relation between trunk impairment and performance determining activities has been examined (Altmann et al., 2017). It was shown that trunk impairment was the most important factor in tilting the chair, impulse of a hit and acceleration in the first meter. The results implied that athletes with higher scores in the trunk impairment classification system are more proficient in wheelchair rugby than athletes with lower scores (Altmann et al., 2017).

In para swimming, Payton et al. (2020) examined the strength of association between measures of active and passive drag and type of impairment, swimming performance and sport class. Para swimmers with limb deficiency and central motor and neuromuscular impairments as well as highly trained non-impaired swimmers participated in the
study. Active and passive drag were the only determinants of swimming speed of athletes with central motor and neuromuscular impairments. These measures did however not explain the activity limitation within the group of para swimmers with anthropometric impairments. The authors suggested that the classification of these groups of athletes should be different (Payton et al., 2020). The results provide important information for the sport in terms of understanding what factors should be taken into consideration during classification.

Relationships between impairment and performance have also been examined in athletic events such as running (Beckman et al., 2016; Connick et al., 2015) and wheelchair racing (Vanlandewijck et al., 2011a). In running the relationship between running performance and lower body strength, ROM and coordination has been examined in non-impaired runners and para runners with impairments causing ataxia, hypertonia or athetosis (Beckman et al., 2016; Connick et al., 2015). In the study where the relation between running performance and lower body strength was examined, the results suggested that strength was not an important predictor of running performance in athletes with mild impairments to muscle strength as a result of impairment causing ataxia, hypertonia or athetosis (Beckman et al., 2016). The authors concluded that the relationship between strength and performance in athletes with more severe impairments to muscle strength should be examined. In the study of the relationship on running performance and ROM and coordination, the results showed that five of the ROM measures significantly affected sprint performance in the para athletes (Connick et al., 2015). These measures were deemed valid for the purposes of classifying impairments in some of the classes, but no correlations were seen between performance and any of the coordination tests and are therefore not valid to use in classification (Connick et al., 2015). In wheelchair track racing the relation between impaired trunk strength and performance has been examined (Vanlandewijck et al., 2011a). The results showed that there were no differences between male wheelchair athletes with full trunk strength and without full trunk strength in distance covered after 1, 2 and 3 s. In addition, no significant correlations were observed between trunk strength and wheelchair track acceleration (Vanlandewijck et al. 2011a). The authors concluded that in track athletics it is valid to have athletes with and without trunk impairment in the same class which is important evidence for developing an evidence-based classification system.
2.4 Paracanoe

In paracanoe, athletes with physical impairments compete over 200 m in one of two disciplines, para va’a or para kayak. Para va’a is competed in an outrigger canoe and is propelled using a single blade paddle, whereas para kayak is competed in a kayak and is propelled using a double-blade paddle (Figure 1). Paracanoe as an international competitive sport is relatively new, the first World Championships in paracanoe were held in 2009 in Dartmouth, Canada (Edwards et al., 2019). During the 2009 World Championships, 27 para athletes from seven federations participated. The participation in paracanoe has grown considerably since then, and in 2019 the Paracanoe World Championships had 169 athletes from 41 federations participating. Since the sport is relatively new, no known research has been published on elite paracanoe athletes (except for the articles within this thesis), however research conducted on elite non-impaired athletes is described below.

2.4.1 Va’a paddling

The outrigger canoe has been a common means of transportation in Oceania but has evolved to an international competitive sport. In Tahiti the word for an outrigger canoe is va’a and this thesis will henceforth use the term va’a. This terminology is consistent with the terminology chosen by the International Va’a Federation (IVF) which is the international governing body for outrigger/va’a. The va’as can seat one person (V1), six persons (V6) or 12 persons (V12). In the literature, the terms outrigger and va’a are commonly used interchangeably but there are actually small differences between the one person canoes (OC1 and V1). The OC1 is a newer form of canoe that has a rudder (a steering device) which the V1 does not have. This makes the V1 more challenging to paddle (West, 2014). Additionally, in the OC1 the athletes sit higher up in the cockpit whilst in the V1 the athletes sit lower inside in the cockpit (West, 2014).
The IVF govern the World Championships in distance and sprint va’a for non-impaired athletes. In the distance races athletes compete in V1 or V6 over 16 or 24 km. In sprint races, athletes compete over 500, 1000 or 1500 m in V1, V6 or V12. For para va’a the international competitions are governed by either the IVF or the International Canoe Federation (ICF). The IVF governed para va’a races are either V1 races over 250 or 500 m, V6 races over 500 or 1000 m or V12 races over 500 m. The IVF governed competitions are traditionally contested on open water. The ICF governed para va’a races on the other hand are V1 races over 200 m on flat water, which is what this thesis will focus on.

The va’as have an outrigger assembly on the side called ama which is held into place by two booms called i’ato (Figure 2). The boat restrictions in para va’a are that the va’a must be a maximum of 7.3 m long and weigh a minimum of 13 kg (this includes the hull, ama and i’ato) (ICF, 2019). In in para va’a, unlike in non-impaired va’a paddling, the athletes are allowed to use a footrest. In addition, para va’a athletes are allowed to use either a sit-in va’a or a sit-on-top va’a (ICF, 2019).

Figure 2. An example of a V1 paracanoe from the manufacturer Plastex. Picture adapted with permission from Plastex.

Limited research has been conducted on non-impaired va’a paddlers. From a non-impaired perspective, it has been noted that the use of the trunk and legs in va’a paddling seem to vary amongst traditions, and two common paddling styles have been described (Sealey et al., 2011). Using a greater trunk flexion/extension ROM and a longer stroke is termed ‘Hawaiian style’, whereas having more trunk rotation and a shorter stroke is termed ‘Tahitian style’ (Sealey et al., 2011). Since each paddling style involves a combination of trunk flexion/extension and rotation, the trunk clearly plays an active role in va’a paddling (Sealey et al., 2011). The contribution of the legs to the va’a momentum has not been researched. It has however been described that for a crew boat paddler, the leg on the paddling side is positioned with the hip and knee flexed and pushing isometrically against the hull, whilst the non-paddling side leg is positioned behind the seat.
(Sealey, 2010) (Figure 3). During V1 paddling it is however common to sit with both legs in front (Figure 3) (West, 2014).

In crew boat paddling it has been described that it is common to switch paddling sides after 14-15 strokes (Humphries et al., 2000). It is however not uncommon in V1 paddling to spend a lot of paddling time on the ama side since greater power can be applied over a longer distance and a straighter line can be maintained (West, 2014). In sprint distances it is even more common to spend most of the time paddling on the ama side, only to briefly switch sides to steer the boat (since the va’a does not have a rudder) or rest the arms (West, 2014). Since the competition distance in para-va’a is 200 m, many athletes tend to paddle on their dominant side the entire race or only switch and paddle a few strokes on the non-dominant side.

Limited research has been conducted on competitive va’a paddling and most research has been in the physiological field (Kerr et al., 2008; Sealey et al., 2010, 2011). The kinanthropometric characteristics in va’a paddlers (Humphries et al., 2000) and kinematics during va’a paddling in female paddlers (Sealey et al., 2011) have been examined. Due to the asymmetrical nature of the va’a stroke, it was shown that there are significant differences between the dominant and non-dominant side in isokinetic flexion and extension torque of the shoulder joint (Humphries et al., 2000). Sealey et al. (2011) conducted a study on experienced competitive female va’a paddlers with the aim to identify the effect of different techniques using different stroke rates on various kinematic parameters during 1000 m ergometer paddling. It was found that during the higher stroke rate technique, the athletes adopted a shorter stroke whereas during the lower stroke rate technique, the athletes adopted a longer stroke and used a greater range of trunk flexion movement.
2.4.2 Kayak paddling

International level canoe and kayak competitions are governed by the ICF. In non-impaired canoeing, the disciplines are canoe sprint, canoe slalom, extreme canoe slalom, canoe marathon, canoe polo, wildwater canoeing, canoe freestyle, dragon boat, canoe ocean racing and stand-up paddling (https://www.canoeicf.com/). Canoe sprint has been an Olympic sport since 1936 and includes kayaking and canoeing. The kayak discipline in canoe sprint is the non-impaired equivalent to para kayak. In non-impaired kayaking the athletes compete over 200, 500, 1000 and 5000 m races in a kayak which seats one person (K1), two persons (K2) or four persons (K4). In para kayak the athletes compete in a K1 over 200 m. The boat restrictions for K1 kayaks are that they must have a maximum length of 5.2 m and weigh a minimum of 12 kg (ICF, 2019). An additional rule for the K1 para kayaks is that they must have a minimum width of 50 cm (Figure 4). Para kayaks, like sprint kayaks, are allowed to have one rudder.

Figure 4. An example of a K1 para kayak from the manufacturer Plastex. Picture used with permission from Plastex.

From a biomechanical point of view, kayak average velocity is mainly dependent on the kayak athlete’s ability to generate propulsion and to minimise the drag forces acting on the kayak (Michael et al., 2009). Understanding the motion of the kayak and the athlete and the forces acting on the kayak is important to know how to maximise kayak paddling performance (Michael et al., 2009).

The kayak paddling movement is complex and involves three-dimensional (3D) arm, trunk and pelvic movements combined with a coordinated two-dimensional (2D) leg movement during the kayak stroke. Kinematic analyses conducted on kayak ergometer paddling have examined 2D (Fleming et al., 2012a; Mann & Kearney, 1980) and 3D kinematics (Bjerkefors et al., 2018; Fleming et al., 2012b; Wassinger et al., 2011). Due to the complex 3D upper-body movement during kayaking, previous kinematic kayak research has mainly focused on upper-body movement (Fleming et al., 2012b; Wassinger et al., 2011). It has for example been found that experienced wildwater kayakers had no kinematic differences between body sides during paddling on a kayak ergometer (Wassinger et al., 2011) and that the mean values for humeral elevation ranged from 18 to 76° during the kayak stroke cycle. In elite flat-water kayakers it has been shown that the overhead arm movements, defined as elbow over acromion, during flat-water kayaking accounted for approximately 40% of the stroke cycle (Fleming et al., 2012b).
Only two studies have previously examined both the upper and lower body kinematics in kayak paddling (Bjerkefors et al., 2018; Limonta et al., 2010). Limonta et al. (2010) found that male elite athletes have a significantly higher pelvis rotation ROM compared to male intermediate and novice paddlers and a higher trunk rotation ROM compared to novice paddlers during kayak ergometer paddling. Bjerkefors et al. (2018) found that in elite male and female athletes the trunk and pelvis rotation ROM and hip, knee and ankle flexion ROM as well as power output increased from paddling at a low intensity level to paddling at a high intensity level on a kayak ergometer. The results indicated that the movement of the trunk, pelvis and legs contribute to paddling power output. Similar results have been found by Brown et al. (2011) who conducted a notational analysis of international, national and club level sprint kayakers. It was found that the rotation of the trunk and pelvis plays a dominant role in technique and performance (Brown et al., 2011). Additionally, a clear link between race time and greater motion of the legs, whilst minimising any lateral motion of the body, was also found.

The kayak paddle transmits the water-on-blade reaction forces through the paddler to the kayak via the footrest and seat (Michael et al., 2009). A forward movement occurs because the paddler applies a force against the water through the paddle blade (Michael et al., 2009). Forces at the paddle (Gomes et al., 2015; Nilsson & Rosdahl, 2016), seat (Begon et al., 2009) and footrest (Begon et al., 2009; Begon et al., 2010; Klitgaard et al., 2021; Nilsson & Rosdahl, 2016) have been measured during both on-water paddling and kayak ergometer paddling. Gomes et al. (2015) examined the magnitude and shape of the paddle force–time curve at different stroke rates to understand its impact on performance. To maximise performance a rectangular force time profile is desired which Gomes et al. (2015) suggested can be achieved by having a stronger water phase with a rapid increase in force immediately after paddle blade entry, and a quick exit before the force drops far below the maximum force.

Measuring the forces at the seat and footrest have been of interest since it has been shown that the push and pull forces on the footrest contribute to performance (Klitgaard et al., 2021; Nilsson & Rosdahl, 2014, 2016). Nilsson and Rosdahl (2014) created and validated a new portable device for measuring the push and pull forces on the footrest and the horizontal forces generated at the seat during paddling. The method for measuring force at the footrest was used in a study examining the role of the legs in kayak paddling in five elite non-impaired athletes when paddling on water (Nilsson & Rosdahl, 2016). The results showed that restricting the leg movement during paddling resulted in a reduction of up to 21% in mean paddle stroke force and 16% reduction in kayak mean speed (Nilsson & Rosdahl, 2016). Klitgaard et al. (2021) have also examined forces at the footrest and kayak velocity during paddling on water in girls under 16, boys under 18, and senior men and women. The study found that the four characteristics of leg pushing force (mean force, peak force, impulse over one stroke cycle, impulse over 10
seconds) all demonstrated a significant positive relationship with kayak velocity. This indicates that leg pushing force is a vital factor for increasing kayak velocity (Klitgaard et al., 2021). Begon et al. (2010) examined lower limb contribution to kayak performance during kayak ergometer paddling by computer simulation modelling and found that the asymmetric leg movement seen during kayak paddling produces about 6% of the propulsion. Furthermore, this movement contributes to pelvis rotation and pelvis rotation was shown to increase paddle velocity (Begon et al., 2010).

Few studies have been conducted on paracanoe. Kayak paddling has shown to significantly improve functional performance, shoulder muscle strength, and the ability to maintain an upright sitting posture in response to externally generated balance perturbations in people with long-standing SCI (Bjerkefors et al., 2006, 2007; Bjerkefors & Thorstensson, 2006; Grigorenko et al., 2004). Furthermore, a case study conducted on a male recreational para kayaker with a transfemoral amputation found that when the para kayaker did not use a prosthesis, the power output and stroke speed increased compared to when the kayaker used a prosthesis (Ellis et al., 2018). The authors however concluded that the kayak stroke became erratic which was not optimal for performance. It should be acknowledged that when the para kayaker did not wear a prosthesis, he did not have any support for the residual limb either. In elite para kayak, athletes who have a transfemoral amputation often use an adaptation which is fastened securely to the boat in which the residual limb is fastened. This facilitates force transmission from the body to the kayak.

2.5 The paracanoe classification systems

2.5.1 The paracanoe classification systems between 2009-2014
The paracanoe classification system that was used for both para va’a and para kayak between 2009 and 2014 was a functional classification system which was adapted from the para-rowing classification system and consisted of three classes: Arms, Trunk and Arms and Leg, Trunk and Arms. As the names suggest, the Arms class included athletes with arm function, and was the class which included athletes with the greatest impairment. The Trunk and Arms class included athletes with arm and trunk function and the Legs, Trunk and Arms class included athletes with function in arms, trunk, and partial function in legs. The athletes were assessed based on muscle strength and joint ROM using manual muscle testing (MMT) for upper and lower limbs on a 0 to 5 scale. The trunk test battery consisted of three tests scored from 0 to 2. A technical observation, although not scored, was also performed on ergometers and on water. This system had no research supporting the class structures or class allocation. In 2010 the IPC decided
to include paracanoe as sport to be contested at the Paralympic Games in Rio de Janeiro 2016. Paracanoe was however conditionally approved provided that the sport, amongst other conditions, develop and implement a classification system based on scientific evidence (Edwards et al., 2019).

2.5.2 The development of new evidence-based classification systems for paracanoe

In September 2012 a research team from The Swedish School of Sport and Health Sciences (GIH) lead by Associate Professor Anna Bjerkefors, was recruited by the ICF to assist in the development of the new evidence-based classification systems. The deadline to have finished the systems was set to December 31st 2014. The deadline was set so that the IPC could approve the system in February 2015 and be implemented during 2015 before the Paralympic Games in 2016. The implementation included informing and educating the national federations and classifiers as well as reclassifying all athletes in the new system.

The development of the evidence-based classification systems for paracanoe was similar to the stepwise process of creating evidence-based classification systems described by Tweedy et al. (2016) and will be explained in short in the following section. More details about the processes of how the evidence-based classification systems for para va’a and para kayak were developed are described in the classification system proposals to IPC (Appendix 1 for para va’a and Appendix 2 for para kayak). Step 1 was to define the eligible impairment types for paracanoe which were: impaired muscle power, impaired passive ROM and limb deficiency. Step 2 was to define key performance determinants for para va’a and para kayak since no studies had previously been conducted in these sports. As mentioned in the sections above (2.4.1 Va’a paddling and 2.4.2 Kayak paddling) the sports are quite different from each other and a separate study on each sport was necessary. This was performed by conducting studies on non-impaired va’a and kayak athletes and para va’a and para kayak athletes during paddling on ergometers. The results from the va’a study are described in this thesis (study I). Results from the para kayak study showed that the abilities to sit with the trunk in a slightly forward flexed position, rotate the trunk and pelvis and flex and extend the hip, knee and ankle joints were correlated with paddling power output (study III). These studies also defined the sport specific joint ROMs for the trunk and leg movements.
In step 3, new medical test batteries evaluating trunk and leg function\(^2\), performed in the defined sports-specific ROM, were developed for each sport. Additionally, technical on-water test batteries for para va’a and para kayak were developed where trunk and leg function during paddling are evaluated. The 4\(^{th}\) step was to examine the test batteries’ relations with performance. Strong correlations between the para va’a and para kayak medical and technical test batteries and paddling performance were observed (Appendices 1 and 2). In step 5 further statistical analyses including k-means cluster analyses were performed to define sport classes for the new evidence-based classification systems for para va’a and para kayak (Appendices 1 and 2).

The results from the research studies and statistics conducted formed the basis of the sports’ new classification systems and two proposals were in 2015 submitted to the IPC, one for the classification system for para kayak (Appendix 2) and one for the classification system for para va’a which was done in collaboration with a research team at Loughborough University led by Professor Vicky Tolfrey. The para kayak classification system was accepted by the IPC in 2015 which resulted in para kayak being introduced in the 2016 Paralympic Games in Rio. The para va’a system was however not directly accepted by the IPC due to too few elite level athletes included in the research study, and para va’a was therefore not included in the 2016 Paralympic Games. The recommendation from IPC was to include more international level para va’a athletes. Between 2015 and 2017 data from 30 more elite para va’a athletes were therefore collected and analysed (study 1) and a new evidence-based classification system proposal was submitted to IPC in the end of 2017 (Appendix 1). In 2018 the para va’a classification system was accepted by the IPC and para va’a was also accepted to be included in the Paralympic Games. The whole sport of Paracanoe, including both disciplines, therefore debuted in the Paralympic Games in Tokyo 2021.

2.5.3 The new evidence-based paracanoe classification systems

The classification systems for both disciplines consists of three classes: Va’a Level 1 (VL1), Va’a Level 2 (VL2) and Va’a Level 3 (VL3) for para va’a and Kayak Level 1 (KL1), Kayak Level 2 (KL2) and Kayak Level 3 (KL3) for para kayak. The greater the number the less impairment the athletes have. In order to be allocated to a class, the athletes need to go through a medical and a technical assessment. The medical assessment consists of the newly developed trunk (c.f. 2.5.3.1) and leg test (c.f. 2.5.3.2) batteries,

\(^2\) Unfortunately, a low number of para athletes with upper limb impairment participated in the research studies which formed the basis of the new classification systems. Therefore, no conclusions could be drawn regarding the effect of different upper limb impairments on paddling performance. The current classification systems do therefore unfortunately not include athletes with solely upper limb impairment.
and the technical assessment consists of the newly developed on-water test battery (c.f. 2.5.3.3).

2.5.3.1 Trunk test batteries

The trunk test batteries in the para va’a and para kayak classification systems consist of 42 tests (examples of tests are seen in Figure 5) and are scored on a 0 to 2 scale. The trunk test battery consists of two parts: in the first part the athlete lays on a bench and perform trunk flexion, trunk rotation, trunk bending and trunk extension. The second part consists of static, dynamic and perturbation tests where the athlete is sitting on the bench. The perturbation tests are performed with or without a wobble cushion. In para va’a it is however only the six dynamic tests that are used towards class allocation and MIC; trunk flexion, trunk extension, trunk bending to each side and trunk rotation to each side. The trunk test battery manual where detailed descriptions of how to perform and score each test is found in Appendix 3.

![Figure 5. Examples of trunk tests included in the trunk test batteries. From left: dynamic trunk flexion and perturbation test. More detailed information of each test included in the trunk test battery can be found in the trunk test manual (Appendix 3).](image)
2.5.3.2 Leg test batteries

The leg test battery for both disciplines consists of 14 tests where the function in hip, knee and ankle flexion and extension for each leg in sport-specific ROM are scored on a 0 to 2 scale. Each discipline also has its separate leg press test which is performed for each leg (Figure 6). The manual for the para va’a leg test battery is found in Appendix 4.

Figure 6. Examples of leg tests included in the leg test batteries. From left: leg press for para va’a classification and leg press for para kayak classification. More detailed information can be found in the leg test manual (Appendix 4).

2.5.3.3 On-water test batteries

The on-water test battery consists of three tests for para va’a classification and six tests for para kayak classification. The tests were developed based upon what was shown to be correlated with performance in the studies conducted for the classification systems (correlation results are presented in studies I and III). For para va’a the items are: leg movement of the leg that moves the most, trunk rotation and trunk flexion and for para kayak: trunk flexion, trunk rotation, trunk bending, balance and left and right leg movement and. The on-water test battery manual for para va’a is found in Appendix 5.

During the on-water tests the athletes use their own preferred boat and individual adaptations so that the boat setup replicates what the athlete normally uses during competition. The athletes must hand in an equipment passport prior to classification and competition which demonstrates the equipment used and how the athlete uses it. The equipment the athletes uses during classification must then be used during all competitions. To ensure this, the equipment passport is checked during every competition. If the athlete wishes to make a change in the adaptive equipment or how the equipment is used, the athletes must submit a request to the Head of Classification prior to the competition. The Head of Classification decide if the equipment change warrant a re-classification of the athlete (ICF, 2019).
2.5.3.4 Minimal impairment criteria (MIC)

The MIC differ between the two disciplines. To meet the MIC for para va’a, the athletes have three options. The first two criteria refer to the legs where MIC is defined as having a loss of 10 points or more in one leg or a loss of 11 points or more over two legs in the leg test battery. This corresponds, for example, to an athlete with no function in the ankle or the knee (will lose 10 points) or an athlete with partial leg function in both legs. In addition to the MIC for the legs, a MIC for the trunk has also been established to include para va’a athletes with an impairment that affects the trunk more than the legs. These athletes need to have a loss of 7.5 points or more on the trunk test battery and in addition they need to have a loss of 8 points or more on the leg test battery. The MIC for competing in para kayak is that the athlete needs to have a loss of at least four points on one leg in the leg test battery. This corresponds to for example having no function in an ankle joint such as having an amputation below the knee.

2.5.3.5 Class allocation

The class allocation for para va’a and para kayak classification systems are also quite different. This leads to there being a difference in the characteristics of the classes between the two disciplines where a para va’a athlete in for instance the VL3 class can have more impairment than a para kayak athlete in the KL3 class (Figure 7). For example, an athlete with bilateral above knee amputation can compete in the VL3 class in va’a and the KL2 class in kayak.

![Diagram of class allocation](image)

Figure 7. A graphical demonstration over the overlapping nature of the para va’a and para kayak classification systems. One athlete who competes in both disciplines can compete in different classes in the different disciplines whilst another athlete can compete in the same class in both disciplines.

For para kayak, each test battery results in a total score which is placed in a cluster ranging from one to three (Figure 8). The cluster numbers from each test battery are then
added into a total cluster score ranging from three to nine (Figure 9). Athletes with a total cluster score of 3 are allocated the KL1 class (Figure 9). Athletes in KL1 therefore have the most severe impairments and are typically athletes with very limited or no function in either trunk or legs, for example, athletes with a complete SCI at thoracic level. Athletes with a total cluster score of 4 to 7 are allocated the KL2 class (Figure 9). Athletes in KL2 have less severe impairments than KL1 and are typically athletes with limited or full function in trunk and limited or no leg function. This includes for example, an athlete with a bilateral above knee amputation or an athlete with an incomplete SCI at T12-L5 level. Athletes with a total cluster score of 8 or 9 are allocated the KL3 class (Figure 9). Athletes in KL3 have the least severe impairments, typically athletes with near to full or full function in the trunk and limited function in one or both legs. This includes for example athletes with unilateral above or below knee amputation.

![Diagram of cluster allocation](image)

**Figure 8. Schematic of the cluster allocation for each classification test.**

![Diagram of para kayak class allocation](image)

**Figure 9. Schematic of the para kayak class allocation**
For the para va’a classification system the total scores from the trunk and on-water test batteries are each multiplied with a conversion factor. This was decided due to a desire to have all three test batteries weighted equally since the total scores for eligible athletes vary (6 points for the on-water test, 12 points for the dynamic trunk test and 18 points for the leg test). The on-water test battery score is multiplied with three and the trunk test battery score is multiplied with 1.5 in order to reach the same total score as for the leg test (18 points) (Appendix 1). The athletes who are allocated the lowest functioning class, VL1 (Figure 10) have no dynamic trunk function which is defined as not being able to sit upright on a bench with the legs hanging whilst the thighs and/or pelvis are secured and not moving the trunk in flexion, extension, rotation and lateral flexion. This corresponds to having 0 points on the dynamic tasks in the trunk test. These athletes do not have any leg function (0 points on leg test) and should not score any points in the on-water test. These athletes therefore have a total score of 0. Athletes in VL1 are typically athletes with a SCI at T6 or above. Athletes with full dynamic trunk function or almost full dynamic trunk function (15-18 points) and score 18 points or below on the leg test and on-water test are allocated the VL3 class. The exception to this rule are athletes who score 13.5 points or lower in the trunk test but have a total score of 28 points or over, they are also allocated the VL3 class athletes. The athletes in the VL3 class can for instance have a unilateral above knee amputation or a bilateral above knee amputation. Athletes scoring between 1.5 and 13.5 points on the trunk test and have a total score of 27 points or lower are allocated the VL2 class (Figure 10). Athletes in the VL2 class can be athletes with partial trunk function for instance athletes with an SCI at T12 level.

Figure 10. Schematic of the para va’a class allocation
3 Aims

The overall aim of this thesis was to examine the effect of impairment on performance determinants in para va’a and para kayak athletes during paddling on ergometers to provide evidence for the development of the evidence-based classification system for para va’a and to increase the knowledge about the evidence-based classification system for para-kayak. The aim was also to examine the reliability of the new classification system for para va’a and the validity of the new classification system for para kayak. The specific aims of each study are specified below.

**Study I**: To examine kinematic and kinetic performance variables in non-impaired va’a and para va’a athletes during high intensity va’a ergometer paddling and to determine whether differences exist based on the level of impairment. Secondly, to determine the relationship between joint angles and paddling force of non-impaired va’a and para va’a athletes.

**Study II**: To examine the IRR of the trunk, leg and on-water test batteries and the sport class allocation in the new evidence-based classification system for para va’a.

**Study III**: To examine kinematic and kinetic performance variables in non-impaired kayak and para kayak athletes during high intensity kayak ergometer paddling and to determine whether differences exist based on the level of impairment. Secondly, to determine the relationship between joint angles and paddling power output of non-impaired kayak and para kayak athletes.

**Study IV**: To compare differences in kinematic and kinetic performance variables concerning the body, paddle, seat and footrest between para-kayak athletes with unilateral above and below knee amputation during high intensity kayak ergometer paddling. Secondly, to examine differences between the non-amputated and amputated sides.
4 Method

4.1 Participants

In total, 20 elite non-impaired va’a and kayak athletes and 114 elite paracanoe athletes have participated in the four studies (Table 2). The inclusion criteria for all athletes were that they had to compete on a national or international level and follow an established training program for at least one year. The paracanoe athletes also had to have an eligible impairment type for para kayak or para va’a: limb deficiency, impaired passive ROM or impaired muscle power affecting the trunk and/or legs. In study I 54 va’a athletes were divided into four different groups; non-impaired athletes, athletes with trunk and bilateral leg impairment (TL), athletes with bilateral leg impairment (BL) and athletes with unilateral leg impairment (UL)) (Table 2). The group allocation was based on the athlete’s results from the trunk and leg tests performed in a classification within the same year as the athlete’s participation in the data collection. In Study II 12 para va’a athletes participated (Table 2). Since the aim of study II was to classify these athletes, their classification is not listed in Table 2. Three classifier teams, each comprised of a level 5 international medical and technical classifier, also participated in the study. The six classifiers had $6 \pm 3$ years of experience in paracanoe classification with a range of 3–9 years of experience for the medical classifiers and 2–9 years for the technical classifiers. In study III 10 non-impaired kayak athletes and 41 para kayak athletes participated. All para kayak athletes were classified by international classifier teams and divided into these classes for the study (KL1, KL2 or KL3) (Table 2). In study IV, 17 para kayak athletes were divided into a group depending on the level of their amputation: above knee amputation (AK) or below knee amputation (BK) (Table 2). The participants in all studies have mostly been international level athletes with the exception of seven national level athletes participating in study I and 11 national level athletes participating in study III. All participants received oral and written information regarding the study and signed a consent form and health declaration to participate in the studies. Ethical approval for all studies was granted by the Stockholm Regional Ethical Committee (Study I: DNR: 2014/1328-32; Study II: DNR: 2018/477-32; Study III: DNR: 2013/1040-31/3; Study IV: DNR:2017/1113-32).
Table 2. Details of the participants included in studies I-IV.

<table>
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<th>Classification</th>
<th>Gender</th>
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<th>Age (yr)</th>
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<tr>
<td>Va’a</td>
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<tr>
<td>Kayak</td>
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<td>68 ± 4</td>
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</tr>
<tr>
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<td>6</td>
<td>24 ± 3</td>
<td>86 ± 6</td>
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<tr>
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<td>36 ± 7</td>
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<td>47 ± 6</td>
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<tr>
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<tr>
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<td>12</td>
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<td>81 ± 9</td>
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<td><strong>Study IV</strong></td>
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<td>30 ± 9</td>
<td>67 ± 6</td>
<td>1.69 ± 0.06</td>
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<tr>
<td></td>
<td>M</td>
<td>4</td>
<td>25 ± 2</td>
<td>81 ± 16</td>
<td>1.81 ± 0.12</td>
</tr>
</tbody>
</table>

4.2 Equipment

4.2.1 Ergometers (studies I, III and IV)

The va’a paddling in study I was performed on either a D1-M KayakPro va’a ergometer (KayakPro, Miami, FL, USA) (n= 36 para athletes) or a Concept 2 ergometer (Concept, Nottingham, England, UK) with an adaptation for va’a paddling (Paddlesport Training Systems, East Hardwick, VT, USA) (n=10 non-impaired va’a athletes; n=8 para va’a athletes). The kayak paddling in studies III and IV was performed on a kayak ergometer (Dansprint ergometer; Dansprint ApS, Hvidovre, Denmark). The ergometer settings were based on athletes’ preference and fitting of adaptive equipment. For all studies, adaptive equipment was fitted so that it replicated the athlete’s normal competition and
training set-up as close as possible to increase ecological validity. Athletes used their own adaptive equipment where applicable, chose their preferred seating position and used their own preferred technique. All athletes had previous experience with paddling on a kayak or va’a ergometer. The resistance during va’a and kayak ergometer paddling will be determined by the force produced by the athlete and the damper setting. The more force that the paddler exerts on the flywheel, the larger the resistance will be (Concept, 2021). The flywheel damper setting (regulation of air intake of the flywheel) could be adjusted from 1 (lightest feel of force input) to 10 (heaviest feel of force input). Higher damper settings allow more air into the flywheel housing resulting in that the flywheel decelerates faster during the recovery phase and requires more force to accelerate it during the next paddle stroke (Concept, 2021). For studies I and IV the damper setting was freely chosen by all athletes. For study III, the damper settings were 4 for all para kayak athletes as they all could paddle at this setting, setting 8 for non-impaired female athletes (≤75 kg body mass) and 10 for non-impaired kayak male athletes (≥76 kg body mass).

4.2.2 Kinematic data (studies I, III and IV)

Three-dimensional kinematic data collected for study I, III and IV were collected using a 12-camera optoelectronic system (Oqus4, Qualisys AB, Gothenburg, Sweden) at a sampling frequency of 150 Hz. The system was calibrated according to the manufacturer’s guidelines. The criteria for accepted calibration for all studies was that the camera residuals should not exceed 2 mm and that the SD for the length of the 602.3 mm wand should not exceed 1 mm. An example from study I of the set-up with cameras and ergometer is shown in Figure 11.

![Figure 11. An example from study I of the set-up with cameras and KayakPro va’a ergometer.](image)
Between 39 and 78 reflective markers (12 mm diameter) were attached to anatomical landmarks in order to construct a whole-body model consisting of 11 to 15 segments (Figure 12). The number of markers and segments depended on whether the athletes with limb deficiencies used their prostheses or not. In addition, markers were placed on the va’a and kayak paddle shaft and on the ergometers. For studies III and IV two markers were also attached on each side of the flywheel rotation centre in order to create virtual markers at the fixed points where the rope runs into the ergometer flywheel on each side (Bjerkefors et al., 2018). In study III two reflective markers were placed on each side of the force transducers at the paddle whilst for studies I and IV reflective tape was attached instead on the middle of the force transducers.

![Figure 12. Example from study IV of marker placement and segments.](image)

4.2.3 Kinetic data (studies I, III and IV)

Piezoelectric force transducers (Type 9311B, Kistler Instruments AG, Winterthur, Switzerland) were connected between the rope and the end of the paddle shaft to continuously measure force at the paddle (Figure 13). In addition to the force transducers at the paddle, study IV also included a force plate (Model 2550-06, Bertec Corporation, Columbus, Ohio, US) and two 3D piezoelectric force transducers (Type 9347B, Kistler Instruments AG) (Figure 13). The force plate was attached to the ergometer and had a kayak seat mounted on top in order to measure 3D forces and moments at the seat. The two 3D piezoelectric force transducers were used in a custom-made footrest to measure forces at each foot. The sampling frequency of the kinetic data was 1500 Hz in studies I and III and 150 Hz in study IV. The force plate and transducers were connected to an amplifier (paddle: Type 5073, Kistler Instruments AG, seat: Model 3282013, Bertec
Corporation, footrest: Type 5405A; Kistler Instruments AG) and signals were A/D converted (Qualisys AB). In all three studies, the kinematic and kinetic data were simultaneously collected and synchronized using Qualisys Track Manager (Qualisys AB).

Figure 13. Pictures of a) the force transducer attached between the paddle shaft and the flywheel rope used in studies I, III and IV, b) footrest setup used in study IV where two 3D force transducers were connected c) the seat mounted on top of the force plate in study IV and d) the adaptive device mounted on the force plate and seat used by the athletes in study IV with above knee amputation.
4.3 Data collection procedures

The data for this thesis were collected between 2013 and 2018 at several places around the world (Table 3).

Table 3. Overview of data collection locations and events for each study.

<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>Event</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>2014</td>
<td>-</td>
<td>Uni. of Oregon, US</td>
</tr>
<tr>
<td>Va’a</td>
<td>2014</td>
<td>-</td>
<td>GIH, Sweden</td>
</tr>
<tr>
<td></td>
<td>2014</td>
<td>ICF Paracanoe World Championships</td>
<td>Moscow, Russia</td>
</tr>
<tr>
<td></td>
<td>2015</td>
<td>ICF Paracanoe World Championships</td>
<td>Milano, Italy</td>
</tr>
<tr>
<td></td>
<td>2016</td>
<td>ICF Paracanoe World Championships</td>
<td>Duisburg, Germany</td>
</tr>
<tr>
<td>II</td>
<td>2018</td>
<td>-</td>
<td>Castel Gandolfo, Italy</td>
</tr>
<tr>
<td>Va’a</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>2013</td>
<td>ICF Paracanoe World Championships</td>
<td>Duisburg, Germany</td>
</tr>
<tr>
<td>Kayak</td>
<td>2014</td>
<td>-</td>
<td>GIH, Sweden</td>
</tr>
<tr>
<td></td>
<td>2014</td>
<td>-</td>
<td>Nottingham, UK</td>
</tr>
<tr>
<td></td>
<td>2014</td>
<td>-</td>
<td>Leipzig, Germany</td>
</tr>
<tr>
<td>IV</td>
<td>2017</td>
<td>ICF Paracanoe World Championships</td>
<td>Racice, Czech Republic</td>
</tr>
<tr>
<td>Kayak</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.3.1 Studies I, III and IV

Prior to data collection the athletes were introduced to the test procedure and if the para athletes used adaptive seats or straps, these were attached on the ergometers. The athletes’ body mass and height were recorded. The athletes then performed a ten-minute warm-up at a self-selected intensity. After the warm-up the va’a athletes in study I and the kayak athletes in study III paddled at a high intensity level, which was defined as the highest intensity that the athlete could stably maintain during 20 stroke cycles. Furthermore, the va’a athletes in study I were asked to paddle on their preferred paddling side. The kayak athletes in study IV were asked to paddle at a racepace intensity. This intensity was performed by the athletes first successively increasing their intensity for 10 stroke cycles and then paddling at their race pace intensity for 10 stroke cycles. The athletes in all studies were asked to maintain their intensity level through visual feedback of the power output and stroke frequency on the ergometer display.
4.3.2 Study II

Detailed manuals for the test batteries were created together with the classifiers who were members of the ICF’s Paracanoe classification committee prior to the data collection. The manuals included instructions and pictures describing how the classifiers should perform each test including how to position, instruct and score the athletes (Appendices 3-5). The manuals were sent to the participating classifiers four weeks prior to the data collection. The data collection was conducted over two days. The classification process for the study followed the international classification standards for para va’a and consisted of the para va’a trunk, leg and on-water test batteries and followed the same MIC and class allocation definitions that has previously been described in the introduction of this thesis. All athletes used their preferred boat type and individual adaptations during the on-water test battery, so that the boat set-up replicated what the athlete normally used during competition.

The classifiers were divided into three teams which were each comprised of a medical and a technical classifier. The medical classifier was present at the technical classifier’s test and vice versa, within the same classifier team. For the purpose of the study, each team classified each athlete once and therefore all athletes were classified three times. Each classifier team was blinded to the evaluations and the scores of the other classifier teams (Rosén et al., 2020). The medical evaluations (the trunk and leg test batteries) took approximately 30 minutes per athlete and were conducted during day one and half of day two. After three athletes had been classified, each classifier team had 60 minutes to deliberate the scoring of the tested athletes. The technical evaluations (the on-water test battery) were conducted during the other half of day two. All three classifier teams assessed one athlete at a time. As usually during para va’a classification, all classification tests were filmed which meant that the technical classifiers filmed the medical tests and vice versa (Rosén et al., 2020). Each classifier team had a standard video camera (Sony RX100V, Tokyo, Japan) that they used during the filming. In addition to the video camera, an action camera (GoPro Hero5 black, San Mateo, CA, USA) was used during the on-water test battery which was mounted in front of the cockpit on the i’ato’s of the va’a (GoPro Jaws mount, San Mateo, CA, USA). This enabled a close-up view of the athlete in order to better see the trunk and leg movement during the paddling on water. For the purpose of this study, all films could also be used by the research team if discrepancies were observed in class allocation of an athlete. This enabled the possibility that the research team could examine the videos and investigate whether the classifiers provided the athletes with the same instructions and whether the athletes performed consistently during all classifications (Rosén et al., 2020).
4.4 Data analyses

4.4.1 Kinematic data (studies I, III and IV)

Kinematic and kinetic data analyses were performed in Visual3D (versions 4, 5 and 6, C-Motion, Inc., Germantown, MD, USA) and Matlab (versions 8.4, R2016a and R2017b The MathWorks, Inc., Natick, MA, USA). Kinematic data were smoothed with a second-order, bi-directional, low-pass Butterworth filter with a 7 Hz cut-off frequency for studies I and III and 10 Hz cut-off frequency for study IV. The global coordinate system (GCS) was for studies I, III and IV set with a positive X-axis in the direction the athlete was facing, a positive Y-axis directed to the left of the athlete and a positive Z-axis pointing upward. The segment coordinate systems (SCS) for all segments except for the pelvis segment were defined using the proximal and distal endpoints of each segment in accordance with Visual 3D recommendations. The SCS z-axis (inferior to superior) was defined by the unit vector directed from the distal segment endpoint to the proximal segment endpoint. The SCS y-axis (posterior to anterior) was defined by the unit vector that was perpendicular to the frontal plane and z-axis. The SCS x-axis (medial to lateral) was determined by the right-hand rule. The location of the SCS for the pelvis segment originated from a mid-point between the markers placed on the anterior superior iliac spine and is shown in Figure 14.

![Figure 14. The location of the segment coordinate system for the pelvis segment.](image)

Maximal and minimal angles and total ROM for flexion and extension were calculated during the stroke cycles for the shoulder, elbow, wrist, trunk, hip, knee and ankle joints, with the exception for study IV which did not include upper limb variables. In study IV, angular velocities for hip, knee and ankle flexion and extension were also calculated. The angles and angular velocities were calculated using a Cardan/Euler rotation sequence of x, y, z which corresponded to forward flexion, abduction and axial rotation. Additionally, maximal and minimal angles and ROM were calculated for shoulder rotation and abduction (studies I and III), trunk rotation (studies I and III), trunk and pelvis...
rotation (studies I, III and IV), pelvis rotation (study IV) and trunk bending (studies I and III). For study I the joint angle data were divided into top hand (TH) side and bottom hand (BH) side for the arms and legs because of the va’a paddling movement being asymmetric (Figure 15). For all studies, stroke frequency was also calculated. In study IV the kinematic data also included paddle velocity, drag length, time to peak force, cycle time and peak-to-peak anterior/posterior and lateral COP displacement. Maximal paddle velocity and drag length were calculated during the drag phases in the GCS X direction. Since the force curves could have multiple peaks, the variable time to peak force was calculated from catch to the first peak in the force curve. The peak-to-peak anterior/posterior and lateral COP displacements at the seat were calculated during the drag phases of the amputated (A) and non-amputated (NA) sides and the cycle time and hip, knee and ankle flexion and extension angular velocities were calculated during the stroke cycles.

Figure 15. Picture of a para va’a paddler. The top hand for this athlete is his right hand and the bottom hand is his left hand. Preferred paddling side is associated with the bottom hand on the paddle and the limbs on that side. Photo credit: ICF/canoeaphotography.com.

One stroke cycle was defined as from catch to catch on the same side, one stroke was defined from catch of one side to catch of the other side and the drag phase was defined as from catch to release. In studies I and III the catch was defined as the maximum position of the paddle in the positive X direction in the GCS (Bjerkefors et al. 2018; Michael et al. 2012). In study IV the catch was defined as when the paddling power output crossed the zero line from negative to positive (Figure 16). The release was defined the same for all studies: when the marker placed at the ulnar styloid process was in the maximum position in the negative X direction of the GCS. For all studies, ten stroke cycles/strokes/drag phases were used for the analyses.
4.4.2 Kinetic data (studies I, III and IV)

Force data were smoothed with a second-order, bi-directional, low-pass Butterworth filter with a 10 Hz cut-off frequency for studies I and III and 20 Hz cut-off frequency for study IV. In study I the mean paddling force was calculated during each drag phase. For studies III and IV the mean paddling power output during each stroke was calculated. The paddling power output was defined as a product of paddle force measured by the force transducers and velocity of the force transducer displacement in the direction of the rope (Bjerkefors et al., 2018). The displacement was defined as a magnitude of the vector between the virtual marker and the marker attached on the force transducer for each side (study III) or for the reflective tape attached on the force transducer (study IV). The velocity was defined as a rate of change (as a function of time) of the force transducer displacement using a central difference theorem.

Study IV had the most kinetic variables. In addition to paddling power output the following kinetic variables were calculated: paddling force, paddle work, paddle impulse, anterior/posterior force at the seat, push/pull force at the footrests and hip, knee and ankle flexion and extension moment. Mean and maximal paddling force were calculated at each side of the paddle during the drag phase. Maximal paddle force was calculated for the largest peak. In addition, paddle work and paddle impulse during the drag phases at each side were calculated as the integral of power output and paddle force, respectively, over time. Maximal, minimal and mean anterior/posterior force at the seat were calculated during the drag phases of the A and NA sides. The maximal push and pull forces at the footrest of the A leg and the NA leg were calculated during the drag phase of the A and NA sides. The joint moments in study IV were normalised to body mass and were resolved in the coordinate system of the proximal segment (e.g. knee moment was resolved in the coordinate system of the thigh). The maximal and minimal hip, knee and ankle joint moments were calculated during the stroke cycles.
The statistical analyses were performed in IBM SPSS statistics versions 24, 25 and 26 (IBM, Armonk, NY, USA) for studies I, II and IV, respectively and in STATISTICA for study III. Additional statistics exclusive for this thesis were performed in IBM SPSS statistics (version 26 and 27). An overview of all statistical methods is shown in Table 4. The level of significance was set at $p \leq 0.05$ for all studies.

### Table 4. Statistical methods used in studies I-IV.

<table>
<thead>
<tr>
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<th>Study I</th>
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<th>Study III</th>
<th>Study IV</th>
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</table>

### 4.5.1 Differences (studies I, III and IV)

Shapiro Wilk’s W tests were performed to test the data in studies I, III and IV for normality. Levene’s tests for equality were performed to examine if the group variances were equal in the population. If the variables met the assumption of equality ($p < 0.05$), analyses of variance (ANOVA) were performed to examine differences between groups. For the variables which did not meet the assumption of equality, a Welch test was performed (study I). Studies I, III and IV have looked at mean differences between groups using either one-way ANOVA, two-way mixed ANOVA, independent t-test or Mann-
Whitney U-test. Two-way mixed ANOVAs were conducted for study III and IV to examine the differences between the groups and between angles in study III (trunk rotation ROM vs trunk and pelvis rotation ROM) and side in study IV: amputated (A) vs. non-amputated (NA) side. A two-way mixed ANOVA was also conducted as an extra analysis for this thesis to examine the difference between groups (non-impaired va’a athletes, UL, BL and TL) and between trunk rotation ROM and trunk and pelvis rotation ROM for the data from study I. The post hoc tests used for the different studies were for equal variances: Tukey-Kramer, Unequal N HSD and Bonferroni and for unequal variances: Games-Howell. Differences between means have been complemented with 95% confidence intervals (95% CI) and measures of effect size. The effect sizes measures that have been used are eta squared ($\eta^2$) for one-way ANOVAs, partial eta squared ($\eta_p^2$) for two-way mixed ANOVAs and Cohen’s d for independent t-tests.

4.5.2 Relationships (studies I and III)

Studies I and III examined relationships between joint angles and force (study I) or power output (study III). Spearman’s correlation coefficient was calculated for mean paddling force and joint angles for the female non-impaired va’a and para va’a athletes in study I and Pearson’s correlation coefficient was calculated for male non-impaired va’a and para va’a athletes for study I and for both male and female non-impaired kayak and para kayak athletes in study III.

4.5.3 Inter-rater reliability (study II)

In study II, the IRR for the total score of the leg, trunk and on-water test batteries and for the final class allocation was assessed using a two-way random, absolute agreement, single-measures intraclass correlation coefficient (ICC) to assess the degree that classifiers agreed in their classifications of the athletes. The level of clinical significance of ICC was interpreted using the guideline by Cicchetti (1994) where the clinical significance is excellent if ICC is between 0.75 and 1.00. For each individual test in all three test batteries, Fleiss kappa was calculated for each individual score (0, 1 and 2) and for the overall test. The guideline by Landis and Koch (1977) was used for the interpretation of Fleiss kappa where $\kappa <0.00$ corresponds to poor agreement, 0.00 to 0.20 slight agreement, 0.21 to 0.40 fair agreement, 0.41 to 0.60 moderate agreement, 0.61 to 0.80 substantial agreement and 0.81 to 1.00 almost perfect agreement. 95 % CI are reported with the ICC and Fleiss kappa values. Percentage of total agreement was also calculated for all individual tests for each of the three test batteries. The percentage of total agreement was calculated by dividing the number of athletes that all three classifiers were in agreement on with the total number of athletes (N = 12) and multiplying with 100.
4.5.4 Additional statistical analyses for the thesis

Some additional statistical analyses were conducted using the data from studies I and III which are only presented in this thesis. Correlations were conducted from the data of study I to examine the relationship between mean paddling force and the sum of maximal trunk flexion and trunk and pelvis rotation ROM as well as the relationship between mean paddling force and the sum of BH and TH knee and ankle ROM. These sums will be referred to as the trunk and leg compartments. Partial correlation analyses were thereafter conducted to further investigate the role of the legs in para va’a. Partial correlation analyses were conducted for both non-impaired va’a and para va’a athletes together, separated by gender, to examine the relationship between mean paddling force and the trunk compartment when controlling for the leg compartment, as well as the relationship between mean paddling force and the leg compartment when controlling for the trunk compartment. Furthermore, Pearson’s correlation coefficient was calculated to examine the relationship between mean paddling force and the leg compartment in the male UL and BL athletes.

Statistical analyses on differences in power output between the groups were not presented in the article for study III due to “the low number of athletes in each group” (Bjerkefors et al., 2019, p. 96). For this thesis, analyses of the differences in power output between the male non-impaired, KL1, KL2 and KL3 athletes was included. It was decided to only analyse the power output data from male athletes since they had a larger sample size in each group in comparison to the female athletes (Table 2). A one-way ANOVA was conducted to examine the differences in power output between the four groups of athletes after a Levene’s test showed that the data met the assumption of equality. Significant group effects were further examined using a Tukey-Kramer post hoc test and $\eta^2$ was calculated as a measure of effect size.

Additionally, in study III Pearson’s correlation coefficient and Spearman’s correlation coefficient were calculated to examine the relationship between paddling power output and joint angles and ROM concerning the trunk and lower limbs for the male para kayak classes (KL1, KL2, KL3). This was to evaluate whether athletes with larger joint angles and ROM, indicating more movement, produced more power output within each class which is of interest regarding the validity of the classes.
5 Results

This results section summarises the main results of studies I-IV. More detailed results from each study can be found in each publication. New results as an outcome of the additional statistical analyses conducted for studies I and III are also presented.

5.1 Differences between paracanoe athletes and non-impaired athletes (studies I and III)

In study I there was a significant main effect of group for paddling force for the male va’a athletes ($F(3,32)=19.01, p<0.001, \eta^2 = 0.641$). The post-hoc test showed that the male non-impaired va’a athletes had significantly greater paddling force compared to male TL, BL and UL athletes with a mean difference of 76 (95% CI, 49 to 104) N, 51 (95% CI, 21 to 81) N and 47 (95% CI, 20 to 73) N, respectively.

The new statistical analyses on differences in paddling power output in male kayak athletes in study III showed a main effect of group ($F(3,28) = 63.88, p < 0.001, \eta^2 = 0.873$). The male non-impaired kayak athletes demonstrated greater paddling power output compared to male KL1, KL2 and KL3 athletes with a mean difference of 312 (95% CI, 247 to 378) W, 166 (95% CI, 100 to 231) W and 99 (95% CI, 37 to 161) W, respectively (Table 5).

In both studies I and III it was revealed that the non-impaired athletes demonstrated significantly higher stroke frequency compared to the athletes with most impairment, TL (study I) and KL1 (study III), respectively (Table 5).
Table 5. Paddling power output, paddling force and stroke frequency during high intensity va’a and kayak ergometer paddling for male (M) and female (F) non-impaired (NI) va’a and kayak athletes and paracanoe athletes divided into different groups. For para va’a: athletes with trunk and bilateral leg impairment (TL), athletes with bilateral leg impairment (BL) and athletes with unilateral leg impairment (UL). For para kayak: athletes with classification KL1, KL2 and KL3. All results are reported as means ± 1 standard deviation.

<table>
<thead>
<tr>
<th>Study</th>
<th>Sig. group effect</th>
<th>Group</th>
<th>Gender</th>
<th>Power output (W)</th>
<th>Paddling force (N)</th>
<th>Stroke frequency (strokes*min⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>II Va’a</td>
<td>□, #</td>
<td>NI F</td>
<td>NA</td>
<td>133 ± 21</td>
<td>76 ± 6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>159 ± 19</td>
<td>84 ± 21</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>TL F</td>
<td>NA</td>
<td>72 ± 14</td>
<td>61 ± 10</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>83 ± 17</td>
<td>58 ± 16</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>BL F</td>
<td>NA</td>
<td>72 ± 10</td>
<td>68 ± 5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>109 ± 20</td>
<td>66 ± 16</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>UL F</td>
<td>NA</td>
<td>78 ± 2</td>
<td>68 ± 16</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>113 ± 19</td>
<td>74 ± 15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>III Kayak</td>
<td>*, #</td>
<td>NI F</td>
<td>277 ± 26</td>
<td>NA</td>
<td>115 ± 13</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>433 ± 42</td>
<td>106 ± 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>KL1 F</td>
<td>NA</td>
<td>108 ± 40</td>
<td>102 ± 12</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>121 ± 28</td>
<td>85 ± 14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>KL2 F</td>
<td>NA</td>
<td>114 ± 46</td>
<td>85 ± 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>267 ± 26</td>
<td>103 ± 18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>KL3 F</td>
<td>NA</td>
<td>183 ± 35</td>
<td>108 ± 18</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>334 ± 63</td>
<td>107 ± 14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IV Kayak</td>
<td></td>
<td>AK F</td>
<td>272 ± 18</td>
<td>80 ± 2</td>
<td>137 ± 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>427 ± 94</td>
<td>115 ± 18</td>
<td>131 ± 15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BK F</td>
<td>243 ± 16</td>
<td>77 ± 6</td>
<td>111 ± 0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>523 ± 125</td>
<td>133 ± 23</td>
<td>147 ± 11</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NA= not applicable, the variable was not calculated for study I *significant group effect in paddling power output □ significant group effect of paddling force # significant group effect of stroke frequency

The non-impaired va’a and kayak athletes showed larger angle values compared to para va’a and kayak athletes in maximal trunk flexion, trunk and pelvis rotation ROM and in hip, knee and ankle flexion ROM (Table 6). In study III there was a difference between the non-impaired kayak athletes and all classes in maximal shoulder extension and in shoulder flexion ROM where the non-impaired kayak athletes demonstrated smaller values. In both study I and study III, the non-impaired va’a and kayak athletes demonstrated less trunk extension values compared to TL and BL athletes for para va’a and KL1 and KL2 athletes for para kayak. In hip, knee and ankle flexion ROM, the non-impaired va’a athletes showed significantly larger values compared to the TL and BL athletes in both the BH and TH sides. Differences were found between non-impaired va’a
athletes and UL athletes in TH knee and ankle flexion ROM. The non-impaired kayak athletes showed significantly larger values in hip, knee and ankle flexion ROM compared to all three para kayak classes.
Table 6. Peak joint angles and ranges of motion (ROM) in degrees during high intensity va’a and kayak ergometer paddling, in the shoulder, trunk and lower limbs for non-impaired (NI) va’a and kayak athletes, and paracanoe athletes divided into different groups. For para va’a: athletes with trunk and bilateral leg impairment (TL), athletes with bilateral leg impairment (BL) and athletes with unilateral leg impairment (UL). For para kayak: athletes with classification KL1, KL2 and KL3. The shoulder, hip, knee and ankle flexion angle results are divided into top hand (TH) and bottom hand (BH) for the va’a athletes. The kayak athletes’ shoulder, hip, knee and ankle flexion angle results are presented under the BH rows. All results are reported as means ± 1 standard deviation.

<table>
<thead>
<tr>
<th></th>
<th>Study I Va’a</th>
<th>Study III Kayak</th>
<th>Sign. diff</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TL</td>
<td>BL</td>
<td>UL</td>
</tr>
<tr>
<td><strong>Shoulder</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flex (max) (BH)</td>
<td>61 ± 16</td>
<td>79 ± 14</td>
<td>70 ± 18</td>
</tr>
<tr>
<td>Ext (max) (BH)</td>
<td>45 ± 27</td>
<td>32 ± 12</td>
<td>27 ± 14</td>
</tr>
<tr>
<td>Flex ROM (BH)</td>
<td>106 ± 26</td>
<td>111 ± 21</td>
<td>97 ± 19</td>
</tr>
<tr>
<td>Flex (max) (TH)</td>
<td>102 ± 18</td>
<td>119 ± 14</td>
<td>117 ± 17</td>
</tr>
<tr>
<td>Ext (max) (TH)</td>
<td>-24 ± 26</td>
<td>-46 ± 19</td>
<td>-49 ± 20</td>
</tr>
<tr>
<td>Flex ROM (TH)</td>
<td>78 ± 26</td>
<td>73 ± 22</td>
<td>68 ± 26</td>
</tr>
<tr>
<td><strong>Trunk</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flex (max)</td>
<td>-2 ± 15</td>
<td>16 ± 10</td>
<td>19 ± 13</td>
</tr>
<tr>
<td>Ext (max)</td>
<td>11 ± 11</td>
<td>-2 ± 8</td>
<td>-5 ± 6</td>
</tr>
<tr>
<td>Flex ROM</td>
<td>9 ± 5</td>
<td>14 ± 7</td>
<td>14 ± 9</td>
</tr>
<tr>
<td>Rot ROM</td>
<td>21 ± 11</td>
<td>28 ± 7</td>
<td>28 ± 9</td>
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<tr>
<td>Rot ROM incl. pelvis</td>
<td>24 ± 13</td>
<td>33 ± 8</td>
<td>40 ± 14</td>
</tr>
<tr>
<td><strong>Hip</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flex ROM (BH)</td>
<td>6 ± 5</td>
<td>9 ± 6</td>
<td>15 ± 8</td>
</tr>
<tr>
<td>Flex ROM (TH)</td>
<td>5 ± 4</td>
<td>8 ± 4</td>
<td>13 ± 8</td>
</tr>
<tr>
<td><strong>Knee</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flex ROM (BH)</td>
<td>4 ± 3</td>
<td>6 ± 4</td>
<td>16 ± 11</td>
</tr>
<tr>
<td>Flex ROM (TH)</td>
<td>3 ± 2</td>
<td>3 ± 3</td>
<td>7 ± 6</td>
</tr>
<tr>
<td><strong>Ankle</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flex ROM (BH)</td>
<td>3 ± 2</td>
<td>3 ± 2</td>
<td>8 ± 6</td>
</tr>
<tr>
<td>Flex ROM (TH)</td>
<td>2 ± 2</td>
<td>2 ± 2</td>
<td>3 ± 3</td>
</tr>
</tbody>
</table>

40
<table>
<thead>
<tr>
<th>Study I (Va’a)</th>
<th>Study III (Kayak)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a = significant difference between NI and TL</td>
<td>A = significant difference between NI and KL1</td>
</tr>
<tr>
<td>b = significant difference between NI and BL</td>
<td>B = significant difference between NI and KL2</td>
</tr>
<tr>
<td>c = significant difference between NI and UL</td>
<td>C = significant difference between NI and KL3</td>
</tr>
<tr>
<td>d = significant difference between TL and BL</td>
<td>D = significant difference between KL1 and KL2</td>
</tr>
<tr>
<td>e = significant difference between TL and UL</td>
<td>E = significant difference between KL1 and KL3</td>
</tr>
<tr>
<td>f = significant difference between BL and UL</td>
<td>F = significant difference between KL2 and KL3</td>
</tr>
</tbody>
</table>
5.2 Differences between paracanoe athletes (studies I, III and IV)

In study I the post-hoc for paddling force showed that the male UL and BL va’a athletes had significantly greater paddling force compared to the male TL athletes (Table 5). In study III, the new statistical analyses for paddling power output showed that male KL2 and KL3 athletes had significantly greater power output during the kayak ergometer paddling compared to KL1 with a mean difference of 146 (95% CI, 86 to 207) W and 213 (95% CI, 156 to 271) W, respectively. Furthermore, KL3 had significantly greater power output compared to KL2 with a mean difference of 67 (95% CI, 10 to 124) W (Table 5). In contrast to studies I and III, differences in paddling performance variables were not evident between the AK and BK para kayak athletes in study IV (Table 5).

In both studies I and III the post hoc tests for stroke frequency revealed that the athletes with least impairment, UL (study I) and KL3 (study III) had significantly higher stroke frequency compared to the athletes with most impairment, TL (study I) and KL1 (study III) (Table 5).

A difference in the shoulder joint values was seen between the para va’a athletes in study I and the para kayak athletes in study III (Table 6). In study I the BL athletes had significantly larger shoulder flexion values compared to TL athletes. In study III both the KL2 and KL3 athletes had significantly larger shoulder flexion values compared to KL1. It was also evident that in study III the athletes with greater impairment had significantly larger maximal shoulder extension. The KL1 athletes had larger shoulder extension values compared to both the KL2 and KL3 athletes and the KL2 athletes had larger shoulder extension values compared to the KL3 athletes.

In both studies I and III, the athletes with least impairment (study I: UL, study III: KL3) demonstrated significantly greater values in maximal trunk flexion, trunk and pelvis rotation ROM and in hip and knee flexion ROM compared to the athletes with the most impairment (study I: TL, study III: KL1) (Table 6). Additionally, differences between TL and BL athletes and between KL1 and KL2 athletes were found in trunk flexion and trunk extension where the BL and KL2 athletes demonstrated larger trunk flexion and the TL and KL1 athletes demonstrated larger trunk extension.

In study I the UL athletes demonstrated significantly larger hip flexion ROM in both BH and TH sides and a larger knee flexion ROM in the BH side compared to the TL athletes. Differences between UL and BL athletes were seen in the BH side knee and ankle flexion ROM. In study III the KL3 athletes demonstrated significantly larger values in hip and knee flexion ROM compared to both the KL2 and KL1 athletes.
In study IV, the only variables where there were significant differences between the AK and BK groups were in the hip joint in flexion/extension ROM, in flexion and extension velocity and in flexion moment where the BK group demonstrated significantly larger values compared to the AK group (Figure 17). Figures of power output, hip flexion/extension ROM, hip flexion/extension angular velocity and hip flexion/extension moment normalised to the drag phase or stroke cycle are shown in Figure 19 for descriptive purposes. A main effect of side was seen in maximal, minimal and mean posterior force at the seat where the forces were larger during the drag phase of the NA side compared to during the drag phase of the A side (Figure 18). A main effect of side was also seen in peak-to-peak anterior/posterior COP displacement where the COP during the drag phase of the A side was larger compared to during the drag phase of the NA side (Table 7). An interaction of group*side and main effects of group and side were seen for the hip flexion moment. The post hoc test revealed that the AK group had significantly smaller hip flexion moment values compared to the BK group for the A side. Additionally, the AK group demonstrated a significant difference in hip flexion moment between the A and NA sides where the NA side exhibited larger values. No significant differences were seen between AK and BK in any of the variables that concerned the paddle (Table 7) or the footrest (Table 8).
Figure 17. Maximal rotation in trunk and pelvis and in pelvis are shown for athletes with above knee (AK) and below knee (BK) amputation (a). Joint ROM (b), joint angular flexion velocity (c), joint angular extension velocity (d), joint flexion moment (e), and joint extension moment (f) are shown for the hip, knee and ankle for the AK and BK athletes. The horizontal line in the boxes represents the median value and the + sign represents the mean. # indicate a main effect of group, * indicate a main effect of side.

Figure 18. Maximal (max), minimal (min) and mean posterior force at the seat in athletes with above knee (AK) and below knee (BK) amputation. The horizontal line in the boxes represents the median value and the + sign represents the mean. * indicate a main effect of side.
Figure 19. Data of a) power output b) hip flexion/extension angle, c) hip flexion/extension angular velocity and d) hip moment normalised during the drag phase (power output) or stroke cycle (angle, angular velocity and moment) for the athletes with above knee (AK) amputation (left) and below knee (BK) amputation (right). Data from the amputated (A) and non-amputated (NA) sides are shown as mean (solid line) and ± 1 standard deviation (SD) (spaced lines). The dark coloured area represents the mean ± 1 SD for the A side and the light coloured area represents the mean ± 1 SD for the NA side.
Table 7. Kinematic and kinetic paddle and seat variables (means ± 1 standard deviation (SD)) during kayak ergometer paddling for the amputated (A) and non-amputated (NA) sides in athletes with unilateral above knee (AK) or below knee (BK) amputation.

<table>
<thead>
<tr>
<th>Study IV (Kayak)</th>
<th>AK</th>
<th>BK</th>
<th>Significance</th>
<th>Side effect</th>
<th>Group effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>NA</td>
<td>A</td>
<td>NA</td>
<td>Side</td>
</tr>
<tr>
<td><strong>Paddle</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean power output (W/kg)</td>
<td>5.50 ± 1.10</td>
<td>5.77 ± 1.03</td>
<td>5.31 ± 1.79</td>
<td>5.67 ± 1.33</td>
<td>2.14</td>
</tr>
<tr>
<td>Mean force (N/kg)</td>
<td>1.53 ± 0.22</td>
<td>1.54 ± 0.19</td>
<td>1.44 ± 0.38</td>
<td>1.53 ± 0.21</td>
<td>0.68</td>
</tr>
<tr>
<td>Max force (N/kg)</td>
<td>3.29 ± 0.54</td>
<td>3.38 ± 0.56</td>
<td>2.97 ± 0.55</td>
<td>3.11 ± 0.35</td>
<td>1.18</td>
</tr>
<tr>
<td>Work (J/kg)</td>
<td>2.57 ± 0.43</td>
<td>2.60 ± 0.36</td>
<td>2.38 ± 0.58</td>
<td>2.52 ± 0.33</td>
<td>0.62</td>
</tr>
<tr>
<td>Impulse (Ns/kg)</td>
<td>0.61 ± 0.09</td>
<td>0.62 ± 0.09</td>
<td>0.56 ± 0.10</td>
<td>0.59 ± 0.07</td>
<td>0.57</td>
</tr>
<tr>
<td>Max velocity (m/s)</td>
<td>4.85 ± 0.57</td>
<td>4.92 ± 0.50</td>
<td>4.29 ± 2.17</td>
<td>4.34 ± 2.20</td>
<td>1.41</td>
</tr>
<tr>
<td>Cycle time (s)</td>
<td>0.919 ± 0.099</td>
<td>0.918 ± 0.099</td>
<td>0.916 ± 0.143</td>
<td>0.915 ± 0.142</td>
<td>0.26</td>
</tr>
<tr>
<td>Time to peak paddle force (s)</td>
<td>0.140 ± 0.045</td>
<td>0.136 ± 0.040</td>
<td>0.126 ± 0.036</td>
<td>0.135 ± 0.038</td>
<td>0.21</td>
</tr>
<tr>
<td>Drag length (m)</td>
<td>1.484 ± 0.117</td>
<td>1.477 ± 0.106</td>
<td>1.491 ± 0.090</td>
<td>1.438 ± 0.069</td>
<td>0.97</td>
</tr>
<tr>
<td><strong>Seat</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COP ant/pos dis. (m)</td>
<td>0.065 ± 0.023</td>
<td>0.048 ± 0.019</td>
<td>0.056 ± 0.012</td>
<td>0.043 ± 0.027</td>
<td>*</td>
</tr>
<tr>
<td>COP lateral dis. (m)</td>
<td>0.077 ± 0.022</td>
<td>0.071 ± 0.016</td>
<td>0.082 ± 0.027</td>
<td>0.083 ± 0.020</td>
<td>0.26</td>
</tr>
</tbody>
</table>

ant = anterior, pos = posterior, COP = Centre of pressure, dis = displacement, Grp = group, Int = interaction, ηp² = partial eta squared, *main effect of side
Table 8. Kinetic variables at the footrest (means ± 1 standard deviation (SD)) during kayak ergometer paddling for the amputated (A) and non-amputated (NA) sides in athletes with unilateral above knee (AK) or below knee (BK) amputation. Independent t-test results, effect sizes (Cohen’s d) and 95% confidence intervals (95% CI) are reported between the AK and BK groups for the variables on the NA side.

### Study IV (Kayak)

<table>
<thead>
<tr>
<th></th>
<th>AK</th>
<th>BK</th>
<th></th>
<th>t</th>
<th>p</th>
<th>d</th>
<th>95% CI (lower; upper)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>NA</td>
<td>A</td>
<td>NA</td>
<td></td>
<td></td>
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<tr>
<td>Footrest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max push force A side drag (N)</td>
<td>179 ± 48&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-</td>
<td>393 ± 187&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max pull force A side drag (N)</td>
<td>-</td>
<td>187 ± 84</td>
<td>-</td>
<td>241 ± 62</td>
<td>-1.317</td>
<td>0.191</td>
<td>0.70; 138; 30</td>
</tr>
<tr>
<td>Max push force NA side drag (N)</td>
<td>-</td>
<td>373 ± 135</td>
<td>-</td>
<td>427 ± 172</td>
<td>0.713</td>
<td>0.487</td>
<td>0.36; 50</td>
</tr>
<tr>
<td>Max pull force NA side drag (N)</td>
<td>140 ± 71&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-</td>
<td>180 ± 80&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max med force A side drag (N)</td>
<td>25 ± 20&lt;sup&gt;a&lt;/sup&gt;</td>
<td>85 ± 30</td>
<td>50 ± 20&lt;sup&gt;b&lt;/sup&gt;</td>
<td>75 ± 39</td>
<td>0.639</td>
<td>0.533</td>
<td>0.32; 25; 46</td>
</tr>
<tr>
<td>Max lat force A side drag (N)</td>
<td>29 ± 23&lt;sup&gt;a&lt;/sup&gt;</td>
<td>109 ± 30</td>
<td>29 ± 9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>74 ± 36</td>
<td>2.103</td>
<td>0.053</td>
<td>1.07; 0.5; 70</td>
</tr>
<tr>
<td>Max med force NA side drag (N)</td>
<td>23 ± 0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>100 ± 27</td>
<td>41 ± 34&lt;sup&gt;b&lt;/sup&gt;</td>
<td>79 ± 19</td>
<td>1.762</td>
<td>0.098</td>
<td>0.89; 5; 48</td>
</tr>
<tr>
<td>Max lat force NA side drag (N)</td>
<td>9 ± 3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>72 ± 39</td>
<td>20 ± 10&lt;sup&gt;b&lt;/sup&gt;</td>
<td>49 ± 31</td>
<td>1.221</td>
<td>0.241</td>
<td>0.62; 17; 62</td>
</tr>
</tbody>
</table>

<sup>a</sup>the mean and SD presented are only for 2 of the 11 AK athletes, <sup>b</sup>the mean and SD presented are only for 5 of the 6 BK athletes; med = medial, lat = lateral
5.3 Differences between trunk rotation ROM and trunk and pelvis rotation ROM (studies I and III)

In both studies I and III there were significant main effects of trunk rotation type (trunk rotation ROM vs trunk and pelvis rotation ROM) and group as well as significant interactions (study I: $F(3) = 8.87, p < 0.001, \eta^2 = 0.35$; study III: $F(3) = 45.56, p < 0.001, \eta^2 = 0.74$). In study I the post hoc test showed that the non-impaired va’a athletes demonstrated significantly larger trunk rotation ROM compared to the TL athletes group with a mean difference of 12 (95% CI, 0.59 to 22.99)$^\circ$ (Figure 20). The non-impaired va’a athletes and UL athletes demonstrated a significantly larger trunk and pelvis rotation ROM compared to the TL athletes with mean differences of 23 (95% CI, 9.37 to 36.69)$^\circ$ and 16 (95% CI, 4.00 to 27.61)$^\circ$ respectively (Figure 20). Furthermore, all athletes except for TL demonstrated significantly larger trunk and pelvis rotation ROM compared to trunk rotation ROM with mean differences of 14 (95% CI, 9.95 to 18.39)$^\circ$, 12 (95% CI, 8.79 to 15.26)$^\circ$ and 5 (95% CI, 0.47 to 8.91)$^\circ$ for the non-impaired, UL and BL va’a athletes respectively.

In study III the post hoc test showed that the non-impaired kayak athletes demonstrated significantly larger trunk and pelvis rotation ROM compared to the KL1, KL2 and KL3 athletes with a mean difference of 47 (95% CI, 31.45 to 63.07)$^\circ$, 35 (95% CI, 19.28 to 51.55)$^\circ$ and 32 (95% CI, 17.10 to 46.23)$^\circ$, respectively (Figure 20). A difference in trunk and pelvis rotation ROM was also observed between the KL3 and KL1 athletes where KL3 demonstrated larger trunk and pelvis rotation ROM with a mean difference of 16 (95% CI, 1.84 to 29.36)$^\circ$. Furthermore, all athletes demonstrated significantly larger trunk and pelvis rotation ROM compared to trunk rotation ROM with mean differences of 51 (95% CI, 44.99 to 56.37)$^\circ$, 22 (95% CI, 17.62 to 26.10)$^\circ$, 15 (95% CI, 9.50 to 20.34)$^\circ$ and 9 (95% CI, 3.31 to 16.69)$^\circ$ for the non-impaired, KL3, KL2 and KL1 athletes, respectively.
Figure 20. Differences between trunk and pelvis rotation and trunk rotation in studies I and III for non-impaired (NI) va’a and kayak athletes, and paracanoe athletes divided into different groups. For para va’a: athletes with trunk and bilateral leg impairment (TL), athletes with bilateral leg impairment (BL) and athletes with unilateral leg impairment (UL). For para kayak: athletes with classification KL1, KL2 and KL3. * demonstrates where there is a significant difference between the trunk and pelvis rotation and trunk rotation. Differences between groups can be found in Table 6. The horizontal line in the boxes represents the median value and the + sign represents the mean.

5.4 Correlations with performance variables (studies I and III)

For studies I and III, significant positive correlations with force and power output, respectively, were seen for both genders for maximal shoulder flexion (in BH side for study I), maximal trunk flexion, trunk and pelvis rotation ROM and hip (both BH and TH sides for study I), knee and ankle (BH side for study I) flexion ROM (Table 9). In addition, in study I positive correlations with paddling force were also seen for trunk rotation ROM and trunk flexion ROM. In both studies I and III a negative correlation with maximal trunk extension was seen. Furthermore, a negative correlation between paddling power output, and maximal shoulder extension and shoulder flexion ROM was seen in study III (Table 9).

The extra correlation analyses conducted for the male para kayak groups in study III showed that there were no significant correlations between power output and any of the joint angles concerning the trunk or lower limbs for KL1 or KL3. For KL2 significant positive correlations were seen between power output, and hip flexion ROM (Spearman’s rho=0.748, p= 0.033) and knee flexion ROM (Pearson’s r=0.843, p=0.009).
Table 9. Significant correlations between peak joint angles and ROMs, and paddling force (Study I) and paddling power output (study III) for female (F) and male (M) non-impaired va’a and para va’a athletes (study I) and for F and M non-impaired kayak and para kayak athletes (study III). For study I the values are separated into bottom hand (BH) and top hand (TH).

<table>
<thead>
<tr>
<th></th>
<th>Study I (Va’a)</th>
<th>Study III (Kayak)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>r-value</td>
<td>r-value</td>
</tr>
<tr>
<td><strong>Shoulder</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flex (max) (BH)</td>
<td>0.842s</td>
<td>0.462</td>
</tr>
<tr>
<td>Ext (max)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Flex ROM</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Trunk</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flex (max)</td>
<td>0.798s</td>
<td>0.677</td>
</tr>
<tr>
<td>Ext (max)</td>
<td>-0.811s</td>
<td>-0.606</td>
</tr>
<tr>
<td>Flex ROM</td>
<td>0.638s</td>
<td>0.499</td>
</tr>
<tr>
<td>Rot ROM</td>
<td>0.637s</td>
<td>0.546</td>
</tr>
<tr>
<td>Rot ROM incl. pelvis</td>
<td>0.562s</td>
<td>0.687</td>
</tr>
<tr>
<td><strong>Hip</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flex ROM (BH)</td>
<td>0.652s</td>
<td>0.624s</td>
</tr>
<tr>
<td>Flex ROM (TH)</td>
<td>0.585s</td>
<td>0.568s</td>
</tr>
<tr>
<td><strong>Knee</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flex ROM (BH)</td>
<td>0.504s</td>
<td>0.542s</td>
</tr>
<tr>
<td><strong>Ankle</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flex ROM (BH)</td>
<td>0.735s</td>
<td>0.370s</td>
</tr>
</tbody>
</table>

*Spearman’s rank coefficients. All other correlations are Pearson correlation coefficients.*
5.4.1 Extra correlation analyses for study I

The results showed that maximal trunk flexion, trunk rotation ROM and trunk and pelvis rotation ROM during va’a paddling were highly correlated with force production in study I (Table 9). When trunk flexion and trunk and pelvis rotation ROM were summed together into a trunk compartment, a high correlation with paddling force was also seen for both male (Pearson’s $r = 0.752$, $p < 0.001$) and female athletes (Pearson’s $r = 0.746$, $p = 0.001$). Partial correlation analyses were conducted to examine if the leg compartment (the sum of the BH and TH knee and ankle flexion ROM) affected the correlation between the trunk compartment and paddling force and if trunk compartment affected the correlation between the leg compartment and paddling force. The strong correlation between the trunk compartment and paddling force was only slightly affected when controlling for the leg compartment (for males $r = 0.603$, $p < 0.001$, for females $r = 0.583$, $p = 0.017$). The correlation between the leg compartment and paddling force was moderate for both males ($r = 0.620$, $p < 0.001$) and females ($r = 0.573$, $p < 0.05$). However, when controlling for the trunk compartment, the correlation between the leg compartment and paddling force was no longer significant for neither males nor females ($p > 0.05$). In addition, no significant correlations were seen between the leg compartment and mean paddling force in male UL and BL athletes ($p > 0.05$) (Figure 21).

![Figure 21](image)

Figure 21. The relationship between the sum of the bottom hand and top hand knee and ankle flexion ROM (leg compartment) and mean paddling force in male va’a athletes with: bilateral leg impairment (BL) (black dots) and unilateral impairment (UL) (white squares).
5.5 Agreement between classifiers (study II)

The results of study II showed that all classifiers were in agreement regarding the class allocation of the 12 athletes. Six athletes were classified as VL2 and six athletes were classified as VL3. Furthermore, the trunk, leg and on-water test batteries all showed excellent IRR with ICCs of >0.9. On an individual test level, the agreement between classifiers was almost perfect in 14 tests, substantial in four tests, moderate in four tests and fair in one test. The leg test battery showed the best agreement with total percentage of agreement ranging from 83% to 100%. The Fleiss kappa values and percentage of total agreement are presented for trunk extension and trunk rotation for the trunk test, for left ankle plantarflexion and dorsi flexion for the leg test and for trunk flexion and trunk rotation in the on-water test in Table 10.
<table>
<thead>
<tr>
<th>Test battery</th>
<th>Test</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>Overall</th>
<th>% agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Trunk</strong></td>
<td>Trunk ext</td>
<td>0.36 [0.03, 0.68]</td>
<td>0.00 [-0.33, 0.33]</td>
<td>0.55 [0.22, 0.88]</td>
<td>0.31 [0.10, 0.54]</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>Right rotation</td>
<td>0.72 [0.39, 1.05]</td>
<td>0.52 [0.19, 0.85]</td>
<td>0.67 [0.34, 0.99]</td>
<td>0.62 [0.36, 0.87]</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>Left rotation</td>
<td>0.72 [0.39, 1.05]</td>
<td>0.53 [0.21, 0.86]</td>
<td>0.67 [0.34, 0.99]</td>
<td>0.62 [0.36, 0.88]</td>
<td>67</td>
</tr>
<tr>
<td><strong>Leg</strong></td>
<td>Left ankle plant. flex</td>
<td>0.77 [0.44, 1.10]</td>
<td>0.44 [0.11, 0.76]</td>
<td>0.03&lt;sup&gt;NS&lt;/sup&gt; [-0.36, 0.30]</td>
<td>0.55 [0.27, 0.83]</td>
<td>83</td>
</tr>
<tr>
<td></td>
<td>Left ankle dorsiflex</td>
<td>0.77 [0.44, 1.10]</td>
<td>0.27&lt;sup&gt;NS&lt;/sup&gt; [-0.05, 0.60]</td>
<td>0.47 [0.14, 0.80]</td>
<td>0.55 [0.30, 0.81]</td>
<td>83</td>
</tr>
<tr>
<td><strong>On-water</strong></td>
<td>Trunk flex</td>
<td>-0.03&lt;sup&gt;NS&lt;/sup&gt; [-0.36, 0.30]</td>
<td>0.44 [0.11, 0.76]</td>
<td>0.55 [0.23, 0.88]</td>
<td>0.47 [0.17, 0.77]</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>Trunk rot</td>
<td>-0.09&lt;sup&gt;NS&lt;/sup&gt; [-0.42, 0.24]</td>
<td>0.33&lt;sup&gt;NS&lt;/sup&gt; [0.00, 0.65]</td>
<td>0.67 [0.34, 0.99]</td>
<td>0.42 [0.15, 0.69]</td>
<td>50</td>
</tr>
</tbody>
</table>

<sup>NS</sup>Not significant (<i>p</i> > 0.05)
6 Discussion

This thesis has examined the differences in kinematic and kinetic performance variables during paddling on a va’a or kayak ergometer between a) non-impaired athletes and para va’a and para kayak athletes, b) para va’a and para kayak athletes with different level of impairment, and d) NA and A sides in para kayak athletes with AK and BK amputation. The relationship between paddling force or paddling power output and joint angles during va’a and kayak ergometer paddling as well as the IRR of the para va’a classification system have also been examined.

In short, the main results showed that in both va’a and kayak, differences in kinematic and kinetic performance variables between non-impaired athletes and para athletes were apparent as well as differences between para va’a and para kayak athletes with different level of impairment. In general, non-impaired va’a and kayak athletes and para va’a and para kayak athletes with less impairment demonstrate larger values in paddling force (study I) and power output (study III) and in ROM in trunk and legs compared to para va’a and para kayak athletes with greater impairment. A significant positive correlation was seen between maximal trunk flexion, trunk and pelvis rotation ROM, hip, knee and ankle flexion ROM and paddling force (va’a, study I) and paddling power output (kayak, study III). Differences between para kayak athletes with AK and BK amputation were only seen for the hip joint in flexion ROM, flexion and extension angular velocity and flexion moment where the BK athletes demonstrated larger values. Differences between the A and NA sides in para kayak athletes with AK and BK amputation were seen in maximal, minimal and mean posterior force at the seat and in hip flexion moment where the NA side demonstrated larger values. Furthermore, the A side demonstrated significantly larger values in peak-to-peak anterior/posterior COP displacement compared to the NA side. In terms of IRR of the para va’a classification system, the results showed that the reliability was excellent as all classifier teams were consistent in the class allocation of the twelve athletes and only minor discrepancies were seen on an individual test level.
6.1 Paddling force, power output and stroke frequency

In studies I and III the non-impaired athletes exhibited significantly larger paddling force (study I) and power output (study III) compared to the para va’a and para kayak athletes. In study I the BL and UL athletes demonstrated significantly larger paddling force compared to the TL athletes. Furthermore, in study III the KL3 athletes demonstrated larger power output than the KL2 and KL1 athletes and the KL2 athletes demonstrated larger power output than KL1 athletes. The results from both studies showed that the larger the impairment, the lesser the paddling force or paddling output. The impact of trunk and leg impairment will be explained in the further sections.

In both studies I and III, the non-impaired athletes and the para athletes with the least impairment, UL (study I) and KL3 (study III), demonstrated significantly higher stroke frequency compared to the para athletes with most impairment, TL (study I) and KL1 (study III). This is in contrast to results in sit-skiing where the athletes with most impairment have shown to have a higher poling frequency as a compensation for a shorter cycle length (Karczewska-Lindinger et al., 2021). In non-impaired kayak paddling, a higher stroke frequency is correlated with a higher kayak average velocity (McDonnell et al., 2013). That the TL and KL1 athletes in studies I and III demonstrated less stroke frequency, is therefore negative for their performance. Since they are also likely to be limited in their ability to have a longer drag length due to their impairment, increasing the stroke frequency can improve their performance. TL and KL1 may therefore be benefited by experimenting with paddle blade sizes which has been suggested to have an impact on stroke frequency during paddling on water (Michael et al., 2009).

6.2 The impact of trunk impairment on performance

6.2.1 Trunk flexion and extension

Trunk movement during va’a paddling can differ depending on what technique the athlete uses and can include a combination of trunk flexion/extension and trunk rotation but there can also be a larger movement in either trunk flexion/extension or trunk rotation depending if the athlete uses a Hawaiian or Tahitian paddling style (Sealey et al. 2011). In study I all the va’a athletes exhibited both trunk rotation and trunk flexion. The trunk flexion ROM was 16 ± 9° for the non-impaired va’a athletes which is similar to a previous reported value of 17 ± 14° exhibited by non-impaired va’a athletes using the Hawaiian paddling style (Sealey et al. 2011). This ROM value was also higher than the trunk flexion ROM observed in the non-impaired kayak athletes which was 6 ± 3°. Furthermore, in both studies I and III a significant positive correlation was seen between
paddling performance and maximal trunk flexion and a significant negative correlation was seen between maximal trunk extension and paddling performance. Only in study I however, a positive correlation was observed between paddling performance and trunk flexion ROM. These results show that in va’a paddling the athletes use a dynamic trunk flexion movement whilst in kayak paddling the athletes sit with the trunk in a slightly forward flexed static position. This dynamic trunk flexion movement seen during va’a paddling is similar to the trunk movement observed in sit-skiing (Rosso et al., 2016) whilst the static forward leaning trunk position seen in kayak is similar to what is observed after the first push in wheelchair racing (Vanlandewijck et al., 2011b). In fact, Vanlandewijck et al. (2011b) suggested that the role of the trunk after the first push in wheelchair racing is to provide a stable base for generating propulsion force with the upper limbs. This is very similar to the description provided by Brown et al. (2010) that the lower trunk during kayak paddling has a role as a stable platform against which propulsive force is developed.

In studies I and III the athletes with the greatest impairment, TL and KL1, demonstrated significantly smaller maximal trunk flexion and larger maximal trunk extension values compared to the non-impaired va’a and kayak athletes and the two other para athlete groups. This means that the TL and KL1 athletes sat more upright or slightly leaning backwards with the trunk compared to the other athletes. This is not surprising since the athletes in the TL and KL1 classes have an impairment affecting their trunk and hip flexors and extensors which limits their ability to lean forward. Since TL athletes and KL1 athletes do not have the functional capacity to lean forward, these athletes typically strap their trunk against the seat backrest in order to not collapse forwards which makes them sit in a more upright or slightly extended trunk position. This has also been demonstrated in sit-skiing where athletes with higher impairment used strapping which resulted in the athletes sitting in a more upright position and demonstrating less ROM compared to athletes with less impairment (Rosso et al., 2016). Strapping may decrease the athletes’ ability to sit in forward leaning position with the trunk, but it may instead improve trunk stability. West et al. (2014) showed that abdominal binding improved trunk stability, ventilatory efficiency and/or haemodynamics which improved important performance factors such as wheelchair acceleration, in wheelchair athletes with a cervical SCI. Although the TL athletes in study I and the KL1 athletes in study III did not have such high impairment level, and the effects of strapping will likely not change ventilatory efficiency, it will still provide trunk stability which can be beneficial for performance.

Even though the TL athletes used strapping and was in a more upright trunk position compared to the athletes with less impairment, a ROM of 9° was seen indicating that some trunk flexion movement occurred. This has also been seen in sit-skiing where athletes with more impairment demonstrated some trunk flexion ROM (Rosso et al., 2016).
The reason for there being some trunk flexion movement observed in the TL athletes may partly be because the athletes have function in the upper part of the trunk which enables trunk flexion movement in the upper trunk. Another possible reason may be due to gravity and compensation techniques. The trunk flexion can occur by taking advantage of gravity and the trunk extension can occur by compensation mechanisms that exploit head, arms and upper trunk inertia (Gastaldi et al., 2016; Rosso et al., 2016). This has been shown in sit-skiing athletes with more trunk impairment (Gastaldi et al., 2016; Rosso et al., 2016) and may be a possible reason for the trunk flexion movement observed in the TL athletes as well.

In study III it was only in maximal trunk flexion and extension a significant difference was found between the KL1 and KL2 athletes suggesting that the KL2 athletes have slightly better trunk function. This is in accordance with the para kayak classification system which defined that KL1 athletes have no or limited trunk and leg function and the KL2 athletes have no, limited or full trunk and no or limited leg function (Appendix 2). In contrast to the KL1 athletes, KL2 athletes can have function in hip flexors and extensors enabling them to lean forward with the trunk. This may be an explanation to why there was a difference observed between the KL1 and KL2 athletes in trunk flexion but not in trunk and pelvis rotation.

As a result of these findings, trunk flexion is assessed in both the trunk and on-water test batteries for both disciplines. Since there however is a difference in the utility of trunk flexion between the disciplines, the scoring of trunk flexion in the on-water test batteries are different. Para va’a athletes are therefore scored in trunk flexion movement and para kayak athletes are scored in trunk position.

6.2.2 Trunk rotation and the impact of the pelvis

The non-impaired va’a athletes and the UL athletes in study I demonstrated significantly larger trunk and pelvis ROM compared to the TL athletes. Additionally, positive correlations were seen in study I between paddling force and both trunk and pelvis rotation ROM and trunk rotation ROM. In study III however, only the trunk and pelvis rotation ROM was correlated with power output. Additionally in study III, no significant differences were observed between the groups in trunk rotation ROM, but in trunk and pelvis rotation ROM where the non-impaired athletes demonstrated significantly larger values compared to all three classification groups and the KL3 athletes showed significantly larger values compared to the KL1 athletes. A reason for there not being a difference in trunk rotation ROM between the groups or no correlation between trunk rotation ROM and power output, may be due to that the 3D model of the trunk mainly used tracking markers attached on the upper part of the trunk (C7, T5, sternum and T12). All these markers, except potentially the marker on T12, were above the injury level of most of
the athletes and therefore all athletes have a possibility to rotate this part of the trunk. When examining the trunk and pelvis rotation however, there was a significant difference between the groups and a correlation with power output was shown. This is likely due to that the athletes who have injuries affecting the lower spine and pelvis will not be able to rotate the lower part of the spine or the pelvis. It therefore seems that it is trunk rotation in combination with pelvis rotation, and not trunk rotation alone, which has an impact on performance for the para kayak athletes included in this study. Previous research in non-impaired kayak athletes have also suggested that the combined trunk and pelvis rotation is important for kayak performance (Bjerkefors et al., 2018; Limonta et al., 2010; Begon et al., 2010). Additionally, in study III all kayak athlete groups exhibited a statistically significant difference between trunk rotation and trunk and pelvis rotation. Shown in Figure 21, the non-impaired kayak athletes however demonstrated a much larger difference between the two angles. This indicates that the non-impaired athletes to a greater extent used their pelvis to increase trunk rotation. Furthermore, the KL3 athletes also exhibited a larger difference between the two angles compared to the KL1 athletes. The KL1 and KL2 athletes had smaller differences between the two angles which indicate that they rotated their pelvis less and that rotation mostly occurred in their upper trunk.

The results from studies I and III indicate that both trunk flexion and trunk and pelvis rotation are important for va’a and kayak paddling performance. One of the reasons for why being able to sit with the trunk forward flexed or dynamically move the trunk in flexion in combination with having a great trunk and pelvis rotation, may be due to that it increases the chance of a greater forward reach. Forward reach has been shown to increase with increasing intensity in kayak paddling in non-impaired athletes (Bjerkefors et al., 2018) and a greater forward reach has been shown to be a factor contributing to performance (Brown et al., 2011). A greater forward reach increases the distance in which the paddle is immersed in the water and therefore increases the work done. This has also been described in swimming where a longer underwater phase increases the ability to generate force (dos Santos et al., 2021). In combination with a high stroke frequency power output can be increased which on water could potentially increase the velocity of the kayak (Brown et al., 2011). Both the para va’a kayak and para kayak athletes with more impairment (TL and KL1, respectively) exhibit a more upright, or even extended, trunk position since they have an impairment that affect their trunk function. This therefore limits their ability to have a larger forward reach and may be one reason for why these athletes exhibit lower paddling force or power output compared to the other para athlete groups. To overcome this issue, in kayak paddling on water, some individual athletes use adaptations which they can lean into or “hang” in and thus positioning them in a forward flexed trunk position. This therefore enables a longer forward reach which can potentially increase the stroke length.
In sit-skiing a progression in trunk flexion and trunk flexion ROM from the group with least impairment through to the group with least impairment has been shown (Rosso et al., 2016). This was also observed in both studies I and III where a progression in trunk flexion and trunk and pelvis rotation ROM was seen from the athletes with most impairment (study I: TL, study III: KL1) through to the athletes with least impairment (study I: UL, study III: KL3). In study I, only the TL athletes had impairments affecting the trunk. They did not only exhibit less trunk kinematics when paddling but also had significantly lower paddling force compared to the other two groups which did not have trunk impairment. In study III the athletes in the para kayak classes have a progression of trunk function which was also reflected in the trunk kinematics. This same progression was also seen in power output where the athletes with less trunk impairment demonstrated larger power output values compared to the athletes with most impairment. This thesis has therefore shown that in both para va’a and para kayak having an impairment affecting the ability to flex the trunk and rotate the trunk and pelvis will impact on performance. It is therefore important that both trunk flexion and trunk and pelvis rotation are examined in para va’a and para kayak classification. This is also currently the case for both sports. Trunk flexion and trunk rotation are both scored when the athletes are in an unsupported position on a bench where no equipment are used, and in a supported position in the va’a or kayak where the athletes are in their competition set-up.

6.2.3 Upper limb compensation
Athletes with impairments that only affect the arms are not eligible to compete in either para va’a or para kayak at international events organised by the ICF. It was therefore interesting that in both study I and III, differences between the non-impaired athletes and the para athletes were found in shoulder kinematics during paddling. Indeed, in study I the non-impaired va’a athletes demonstrated more shoulder flexion for both the TH and BH sides and less shoulder extension in the TH side compared to the TL athletes (Table 6). In study III even more differences were observed. The non-impaired kayak athletes exhibited more maximal shoulder flexion compared to the KL1 athletes, less shoulder extension compared to KL1 and KL2 athletes and a smaller shoulder flexion ROM compared to all three para athlete classes (Table 6). The results show that the non-impaired kayak athletes do not extend the shoulder as seen in the para kayak athletes. This results in a lower shoulder flexion ROM for the non-impaired kayak athletes compared to the para kayak athletes. A possible explanation is that the athletes who have greater impairment compensate for their impairment by depending upon their upper limb function for force and power production to a greater extent than non-impaired athletes and less impaired athletes. Furthermore, the reason for the non-impaired va’a and kayak athletes
demonstrating larger shoulder flexion values compared to the TL and KL1 athletes may be due to that they also lean more forward with the trunk during paddling. Since the shoulder flexion angle is calculated as the angle between the upper arm and the trunk, leaning forward with the trunk with a concomitant constant upper arm angle will increase maximal shoulder flexion. The TL and KL1 athletes cannot lean forward with their trunk due to their impairment which will result in a smaller shoulder flexion angle. The compensation of using more shoulder movement is important to examine during the on-water tests so that the athletes are not inaccurately scored higher in the trunk tasks.

6.3 The role of the legs

6.3.1 Hip flexion and extension
In both studies I and III, the non-impaired va’a and kayak athletes demonstrated similar hip flexion ROM values, 26 ± 3° in study I and 20 ± 11° in study III. In study I the non-impaired va’a athletes demonstrated significantly larger hip flexion ROM values compared to the TL and BL athletes for both the TH and BH side, but not compared to the UL athletes. In study III however, the non-impaired kayak athletes demonstrated larger values compared to all three classification groups. Furthermore, in study III the KL3 athletes demonstrated significantly larger values compared to both KL1 and KL2. In study I the UL athletes only demonstrated larger values compared TL athletes. This difference in the results between the studies is not surprising since in study I both the UL and BL athletes have full trunk function, which usually includes function in the hip flexors and extensors, otherwise the athletes cannot perform a dynamic trunk flexion or extension in a seated position during the medical classification. In study III on the other hand, the KL2 athletes can have either full or slightly impaired trunk function which means that some athletes have full function in hip flexors and extensors, and some do not. That there was a difference between the non-impaired va’a and BL athletes in hip flexion ROM could be due to that the BL athletes have limited function in the knee and ankle joints which limits them to use the legs actively during paddling. The athletes therefore exhibit less hip flexion even though they have function in the hip flexors and extensors.

Study I demonstrated a significant correlation between paddling force and both TH and BH hip flexion ROM. Similarly, study III showed a positive correlation between hip flexion ROM and paddling power output. Interestingly it was only hip flexion ROM out of the lower limb joint variables that was significantly correlated with paddling force for the TH side. One reason for this may be due to that the hip flexion angle is calculated as the angle between the thigh and the trunk. The hip flexion angle can therefore
increase both as a result of lifting the thigh closer to the trunk, or by leaning the trunk forward towards the thigh. Since vaʻa paddling exhibits a lot of trunk flexion movement, it is possible that this partially explains the positive correlation between the hip flexion ROM and power output.

It was only in variables at the hip joint a significant difference between the AK and BK athletes were seen for study IV. The BK group demonstrated significantly larger values in hip flexion/extension ROM, flexion and extension velocity and flexion moment. A likely reason for this is because the BK athletes have two full functioning knee joints, and usually wear a prosthesis when paddling, enabling them to also flex and extend the hip joint. The AK athletes however, typically lock their residual limb into an adaptive device which restricts their ability to flex and extend the hip joint. It however instead enables them to transfer momentum and force onto the adaptive device and the kayak in connection with the paddle action. It is also likely that there would have been differences between the AK and BK groups in variables concerning the knee and ankle on the A side, but because the number of athletes who wore a prosthesis in the AK group was too small, no statistics could be conducted on the A side.

6.3.2 Knee flexion and extension
The knee flexion and extension ROM in the non-impaired kayak athletes in study III was similar to what has previously been reported in non-impaired kayak athletes whilst paddling on-water (Nilsson & Rosdahl, 2016) and on ergometer (Limonta et al., 2010). No equivalent previous study has however examined the leg movement in vaʻa paddling whereby no comparisons with other studies can be made. It is however apparent that the non-impaired vaʻa athletes show less knee ROM compared to the non-impaired kayak paddlers. The non-impaired vaʻa athletes demonstrated a knee flexion ROM in the BH side, which is the leg demonstrating largest movement, of 20 ± 8° which is more than half the ROM observed in the non-impaired kayak athletes. Even so, in both studies I and III a significant correlation was observed between knee flexion ROM, and paddling force (study I) and power output (study III) demonstrating that flexion and extension of the knee joint is of importance in both disciplines.

In study I the non-impaired vaʻa athletes demonstrated significantly larger knee flexion ROM values in both the TH and BH side compared to the BL and TL athletes whilst in study III the non-impaired kayak athletes had larger values compared to all the para kayak groups. In study I the UL athletes demonstrated larger knee flexion ROM values compared to both the other para vaʻa groups on the BH side which was similar to the results of study III where the KL3 athletes demonstrated larger values compared to KL1 and KL2. These results from both study I and III are in accordance with the athletes’
function, in studies I and III the UL and KL3 athletes, respectively, have more function in the legs compared to the other para athlete groups.

The reason for there only being a difference in the BH side between the UL athletes and the TL and BL athletes in study I is likely due to that 14 of the 17 UL athletes used their full functioning leg on the BH side. When examining the results from the non-impaired va’a athletes, it is evident that they have larger ROMs on the BH side leg compared to their TH side. In a PhD thesis by Sealey (2010) it was suggested that during va’a crew paddling the legs work isometrically. The results from study I show that this is not observed in the V1 paddlers in regards to the BH side leg, however the smaller ROM values observed in the TH side may indicate that the TH side leg is working more isometrically. In addition, a significant positive correlation with paddling force was only seen for the BH side knee flexion ROM, not for the TH side. The fact that the majority of the UL athletes chose to have their full functioning leg on the BH side, that the non-impaired va’a athletes have larger ROM values in knee flexion on the BH side and that there was only a positive correlation for the BH side knee flexion with paddling force indicate that the BH side leg acts as a more driving leg during V1 paddling. This larger leg movement seem to contribute to the paddle propulsion force. Interestingly however, the only notable differences in joint ROM between the non-impaired va’a and UL athletes were in TH knee and ankle flexion even though the non-impaired athletes demonstrated a significantly higher mean paddling force. It therefore seems that even if the TH leg does indeed work more isometrically, it might still be related to paddling force and even if an athletes has a full functioning leg on the BH side, having an impairment of the TH side leg affects the performance.

The results showed that only the BH leg was correlated with paddling force in va’a paddling which gave an indication of how leg movement in the on-water test battery for para va’a should be scored. In para kayak both legs are scored but in para va’a it was decided to score “the leg that moves the most” to get a more accurate score. If only the BH side is scored the athletes can paddle with the more impaired leg on the BH side and less impaired leg on the TH side during the classification, resulting in very limited leg movement in total. The athletes can then switch to paddle with the impaired leg on the BH side during competition. It would not be plausible to check this for every athlete during each competition so now the athletes have to paddle on both sides during the classification and whichever leg moves the most is scored.

6.3.3 Ankle flexion and extension

In study I the non-impaired va’a athletes demonstrated significantly larger ankle joint values compared to all three para va’a groups on the TH side and compared to BL and TL also on the BH side. This is most likely due to that the majority of the UL athletes
have their impaired leg on the TL side and a difference compared to the non-impaired va’a athletes is therefore seen on that side and not on the BH side. Furthermore, in study III the non-impaired kayak athletes demonstrated larger values compared to the para kayak athletes. No significant differences were observed between any of the para kayak athlete groups. This is most likely due to that the MIC in para kayak is that the athletes must have a loss of four points on the same leg in the leg test corresponding to, for an example, having no function in an ankle. This means that on a group level, all three para kayak groups have limited or no function in the ankle.

6.3.4 The legs’ contribution to trunk and pelvis rotation

It has previously been described in kayaking for non-impaired athletes that the pedalling motion of the legs causes pelvis rotation, initiates trunk rotation and increases the stroke length and paddle velocity (Begon et al., 2010). It is therefore not unexpected that the legs seem to have a role in trunk and pelvis rotation in both para va’a and para kayak as well. In study I the para va’a TL and BL athletes, had similar differences between the trunk and pelvis rotation ROM and trunk rotation ROM (TL: 4° and BL: 5°) even though the BL athletes have full trunk function and function in hip flexors and extensors. This indicates that it is the pelvis rotation which is the limiting factor for BL athletes which is most likely because of their leg impairment. In kayak paddling, Begon et al. (2010) found that the asymmetric leg movement seen during kayak paddling contributes to pelvis rotation. If athletes have no function in the legs, pelvis rotation will be limited. Even though the study by Begon et al. (2010) was conducted on kayak paddling, it is likely that the same relation between legs and pelvis exist in va’a paddling.

A smaller difference between trunk rotation and trunk and pelvis rotation was seen for the KL1 and KL2 athletes compared to the KL3 and non-impaired athletes. This is most likely because these athletes have limited or no leg function which as previously described, will affect pelvis rotation. The impact of the leg movement on pelvis rotation may also explain why there was no significant difference between the KL1 and KL2 athletes in trunk and pelvis rotation even though the KL2 athletes should have more trunk function. The results from both study I and study III indicate that the pelvis rotation capacity is debilitated in the athletes who have no or limited leg function as the TL and BL athletes in study I and the KL1 and KL2 athletes in study III. This will as previously mentioned affect performance. Similarly, even though the KL3 athletes in study III have full trunk function, they still exhibited significantly less trunk and pelvis rotation ROM, but not trunk rotation ROM, compared to the non-impaired kayak athletes. Since the KL3 athletes have an impairment which only affects the legs, this result also shows that the pelvis rotation will be debilitated if the athletes have limited leg function. Previous studies (Begon et al., 2010; Limonta et al., 2010) have shown that the ability to
push and pull on the footrest increases pelvis rotation. The TL and BL athletes in study I and the KL1 and KL2 athletes in study III will all have a limited ability to push and pull on the footrest because of their impairment. KL3 athletes who do not wear a prosthesis will not have a connection with the footrest and will also not be able to push and pull on the footrest. In study III, five of the nine KL3 athletes with amputation did not use prostheses when paddling due to either pain or discomfort in the residual limb or due to a lack of well-functioning prostheses. This might explain the differences in trunk and pelvis rotation compared to the non-impaired kayak athletes. Interestingly however, in study IV where all athletes had an amputation, no significant differences between the AK and BK athletes were observed in either trunk and pelvis rotation ROM or in pelvis rotation ROM. This was despite that only two of the 11 AK athletes wore a prosthesis. If it indeed is the connection to the footrest that helps the pelvis to rotate, there would have been a difference between the AK and BK athletes. The reason for this discrepancy may be explained by the use of an adaptation for the residual limb. In study III, the athletes who did not wear a prosthesis did not have an adaptation for the residual limb during the data collection, even though they might use one during competition. In study IV however, an adaptation for the residual limb was created and offered to the athletes who did not wear a prosthesis, which all AK athletes who did not wear a prosthesis used. The adaptation secures the residual limb and provides a connection to the ergometer much like their adaptation in the boat which provides a connection to the kayak. This results in the athletes having a resistance of which they can push and pull against, similarly to a footrest, and may therefore facilitate pelvis rotation.

The non-impaired va’a athletes in study I exhibited a numerical difference in the ROMs between the TH and BH sides where the BH hip, knee and ankle ROMs were larger. The reason for the BH leg movement being larger than the TH leg movement may partially be due to the necessity of having a trunk rotation on the paddling side. As previously mentioned, the flexion and extension of the lower limb joints helps the pelvis to rotate and as a result also the trunk. The difference is that in kayak, the movement is symmetrical, and the body sides go through the same motions during a stroke cycle resulting in very similar ROMs in the legs of each side and in maximal trunk rotations to each side. In va’a however, the athletes paddle on one side resulting in that the trunk rotation occurs on the paddling side. There is therefore a bigger need for leg movement on the paddling side to facilitate the pelvis and trunk rotation. This might also be a reason for why the UL para va’a athletes choose to paddle with their full functioning leg on the BH side.

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6.3.5 Why para va’a athletes with different level of leg impairment can compete in the same class if they have full trunk function

The BL and UL para va’a athletes both had full trunk function but different level of leg impairment. It was therefore not unexpected that the only differences between the BL and UL para va’a athletes were in BH side knee and ankle flexion ROM. This difference was also most likely to be due to that the UL athletes paddled with their full functioning leg on the BH side. The differences in the BH side knee and ankle flexion ROM did however not seem to affect the ability to produce force since no differences were found in the mean paddling force between these two groups. Both the UL and BL athletes had however significantly larger paddling force and maximal trunk flexion compared to the TL athletes. This suggests that the leg impairment does not seem to matter as long as the athlete has full trunk function (which also includes function in hip flexors and extensors). The movement of the legs therefore seem to be of less importance compared to movement of the trunk. This is also demonstrated in the results of the extra correlation analyses conducted for study I (Figure 21). The partial correlation showed that there was a minor decrease in correlation between trunk movement and paddling force when controlling for leg movement compared to when not controlling for leg movement. In contrast, when examining the correlation between leg movement and paddling force and controlling for trunk movement, there was no longer a significant correlation between the leg movement and paddling force for either the female or male athletes. In addition, when examining the correlation between leg movement and paddling force in male UL and BL athletes with full trunk function, no correlation between leg movement and paddling force was found. On an individual athlete level, a BL athlete could therefore produce more force compared to a UL athlete even though the UL athletes paddled with the full functioning leg on the BH side. The results therefore suggest that para va’a athletes who have full trunk function should be able to compete in the same classification class regardless of their level of leg impairment. This was important information when developing the new evidence-based classification system for para va’a as we had evidence to show that BL and UL athletes should be able to compete in the same class.

The results from study I also assisted in defining one of the MIC for the para va’a classification system. In kayak it is defined as losing four points in the leg test battery which corresponds to for instance having an impairment affecting the ankle (e.g. BK amputation). Since the legs were of less importance in va’a paddling, a higher MIC was decided. It was decided that athletes need to lose at least 10 points in the leg test battery, which corresponds to having an AK amputation.
6.4 Validity of the para kayak classification system

Valid classification systems ensure that successful athletes will not succeed because their impairment is less severe than others, but because they have the most advantageous combination of anthropometric, physiological, and/or psychological attributes (Tweedy et al., 2014; Tweedy & Vanlandewijck, 2011). In order for a classification system to be valid, clear differences between the classes are therefore wanted. The differences between the KL1, KL2 and KL3 athletes in study III were in general what we had hoped to see when developing the new evidence-based classification system for para kayak. There was a progression in power output where the KL3 athletes demonstrated the largest power output and the KL1 demonstrated the lowest power output. For the trunk variables it was also as we had anticipated, the KL3 athletes had significantly larger trunk flexion and trunk and pelvis rotation ROM compared to the KL1 athletes. Between KL1 and KL2 we had anticipated to see some differences in trunk variables which was shown for trunk flexion and trunk extension where the KL2 athletes sat in a more forward flexed trunk position compared to the KL1 athletes. There was however no difference in trunk and pelvis rotation between the two groups which might be due to that both groups have no or very limited function in the legs which, as previously described, facilitate pelvis rotation. Furthermore, the only differences between the KL3 and KL2 athletes were seen in the hip and knee flexion ROM which is also according to the class description that the KL3 athletes should have more function in the legs. In terms of a valid MIC criteria, the KL3 athletes had significantly less ankle ROM compared to the non-impaired kayak athletes as well as a lower power output. Since the only difference between a KL3 athlete and a non-impaired athlete could be in the function of the ankle, this was a desired result. These results indicate that it is possible to discriminate between the para kayak classes and between non-impaired kayak athletes and para kayak athletes which is desirable in terms of validity of the classification system.

The extra correlation analyses between power output and joint ROMs or maximal joint angles concerning the trunk and legs for the male KL1, KL2 and KL3 classes showed that there were no significant correlations for either the KL1 or KL3 classes. This indicates that the athletes within the classes had similar ROM and maximal joint angles as well as power output which is desirable in a valid classification system. There was however a correlation seen between power output and hip flexion ROM and knee flexion ROM for the KL2 class. This implies that the KL2 athletes who have a larger ROM in the hips and knees, will have a higher power output. This was not surprising since the athletes in KL2 have the largest variety of impairments and can have a total cluster score ranging from 4 to 7, which is a large range (Figure 9). This is also reflected in the Proposed Paralympic Classification System for para kayak where it is stated that KL2 athletes “can have no, partial or full trunk function and no or partial leg function”
which is quite a large variation of allowed function. The KL2 class might therefore need to be revised in the future.

The findings of this thesis indicate that the new evidence-based classification system for para kayak is valid for the KL1 and KL3 classes, but there is a question regarding the validity within the KL2 class. Study III was however conducted on an ergometer and we do not know whether the same results would be seen on water. During the Paralympic Games in 2021 there were significant differences between the classes in race time in the A finals for both the men and women where the KL3 athletes exhibited significantly better race times compared to KL2 and KL1 and KL2 exhibited significantly better race times compared to KL1. This is promising in terms of the validity of the para kayak classification system, however standardised studies on water with larger sample sizes are warranted in the future to see whether the findings of study III can be confirmed.

6.4.1 Can para kayak athletes with AK or BK amputation compete in the same class?

The reason for conducting study IV was to examine if athletes with two functioning knee joints should compete in the same class as athletes with only one functioning knee joint since the leg movement has shown to be important for performance in numerous studies (Begon et al., 2010; Bjerkefors et al., 2018; Brown et al., 2011; Nilsson & Rosdahl, 2016). There were however hardly any variables which demonstrated a significant difference between the AK and BK athletes. It was only in hip flexion/extension ROM, hip flexion and extension velocity and hip flexion moment significant differences were apparent. Since only two AK athletes wore a prosthesis, no statistical tests could be performed for the A side in any of the variables concerning the knee and ankle joints or in forces at the footrest. It is however quite clear when examining the data from the two AK athletes that there are numerical differences in the knee and ankle joint compared to the BK group in the A side.

A main effect of side was observed for anterior/posterior force at the seat and for the peak-to-peak COP displacement during the drag phase. A larger peak-to-peak COP displacement can be seen on the A side for both the AK and BK athletes (Table 7). When conducting the tests, we reflected on that the athletes seemed to take a longer stroke on the A side. Even though not significant, a numerical difference in drag length is seen between the A and NA sides for both the AK and BK athletes where the A side demonstrates larger values. Since the drag length is larger on the A side it might explain why the peak-to-peak anterior/posterior COP displacement also is larger on the A side. Another interesting finding was that the AK athletes exhibited an anterior force on the seat (negative values in the minimal posterior force at the seat) (Figure 18). Usually, as
Kayak athletes extend their leg and rotate their pelvis during the drag phase, the athletes push on the posterior part of the seat with their buttocks thus creating a posterior force on the seat. The AK athletes however pushes anteriorly on the seat. A reason for this might be because the buttocks glide anteriorly on the seat creating an anterior action force due to that most of the athletes do not have a leg to push with on the A side.

Even though the results show some significant differences between the two groups, no significant differences were found between the groups in the major performance variables such as paddling power output, paddling force, stroke frequency, drag length or paddling velocity. It is apparent that there are numerical differences between the groups in some of the performance variables such as paddling power output, paddling force and paddle velocity. The exact translation of this to kayak velocity on water during a 200 m race is however unknown as other factors such as the ability to master the waves and stroke efficiency would have an effect. On the ergometer it might therefore be easier for the athletes to produce a high power output without the technical skills required to produce such a high power output on water.

The results from study IV seem to indicate that the AK and BK athletes may indeed be able to compete in the same class, however it is preferable if the study could be reproduced on water with a larger sample size before any definite conclusions can be drawn. The personal best times for the AK and BK athletes during the 2017 World Championship (where the data was collected) however seem to give the same indication as the conclusion from study IV. The male AK and BK athletes demonstrated very similar personal best times of 43.047 ± 2.147 s and 43.901 ± 2.787 s, respectively. No such information can however be given for the female athletes as one of the BK athletes did not participate in the competition and the result from one female BK athlete cannot be presented due to the risk of identification of this athlete.

6.5 Reliability of the para va’a classification system

As study I has shown, there is a need of having classification tests in para va’a which assess trunk and leg function. After study I was conducted, a new evidence-based classification system for para va’a, including new leg, trunk and on-water test batteries, was developed (Appendix 1). As previously mentioned, to have the classification be as fair as possible, it is important that the tests are valid and reliable. If classifiers are classifying athletes with similar impairments inconsistently, then the credibility of the classifiers and the classification system becomes flawed. Study II therefore examined the IRR of the new evidence-based classification system for para-va’a which was developed after study I was conducted. The results from study II showed that the IRR of the overall class allocation and the test batteries were excellent as the three classifier teams were
consistent in the allocation of the 12 para va’a athletes and all test batteries showed an ICC of >0.9. The studies in wheelchair rugby and para Nordic skiing which examined the IRR of their trunk impairment classification exhibited a lower IRR compared to the results of this study. In wheelchair rugby the overall Fleiss kappa for the trunk impairment classification was 0.76 and 0.75 in a first and second session respectively (Altmann et al., 2013). Pernot et al. (2011) demonstrated a Spearman rank correlation of 0.95 which according to Altmann et al. (2013) corresponds to an overall Fleiss kappa of 0.8. In addition, the difference between the classifiers in their studies resulted in differences in class allocation for a few athletes, which was not the case in our study. The reason for this may be due to that in the research conducted on wheelchair rugby and para Nordic skiing, the class allocation was based upon one individual test battery, whilst in study II it was based upon three test batteries. This allows for minor differences between the classifiers on an individual test level and on a test battery level without it affecting the overall class allocation.

High IRR was also seen on an individual test level in study II. Twelve of the fourteen leg tests in the leg test battery exhibited overall Fleiss kappa values of almost perfect agreement. Furthermore, the leg movement test in the on-water test battery exhibited the highest Fleiss kappa values both for each score and for overall Fleiss kappa. Left ankle plantar- and dorsiflexion in the leg test battery however, exhibited overall Fleiss kappa values corresponding to moderate agreement but was accompanied with a high agreement of 83% for both tests. The discrepancies between the low value of Fleiss kappa and the high percentage of total agreement may be explained by the low prevalence of scores 1 and 2 in these two tests. Since the MIC is to have a loss of at least 10 points in one leg, athletes usually have an impairment which at least affects the whole ankle. This results in the majority of the athletes scoring 0 in the ankle. Low values of Fleiss kappa with high percentages of agreement indicate a skewed distribution of scores, which was apparent for these leg tests. Since kappa statistics are influenced by the prevalence of entities for each score, it may not be the most appropriate statistic to assess reliability for these cases (Feinstein & Cicchetti, 1990).

The trunk test battery and the trunk tests in the on-water test battery showed a slightly lower IRR compared to the leg test battery and the leg tests in the on-water test battery. Especially the trunk extension test in the trunk test battery and the two trunk tests in the on-water test battery exhibited a lower value of overall Fleiss kappa as well as poor and non-significant Fleiss kappa values for individual scores. There was a low spread of scores in these tests similarly to the left ankle plantar- and dorsiflexion but the percentage of agreement was not as high indicating that there is an actual lower IRR for these tests. The classifiers therefore seem to have difficulties in scoring these trunk tests. The difficulty is most likely due to that the athletes can use compensation strategies to perform this movement. Athletes with trunk impairment can compensate during
these trunk tests by using upper trunk muscles with intact innervation or using normally non-postural upper trunk muscles (Bjerkefors et al., 2009; Potten et al., 1999; Seelen et al., 1998). Another compensation strategy for athletes with impairment that affect their ability to activate muscles around the pelvis such as hip flexor and extensor muscles, is to perform the trunk tests with trunk kyphosis or lordosis (Rosén et al., 2020). As mentioned by Rosén et al. (2020) it is difficult for the classifiers to distinguish the movement caused by a compensation strategy because the compensation might make the movement look exaggerated. Altmann et al. (2013) also discussed the difficulties involved in distinguishing trunk impairment from compensation strategies during classification. Altmann et al. (2013) suggested that test descriptions should place emphasis on describing the difficulties and also demonstrated that reliability can increase if test descriptions in classification manuals are made more clear. To further increase the reliability of trunk flexion and extension tests in the trunk and on-water test batteries in the para va’a classification system, the possible usage of compensation strategies should be discussed amongst classifiers and subsequently, the descriptions in the trunk and on-water test manuals should be made more clear.

The test batteries included in para va’a classification are not following all of the recommendations for measures of impairment in an evidence-based classification system. The recommendations state that the measures should be objective, reliable, precise, specific to the impairment of interest, parsimonious and training resistant (Vanlandewijck & Tweedy, 2011). None of the test batteries mentioned above are ratio scaled or objective, since they are graded by classifiers. Special critique has been given to the usage of MMT during classification. MMT is commonly used in medical assessments in classification systems to assess impairments affecting muscle strength since it requires limited equipment and can be used by classifiers all around the world (Beckman et al., 2017; Tweedy et al., 2010, 2014, 2018). The recommendation against using MMT in evidence-based classification system is because it is scored on an ordinal scale and subjective which can make it difficult in achieving acceptable reliability (Beckman et al., 2017; Tweedy et al., 2014; Tweedy & Vanlandewijck, 2011). The leg test battery in the para va’a classification system is the test battery which most closely resembles to MMT and was interestingly the test battery which had the highest IRR. Escolar et al. (2001) have shown that the reliability of MMT can increase if the raters are well trained in the tests and if the test descriptions are good. The classifiers that participated in study II were all well experienced classifiers and had through training in these tests. Furthermore, the manuals created for the test batteries were created by the ICF Paracanoe classification committee in which the head of classification, three technical classifiers, one medical classifier, one medical classifier/researcher and myself are included. Great detail was put into making the manuals as detailed and explanatory as possible and all paracanoe classifiers had a chance to comment and provide feedback on the manual. This
might have contributed to high IRR seen in all test batteries. Furthermore, paracanoe is quite a small sport with around 15 international classifiers. This has the advantage of it not being impossible to hold classifier trainings together with all classifiers. Regular classifier trainings can maybe assist in increasing IRR since all classifiers are then up to date and have practiced and discussed the tests together. In addition, the tests are conducted in sport-specific ROM and only assess the movements relevant for sport performance which has been recommended by Tweedy et al. (2010) in order to increase the reliability.

Another reason for the high reliability may be that the tests use a scale of 0 to 2 instead of the 0 to 5 scale used in MMT. This makes the differences between the scores more distinct and may also be a reason for the high IRR. The reason for changing the scale to a 0 to 2 scale was twofold. The first reason was that we wanted the test to be more relevant for testing function in regard to sports (Appendix 2). MMT is used as a clinical diagnostic tool in for example rehabilitation. Since the classification tests are to be used to assess function in regard to sport, the scale does not have to be as detailed. For example, score 0 in Daniels and Worthingham’s MMT is that no muscle activation can be detected either visually or by palpation (Hislop & Montgomery, 1995). Score 1 is that the examiner can detect visually or by palpation some muscle activity in one or more of the muscles included in the movement being tested (Hislop & Montgomery, 1995). Score 0 and 1 therefore both result in there being no movement in the joint and the palpable difference in muscle activation will likely not contribute to sports performance. The second reason was that we anticipated that there would be a better IRR between the classifiers if the scale was smaller, which also seems to be the case.

6.6 Methodological considerations, study limitations and strengths

6.6.1 Ethics

All studies were granted ethical approval from Stockholm Regional Ethical Committee. The athletes only took part in activities which the athletes do on a regular basis (either paddled on an ergometer or partook in classification), and no invasive tests were conducted. The athletes did however fill out a health declaration in which they stated what impairment they had which is a sensitive information. The athletes were informed that their information would be unidentified by a code and kept in a secured place (locked cabinets and password-protected electronic data) in the principal investigator’s office or laboratory. The athletes were also informed that they could withdraw from the study at any time.
One important ethical aspect that was considered for study II was the repeated classifications. Some athletes may find it intimidating and emotional to partake in classification. It was therefore a strength that only experienced international level classifiers participated in study II, whom all were aware of the delicate situation.

Most of the data collections were conducted during competitions. To ensure that the data collections would not interfere with the athletes’ preparations prior to the competition, the athletes could book themselves into a time slot which suited their racing schedule and preparation.

6.6.2 Ergometers
One of the main limitations for studies I, III and IV is that the studies have been performed on a va’a or kayak ergometer. Although there are advantages in conducting the studies on an ergometer, such as the possibility to standardise the conditions and not having to take account for weather, wind and waves, it would have been better in terms of ecological validity to conduct these studies on water. It is possible that there would be other or larger differences in some of the variables between the groups of athletes if the testing would have been conducted on water. One part of the balance aspect of paddling is minimised during ergometer paddling which could have an influence on variables like COP and seat forces in study IV. One athlete said that paddling on an ergometer is more intimidating in terms of sitting higher up from the surface, which is hard compared to the water, and not being able to balance themselves using the paddle like they can when paddling on water.

A recent study by Klitgaard et al. (2020) examined kinematic differences between paddling on ergometer and paddling on-water in non-impaired kayak athletes and showed that there was a difference between ergometer paddling and on-water paddling in shoulder flexion movement, however no differences were observed in knee kinematics. There were also differences between the conditions in trunk flexion and lateral bending however the differences were between 0.5 and 5 degrees which is also within the equipment’s measurement error whereby no conclusions can really be drawn (Klitgaard et al., 2020). The results from Klitgaard et al. (2020) provide interesting information since only athletes with trunk and/or leg impairment were included in the studies and it is valuable to know that the leg and trunk kinematics might not be as different between the two conditions. The study by Klitgaard et al. (2020) was however only conducted on non-impaired athletes and the differences between the conditions in athletes with impairment is therefore unknown.

The athletes paddled with different damper settings in study I and IV and with a set damper setting for study III. Study III was in chronological order conducted before study I and IV. We learned during study III that there was a variation in the athletes’
perception of how strenuous different damper settings were. We therefore decided for study I and IV that it was better from an ecological validity point that the athletes chose their own damper setting. Furthermore, Concept (the brand of the ergometer used in study I) states on their website that the drag factor can depend on differences in air temperature, elevation and even if there is lint caught in the flywheel housing (Concept, 2021). It may therefore be preferable if athletes choose their own damper setting as in studies I and IV.

6.6.3 Adaptive equipment in paracanoe

In both para va’a and para kayak there are no regulations regarding adaptive equipment other than that the equipment must be available to all athletes (no exclusive patents), the costs involved must be reasonable, there must be equal chances for all athletes and the equipment must be safe and environmentally sound (ICF, 2019). It is also required that the athlete uses the same equipment during classification and competition. This is checked using an equipment passport which the athletes submit prior to classification and is checked during post-race boat control at each competition. The nonregulation of adaptive equipment results in that athletes competing in the same class can have different adaptive equipment and permits the athletes to use for example straps, built in prosthesis or foam to build a perfect set-up for their impairment. As previously mentioned, it is possible that a paracanoe athlete with no or very limited trunk function can increase their forward reach if they are positioned with their trunk in a forward flexed position using adaptive equipment, a position they would not be able to be in without the adaptive equipment.

In studies I, III and IV the athletes were allowed to use their adaptive equipment since we performed sport specific testing and the athletes would not have been able to perform at their fullest if they were not allowed to use this. We therefore in these studies only have knowledge of how the impairment of the athlete affects performance in relation to the usage of adaptive equipment. This means that the findings in this thesis relate to the current rules of adaptive equipment.

In study II where the para va’a athletes participated in classification, the athletes cannot use adaptive equipment during the medical tests but can use adaptive equipment during the technical tests. It is therefore very important that the medical and technical classifiers work together to understand the athlete’s impairment on its own and its relation to adaptive equipment in order to assign the correct class.
6.6.4 Sample size

A limitation that is common within both the sports biomechanics field and within Paralympic sport is small sample sizes. Small sample sizes are also an issue in this thesis. Paracanoe is a very young Paralympic sport and only has around 400 athletes included in the masterlist (not all of which are actively competing), which is not a very big population. This results in that even though the sample sizes in the studies are numerically quite small, they make up quite a big part of the whole paracanoe population. In addition, since studies I, III and IV examined differences in biomechanical variables and performance between paracanoe groups, it was vital that athletes who were on a top level participated so that the effect of the possible cofounding variable of performance level could be reduced. This is also a reason for why most data collections were conducted during the ICF Paracanoe World Championships. This could however also have contributed to that athletes did not want to participate in the study as it could interfere with their competition preparation. To minimise this issue, the athletes could book themselves into a time slot for testing during a time period from of a few days prior to competition to a day after the competition ended.

Study II also included the least number of athletes. It was quite challenging to find participants both because of the study taking place outside of competition and athletes had to be flown in to participate, and because of the nature of the study. The study required participating in classification three times and athletes generally do not find classification particularly joyful. Since the study was conducted prior to the competition season the year that the new evidence-based classification system for para va’a was implemented, it meant that the athletes participating in the study got to know prior to the competition in which class they would compete in. This led to that some of the participating federations sent the athletes that they were most concerned about regarding class allocation. Many athletes were therefore difficult athletes to classify, i.e. athletes who are on the very top of one class and on the boarder to the next class. It was therefore a success that all classifiers classified all athletes the same. A limitation of study II was that no athlete was allocated to the VL1 class. This was a result of the new para va’a classification system having classes that include athletes with more impairment than the para kayak classification system (see Figure 7). Some of the federations sent athletes who were also kayak athletes and classified in the KL1 class, who they anticipated would also be allocated to the VL1 class. In the study however, they were in fact allocated to the VL2 class.
6.7 Future research

Since paracanoe is quite a new sport, the research available within paracanoe is sparse which results in that many exciting research questions need to be answered. One of the top priorities for paracanoe classification will be to further analyse the validity of the two classification systems and in particular the KL2 class in para kayak. These studies should preferably be conducted on water in order to increase the ecological validity of the studies and to further understand the impact of impairment on paracanoe performance. Methods in collecting data on water has improved as the technology has moved forward and sensors which can collect a lot of data without disturbing the athletes in terms of cables or increasing the mass of the canoes are now a reality. This makes studies conducted on water more feasible. When conducting these biomechanical studies on water, it would also be preferable to examine differences between groups using statistical parametric mapping. In the studies included in this thesis, this method was not used whereby it would be interesting if future studies included this method to better understand how para va’a and para kayak athletes with different impairment types differ during whole stroke cycles.

In both the para kayak and para va’a classification systems the test batteries used are to some extent subjective and scored using an ordinal scale, except for the joint ROMs which are measured. The classification manuals are detailed, and the classifiers are well trained in how to perform the tests which we have shown for the para va’a classification. It will however be of interest to in the future explore the possibilities of developing more objective methods for assessing function.

Another important research area within paracanoe is research on the relationship between other impairment types and paracanoe performance. At the moment only athletes with impaired muscle power, impaired ROM and limb deficiency affecting trunk and/or legs are eligible for competing in paracanoe. A study examining the effect of different arm impairments on paddling performance is therefore warranted. In addition, conducting studies on athletes with other physical impairment types such as ataxia, hypertonia and athetosis and on athletes with intellectual or visual impairment is also important so that more athletes can discover the great sport of paracanoe.
This thesis provided new knowledge about the impact of impairment on performance determinants in para va’a and para kayak athletes, the IRR of the para va’a classification system and the validity of the para kayak classification system. The conclusions drawn from the studies included in this thesis are:

- Para va’a athletes with trunk impairment have a performance disadvantage compared to athletes with impairments affecting only the legs. In addition, if the athletes have full trunk function, the level of leg impairment does not affect the performance in terms of paddling force. This was important evidence to provide for the development of the evidence-based classification system for para va’a.
- The IRR of the evidence-based classification system for para va’a was excellent with no discrepancies between the classifier teams in class allocation. Additionally, each classification test battery showed excellent IRR and only minor discrepancies were seen between classifier teams in individual tests. The study indicated that the new evidence-based classification system is reliable in terms of IRR. A study of the validity of the system is still warranted.
- The differences between the para kayak classes were in line with the definition of the classes in the new evidence-based classification system for para-kayak indicating that the classification system is valid. In addition, no significant correlations were seen between power output and joint variables in trunk or legs for the KL3 and KL1 classes indicating that these classes are valid. A significant positive correlation between power output and hip and knee flexion ROM was however seen in the KL2 class indicating that more research is needed on the impact of impairment on performance within this class.
- Athletes with BK amputation only had an advantage compared to the athletes with AK amputation in the ability to flex and extend the hip in terms of joint ROM, angular velocity and moment. This did however not affect the performance variables at the paddle as no differences were seen between the groups indicating that they may be able to compete in the same class.
- Future studies examining the impact of impairment on paddling performance and the validity of the systems should preferably be conducted on water to further increase the ecological validity of the studies.
Svensk sammanfattning

Valida klassificeringssystem är viktiga inom Paralympisk idrott för att minska påverkan av funktionsnedsättningen på idrottsprestationen. För att uppnå valida klassificeringssystem måste varje idrott skapa evidensbaserade klassificeringssystem genom att undersöka relationen mellan funktionsnedsättning och nyckelfaktorer för prestation. De två disciplinerna inom parakanot; para va’a och para kajak, har båda nyligen implementerat evidensbaserade klassificeringssystem. Syftet med denna avhandling var att undersöka påverkan av funktionsnedsättning på nyckelfaktorer för prestation inom para va’a och para kajak. Syftet var också att undersöka reliabiliteten av klassificeringssystemet inom para va’a och validiteten av klassificeringssystemet inom para kajak.

Tio va’a atleter utan funktionsnedsättning och 44 para va’a-atleter med funktionsnedsättning i: bål och ben (TL), båda benen (BL) och ett ben (UL) deltog i studie I. Tre-dimensionell (3D) kinematik i övre och nedre extremiteter och i bålen samt kraft i paddeln samlades in vid paddling på ergometer. Korrelationer mellan paddelkraft och ledvinklar samt skillnader mellan grupperna undersöktes. Signifikanta positiva korrelationer sågs mellan kraft i paddel och; maximal bålflexion, rörelseomfång (ROM) i bålflexion, ROM i bål- och bäckenrotation, ROM i höftflexion och ROM i knä- och fotflexion på paddelsidan. Resultaten visade också att TL-atleter hade mindre paddelkraft och bålflexion jämfört med BL- och UL-atleter. Dessutom sågs inga skillnader mellan BL- och UL-atleter i paddelkraft trots att skillnader sågs i ROM i knä- och fotflexion. Resultaten indikerade att atleter med funktionsnedsättning i ett ben eller båda benen kan tävla i samma klass om de har full bålfunktion. Resultaten gav viktig evidens för utvecklandet av det evidensbaserade klassificeringssystemet för para va’a.

Studie II undersökte interbedömarreliabiliteten (IRR) av det nya evidensbaserade klassificeringssystemet för para va’a. Tre team, med en medicinsk och en teknisk internationell klassificerare, använde de nya testbatterierna och den nya klassindelningen för att klassificera 12 para va’a atleter. Testbatterierna bestod av tester för att bedöma bål- och benfunktion samt idrottsspecifik funktion under paddling på vattnet. Respektive team klassificerade varje atlet en gång vilket medförde att atleterna klassificerades totalt tre gånger. Resultaten visade ingen diskrepans mellan klassificeringsteamen gällande klassindelningen vilket indikerar utmärkt IRR. Dessutom visade varje testbatteri en utmärkt IRR och endast små skillnader sågs mellan klassificeringsteamen i individuella
tester inom respektive testbatteri. Studien indikerar att det nya evidensbaserade klassificeringssystemet för para va’a är reliabel när det gäller IRR.


I studie IV undersökte skillnader i kinematiska och kinetiska prestationselement hos elva KL3-atleter med ensidig amputation ovanför knäleden (AK) och sex KL3-atleter med ensidig amputation under knäleden (BK). Skillnader undersöktes också mellan den amputerade (A) och icke-amputerade (NA) sidan. 3D kinematik i bål och ben och paddeln samt krafterna i fotstödet, sits och paddeln registrerades. Signifikanta skillnader mellan de två grupperna sågs endast för höftleden i; ROM i flexion, vinkelhastighet i flexion och extension och kraftmoment i flexion där BK-gruppen visade på större värden. Skillnaderna mellan sidorna sågs i kraftmoment i flexion i höftleden och i den bakåtriktade kraften i sitsen samt i framåtriktad och bakåtriktad tyngdpunktöverföring i sitsen. Skillnaderna mellan grupperna i höftledsvariablerna resulterade dock inte i någon skillnad mellan grupperna i prestationsvariablerna i paddeln. Resultaten indikerade därför att dessa två grupper möjligtvis kan tävla i samma klass.

Denna avhandling har beskrivit hur atleter med olika nivåer av funktionsnedsättning skiljer sig åt i olika nyckelfaktorer för prestation inom para va’a och para kajak. Resultaten i avhandlingen indikerar att det nya evidensbaserade klassificeringssystemet för para va’a är reliabelt när det gäller IRR och att det nya evidensbaserade klassificeringssystemet för para kajak är valid när det gäller KL1- och KL3-klasserna. Studier som i framtiden undersöker påverkan av funktionsnedsättning på paddlingsprestation och validiteten av systemen bör företrädesvis utföras på vatten för att ytterligare förbättra den ekologiska validiteten.
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10 References


11 Appendices
Proposed revised Paralympic Classification System for Para-Va’a

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Introduction

In recent years, the International Paralympic Committee (IPC) has highlighted the importance of sports specific evidence-based classification systems for all athletes with physical impairments to control the impact of impairment on the outcome of competition (Tweedy & Vanlandewijck, 2011). The International Canoe Federation (ICF) has therefore initiated research projects aimed to evaluate, develop and present a proposal to the IPC relating to a validated and evidence-based classification system for para-kayak and para-va’a for athletes with impaired muscle power, impaired range of motion and limb deficiencies affecting the trunk and legs. Paracanoe is a relatively new sport where athletes with physical impairments compete over 200 m in either para-kayak or para-va’a. Para-kayak is competed in a kayak which is propelled by a double-blade paddle. Para-va’a is competed in an outrigger canoe (a boat that has a pontoon called ama as a support float) and is propelled by a single blade paddle. The first international paracanoe events were held 2009 during the World Championships in Canada. Since then paracanoe and canoe sprint (able-bodied racing) have held their events together.

Para-va’a

A research team from The Swedish School of Sport and Health Sciences conducted research studies examining the three-dimensional (3D) kinematics and kinetics of able-bodied athletes (n=10) and para-kayak athletes (n=41) when paddling on a kayak ergometer. The research on para-kayak was finished in 2014 and a new classification system was created based on the results of these studies in close collaboration with the ICF and international paracanoe classifiers. The system was accepted by the IPC in 2015 and para-kayak debuted in the 2016 Paralympic Games in Rio. Additionally the research team also conducted research on able-bodied va’a athletes and para-va’a athletes using the same methods as the para-kayak study. The study involved ten able-bodied va’a athletes and 29 para-va’a athletes. The results were incorporated into a new classification system for para-va’a and the system was presented in a proposal that was submitted to the IPC in the end of 2014. On the contrary to the para-kayak
classification system, the para-va’a system was not accepted by the IPC due to too few high level athletes included in the study, and para-va’a was not included in the 2016 Paralympic Games. The recommendation from IPC was to include more international level para-va’a athletes in order to have more robust results to base the system on and submit a new proposal for the 2020 Paralympic Games in Tokyo.

2015 para-va’a classification system

Even though the system did not meet the IPC standard the ICF Paracanoe Committee decided that the new system was a large improvement from the old classification system as the old system was adopted and adapted from rowing and had no scientific justification. The research showed that the trunk and leg function were important for force production during va’a paddling and therefore it was decided that the classification system should include tests of these functions. The system included a physical assessment consisting of trunk and leg function tests which included 42 trunk tasks and 14 leg tasks and a technical assessment consisting of an on-water based test examining trunk and leg function during paddling and included 5 tasks. The physical assessment tests were conducted in sport specific ranges of motion (ROM) that were based on the kinematic data from the able-bodied va’a athletes during va’a ergometer paddling. The technical assessment test was based on factors that were shown in the research to contribute to force production during paddling (left and right leg movement, trunk flexion, trunk rotation and balance). All tests were scored on a 0-2 scale. The total number of points for the tests were 84, 28 and 10 for the trunk, leg and on-water tests respectively. Cluster analyses were conducted for each test which resulted in three clusters per test. The boundaries between each cluster were thereafter defined. The cluster allocation from each test for each athlete was then investigated and the most common combination of cluster allocations showed that the three most common cluster combinations for the trunk, leg and on-water test were 1-1-1, 2-2-2 or 3-3-3. This indicated that the new system should consist of three classes. It was decided that to sum the cluster values from each test into a total sum score ranging from 3 to 9 (e.g. ending up in cluster 1 for each test would result in 1+1+1=3 total sum score). The three most common total sum scores were 3, 6 and 9. We decided that the most impaired group should only consist of athletes with a total score of 3 and that the least impaired group should consist of athletes with a total score of 8 and 9. All other total scores (4-7) were the “intermediate” impaired group of athletes. This resulted in three classes which were named; VL1, VL2 and VL3. The athletes in VL1 had very limited trunk function defined as not having the ability to dynamically move the trunk forward and backward during sitting. These athletes had no leg function. The athletes
in VL2 could have full trunk function and limited leg function (e.g. athletes with bilateral above knee amputation) or limited trunk and leg function (e.g. athletes with incomplete spinal cord injury (SCI)). The athletes in VL3 had full trunk function and met the minimal eligibility criteria of losing at least four points in one lower limb (e.g. athlete with unilateral below knee amputation). This system has been in place since the first international event in 2015 and is currently being used by ICF international classifiers during international events.

Reasons for revising the 2015 classification para-va’a system
To meet the recommendation from IPC to include more high level athletes in the research to have a more robust base to base the classification system on, additional data has been collected during the 2015 and 2016 World championships and data from 25 para-va’a athletes were collected. Data from ten athletes were excluded from the initial 29 para-va’a athletes due to that they did not meet our new definition of being a high level para-va’a athlete. The total number of athletes included in the study was 44 and consisted of international level athletes from 15 countries. As a consequence of collecting more data and including a higher level of athletes, the results of the research indicated that the 2015 classification system should be revised. The following report explains the research process, the results of the research and how we would like to implement the results into a revised evidence-based classification system for para-va’a.

Para-va’a research

Participants
Ten able-bodied va’a athletes competing at international level (5 males and 5 females; 44 ± 3 years, 75 ± 8 kg, 1.78 ± 0.1 m) and 44 para-va’a athletes (31 males, 36 ± 9 years, 76.8 ± 16.8 kg, 1.76 ± 0.18 m; 13 females, 33 ± 7 years, 58.0 ± 9.7 kg, 1.62 ± 0.13 m) from 15 countries across 5 continents during 2014-2016 volunteered for the study. The male para-athletes trained in average 5.4±1.4 days per week and 15.0±7.8 hours per week and the female athletes trained in average 5.8±1.1 days per week and 14.1±5.5 hours per week.

The va’a paddling was performed on a D1-M Kayakpro va’a ergometer (Kayakpro, Miami, FL, USA). 3D kinematic data were recorded using a 12-camera optoelectronic system (Oqus4, Qualisys AB, Sweden) at a sampling frequency of 150 Hz. Fifty-four reflective markers (12 mm diameter) were attached to anatomical landmarks in order to construct a whole-body model consisting of 14 segments (Figure 1) and one marker was placed on the va’a paddle shaft. The
number of markers was adjusted for the para-athletes with limb deficiencies that were not using prosthesis/prostheses.

A piezoelectric force transducer (Type 311B, Kistler Instruments AG, Switzerland) was connected with the rope from the ergometer flywheel close to the end of the ergometer paddle to continuously measure force during the stroke cycles at a sampling frequency of 1500 Hz.

**Data collection procedure**

The data collection was conducted during five different occasions at five different locations between 2014 and 2016. Three of the occasions were during the World Championships in Paracanoe. Prior to the data collection the athletes were introduced to the test procedure and if

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**Figure 1.** The para-va’a data collection set-up and the whole body model seen from front and back.

The markers were attached at the following positions for the

a) **hand and arm segments:** 8 markers were attached bilaterally on the wrist and hand and 2 markers were placed on the lateral and medial part of the elbow. A cluster of 3 markers were placed on the upper arms and on the forearms.

b) **trunk segment:** 6 markers were placed in a diamond shape, 3 over the spine at C7, T5 and T12 level and one on the left and right acromion, and one marker attached on the center of the sternum.

c) **pelvis segment:** 4 markers were attached on the left and right anterior superior iliac spinae (ASIS) and on the left and right posterior superior iliac spinae (PSIS). One additional marker was placed on the sacrum level of the spine if the any of the other markers were not visible,

d) **leg and foot segments:** A cluster of 4 markers were attached bilaterally on the thigh (femur), 2 markers were placed bilaterally on the lateral and medial part of the knee joint, a cluster of 4 markers were placed bilaterally on the lower leg and 2 markers were placed on the lateral and medial part of the ankle and foot. On the foot an additional 3 or 4 markers were placed as tracking markers. In addition; 3 markers were attached on the paddle and a reflective tape was attached on the middle of the force transducer.
the para-athletes used adaptive seats or straps, these were mounted on the va’a ergometer in order to replicate the athletes’ boat set-up used in competition. The athletes then performed a seven minute warm-up on the ergometer at a self-selected low intensity. Thereafter the athletes were asked to choose their preferred paddling side and paddle on that side at a high intensity level. The athletes were asked to maintain this intensity level as stable as possible during at least 20 stroke cycles (from catch to catch) through visual feedback of the power output on the ergometer display. After the athletes had paddled at this level, the athletes were asked if they could paddle on a higher intensity. If so, the athletes rested for five minutes and then paddled at the higher level. The highest level the athletes could hold with good technique for 20 stroke cycles was used for analysis. None of the athletes paddled more than two levels before this highest intensity level was found. Kinematic and kinetic data were simultaneously collected and synchronized using Qualisys Track Manager (Qualisys AB, Sweden).

Data processing
Kinematic and kinetic data analysis was performed in Visual3D (version 5, C-Motion, Inc., USA) and MATLAB (The MathWorks, Inc., USA). The joint angles are defined in Table 1. Total ROM and maximal and minimal angle (A\text{Max} and A\text{Min}) for flexion and extension were calculated for the trunk, hip, knee and ankle joints. Additionally, the ROM and A\text{Max} and A\text{Min} were calculated for trunk rotation and lateral bending. Data from the shoulder, elbow and wrist will not be presented in this study. Since the va’a paddling movement is asymmetric, the angle data were divided into ‘top hand side’ and ‘bottom hand side’ for the upper and lower limbs (Figure 2). Kinematic data were also used to calculate stroke cycle and stroke frequency using the marker on the paddle. One stroke cycle was defined from catch to catch. The catch was defined as the maximum point of the bottom hand (metacarpal 5) in the positive x-direction in the global coordinate system (GCS) (Michael et al., 2012). A mean value of the paddling force during each pull phase (defined from catch to the end of pull phase i.e. the maximum point of the paddle in the negative x-direction) was calculated. The mean paddling force of ten pull phases was then calculated from the high intensity level and was used for the data analysis.
Table 1. Joint angle definitions (X, Y and Z to correspond to forward flexion, abduction and axial rotation).

<table>
<thead>
<tr>
<th>Moving segment</th>
<th>Reference segment</th>
<th>Designated joint movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trunk</td>
<td>Global Coordinate System (GCS)</td>
<td>Trunk: flexion/extension</td>
</tr>
<tr>
<td>Trunk</td>
<td>Global Coordinate System (GCS)</td>
<td>Trunk and pelvis: rotation*</td>
</tr>
<tr>
<td>Trunk</td>
<td>Pelvis</td>
<td>Trunk: bending, rotation</td>
</tr>
<tr>
<td>Thigh</td>
<td>Pelvis</td>
<td>Hip: flexion/extension</td>
</tr>
<tr>
<td>Shank</td>
<td>Thigh</td>
<td>Knee: flexion/extension</td>
</tr>
<tr>
<td>Foot</td>
<td>Shank</td>
<td>Foot: dorsal flexion/ plantar flexion</td>
</tr>
</tbody>
</table>

*When the trunk rotation angle is defined in reference to the GCS the calculated angle includes the movement of the pelvis.

Figure 2. Description of top and bottom hand side for: (a) left bottom hand and (b) right bottom hand paddlers. Preferred paddling side is associated with the bottom hand on the paddle and the limbs on that side.
Data and statistical analysis

The statistics was carried out in IBM SPSS statistics 24 (IBM, USA). All parameters are presented as means and standard deviations (SD). The Shapiro Wilks’ W test was performed to test the data for normality. Correlation calculations were conducted to examine the relationship of ROM, $A_{\text{Max}}$ and $A_{\text{Min}}$ of the trunk, hip, knee and ankle with mean paddling force. Pearson’s correlation coefficient was calculated for the female able-bodied athletes and para-va’a athletes for whom the majority of the trunk and leg angles were normally distributed. For the male able-bodied and para-va’a athletes, the majority of the trunk angles were normally distributed whilst this was not the case for the leg angles. Pearson’s correlation coefficient was therefore calculated between power and the trunk angles and Spearman’s correlation coefficient was calculated for the leg angles.

Results

The mean and SD for $A_{\text{Max}}$, $A_{\text{Min}}$ and the ROM at the high intensity level for the trunk of the able-bodied va’a athletes are presented in Table 2. The mean and SD $A_{\text{Max}}$, $A_{\text{Min}}$ and the ROM of each joint angle for lower limbs are presented in Table 3.

Table 2. Peak joint angles and ranges of movement (ROM) of able-bodied athletes presented as means and standard deviations (SD) for the trunk.

<table>
<thead>
<tr>
<th>Trunk</th>
<th>Mean (°)</th>
<th>SD (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion (maximum)</td>
<td>31</td>
<td>14</td>
</tr>
<tr>
<td>Flexion (minimum)</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>ROM</td>
<td>16</td>
<td>9</td>
</tr>
<tr>
<td>and pelvis rotation (catch)</td>
<td>27</td>
<td>9</td>
</tr>
<tr>
<td>and pelvis rotation (release)</td>
<td>20</td>
<td>9</td>
</tr>
<tr>
<td>and pelvis rotation ROM</td>
<td>47</td>
<td>11</td>
</tr>
<tr>
<td>Rotation (catch)</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td>Rotation (release)</td>
<td>15</td>
<td>6</td>
</tr>
<tr>
<td>ROM</td>
<td>33</td>
<td>13</td>
</tr>
</tbody>
</table>
Table 3. Peak joint angles and ranges of movement (ROM) of able-bodied athletes presented as means and standard deviations (SD) for limbs corresponding to the top hand and bottom hand on the paddle.

<table>
<thead>
<tr>
<th></th>
<th>Top hand</th>
<th>Bottom hand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (°)</td>
<td>SD (°)</td>
</tr>
<tr>
<td><strong>Hip</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion (maximum)</td>
<td>80</td>
<td>17</td>
</tr>
<tr>
<td>Flexion (minimum)</td>
<td>63</td>
<td>17</td>
</tr>
<tr>
<td>ROM</td>
<td>17</td>
<td>8</td>
</tr>
<tr>
<td><strong>Knee</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion (maximum)</td>
<td>55</td>
<td>6</td>
</tr>
<tr>
<td>Flexion (minimum)</td>
<td>43</td>
<td>8</td>
</tr>
<tr>
<td>ROM</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td><strong>Ankle</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion (dorsi)</td>
<td>-19</td>
<td>9</td>
</tr>
<tr>
<td>Flexion (plantar)</td>
<td>27</td>
<td>9</td>
</tr>
<tr>
<td>ROM</td>
<td>8</td>
<td>3</td>
</tr>
</tbody>
</table>

Correlations of angles and power output

The trunk, hip, knee and ankle joint angles that significantly correlated with mean paddling force are presented in Table 4. Significant positive correlations were found for both genders between mean paddling force and trunk flexion $A_{\text{Max}}$, $A_{\text{Min}}$ and ROM, trunk and pelvis rotation catch and ROM, trunk rotation catch and ROM, hip flexion top and bottom hand ROM and knee and ankle flexion bottom hand ROM.

Table 4. Correlations between mean paddling force and joint angles for both male and female able-bodied athletes and para-athletes.

<table>
<thead>
<tr>
<th></th>
<th>Males</th>
<th></th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r-value</td>
<td>p-value</td>
<td>r-value</td>
</tr>
<tr>
<td><strong>Trunk</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trunk flexion $A_{\text{Max}}$</td>
<td>0.677*</td>
<td>&lt;0.001</td>
<td>0.798</td>
</tr>
<tr>
<td>Trunk flexion $A_{\text{Min}}$</td>
<td>0.606*</td>
<td>&lt;0.001</td>
<td>0.811</td>
</tr>
<tr>
<td>Trunk flexion ROM</td>
<td>0.449*</td>
<td>0.007</td>
<td>0.638</td>
</tr>
<tr>
<td>Trunk and pelvis rotation Catch</td>
<td>0.417*</td>
<td>0.013</td>
<td>0.508</td>
</tr>
<tr>
<td>Trunk and pelvis rotation ROM</td>
<td>0.687*</td>
<td>&lt;0.001</td>
<td>0.562</td>
</tr>
<tr>
<td>Trunk rotation Catch</td>
<td>0.395*</td>
<td>0.019</td>
<td>0.569</td>
</tr>
<tr>
<td>Trunk rotation ROM</td>
<td>0.546*</td>
<td>0.001</td>
<td>0.637</td>
</tr>
<tr>
<td><strong>Lower limbs top hand side</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip flexion ROM</td>
<td>0.568</td>
<td>&lt;0.001</td>
<td>0.585</td>
</tr>
<tr>
<td><strong>Lower limbs bottom hand side</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip flexion ROM</td>
<td>0.624</td>
<td>&lt;0.001</td>
<td>0.652</td>
</tr>
<tr>
<td>Knee flexion ROM</td>
<td>0.542</td>
<td>0.001</td>
<td>0.504</td>
</tr>
<tr>
<td>Ankle flexion ROM</td>
<td>0.370</td>
<td>0.026</td>
<td>0.735</td>
</tr>
</tbody>
</table>

*Pearson correlation
Implementation of research results into a revised classification system

Results showed that the ability to move the trunk in flexion and extension and to rotate the trunk and pelvis was positively correlated with force production for both female and male able-bodied and para-va’a athletes. Furthermore the ability to move the knee and ankle on the bottom hand side\(^1\) in flexion and extension ROM was also positively correlated with force production for both female and male athletes. The upper limbs are also important for va’a performance, however since only two athletes with upper limb impairments participated in the study, there were no significant correlations between upper limb movement and force production.

After examining the kinematic and kinetic results from the va’a study it was decided together with members from the ICF paracanoe classification sub-committee that the three classification tests (trunk, leg and on-water tests) currently used in para-va’a classification ought to be modified. Consequently, the tests included in the proposed revised classification system assess the joint movements that were significantly correlated with force production in sport specific ROM (a detailed description of the modified classification tests are presented on page 12). This is in line with the recommendations from Beckman, Connick and Tweedy (2016) who stated that it is essential to identify the key muscle groups or joints for performance and that these should then be assessed in a strength test battery to ensure that the tests are relevant to the activity of interest.

In order to evaluate the validity of these revised classification tests positive correlated joint angles and ROMs were compiled into three compartments. The trunk flexion A\(_{\text{Max}}\), A\(_{\text{Min}}\) and trunk and pelvis rotation ROM were summed up into a trunk compartment. The bottom hand side hip, knee and ankle flexion ROM which were correlated with paddling force were summed up into a leg compartment. Furthermore, the trunk and the leg compartment were summed up into a sport specific compartment. These compartments were then correlated with paddling force and the results showed that all compartments were significantly and positive correlated with paddling force (Trunk compartment vs. paddling force: Females: \(r=0.852\) p<0.001, Males: \(r=0.729\) p<0.001; Leg compartment vs. paddling force: Females: \(r=0.657\) p=0.004, Males: \(r=0.591\) p<0.001; Sport-specific compartment vs. paddling force: Females: \(r=0.788\) p<0.001, Males: \(r=0.764\) p<0.001).

Thereafter the compartments were correlated with their respective classification test (trunk compartment with the trunk test, leg compartment with the leg test and the sport specific compartment with the on-water test) for the para-athletes. The results showed that the

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\(^1\) Bottom hand side refers to the body side of the hand that holds the bottom of the paddle shaft.
classification tests were significantly positive correlated with their compartment (Trunk compartment vs. trunk test: $r=0.729\ p<0.001$; Leg compartment vs. leg test: $r=0.609\ p<0.001$; Sport-specific compartment vs. on-water test: $r=0.811\ p<0.001$). This demonstrated that the tests well reflected the athletes’ functional performance during paddling indicating that the classification tests are sports specific and have a high validity.

**Revised classification tests**

The sport-specific mean ROM values from the able-bodied group in the study were used to define in what range the leg and trunk function tasks should be measured. The trunk test in the proposed classification system for para-va’a will be conducted in the same manner as before and include 42 trunk tasks (Appendix 1). However, based on the research results, only the dynamic trunk tasks (i.e. moving the trunk in flexion, extension, rotation and side flexion) will be included in the class allocation. The whole test battery with all the 42 trunk tasks will be conducted so that the classifiers can get an overall picture of the athletes’ trunk function and minimise the risk of misrepresentation. The leg test for para-va’a will include the same leg tasks as before but the position of the athletes during the test procedure has been modified (Appendix 2). The single leg press test will be conducted on both legs in a sport specific position. The items that will be scored on the on-water test are based on the variables that were shown from the research study to be correlated with producing a greater paddling force. The items are: leg movement, trunk rotation and trunk flexion. Since there is only a positive correlation between leg movement and paddling force for one of the legs (i.e. bottom hand side), it was decided to only score the movement of one of the legs during the on-water test. In our study it was the bottom hand side leg that moved the most, however due to a variety of paddling styles and techniques used in va’a, the leg that moves the most will be scored during the on-water classification.

**Revised minimal eligibility**

The previous minimal eligibility criterion for para-va’a was loss of at least 4 points in one leg in the leg test. This could for an example be athletes with a unilateral below knee amputation or unilateral ankle fusion. The results from the research showed that the previous minimal eligibility criterion needed modification. This is due to two main findings; limited ankle flexion ROM during paddling (Table 5) in combination with a low correlation between ankle flexion ROM and force production observed in male athletes (Table 4) and no correlation between force
production and leg function in athletes with impaired leg function and full trunk function (Figure 2).

The actual movement in the ankle joint during va’a paddling is very small (Table 5). In va’a the able-bodied athletes had a mean value of 11° for the top hand side ankle flexion ROM and 16° for the bottom hand side ankle flexion ROM. Compared to able-bodied athletes’ movement during kayak paddling which was approximately 30° flexion in each ankle, it shows that able-bodied va’a athletes do not use ankle movement for producing force to the same extent. Due to that the ankle movement is very limited even in able-bodied athletes, it would be very difficult to measure dynamic function during classification and to define level of impairment using the 0-2 scoring system.

**Table 5.** Ankle flexion ROM (in degrees, °) in able-bodied va’a athletes and para-va’a athletes during paddling on a va’a ergometer. Values are presented as mean ± 1 standard deviation.

<table>
<thead>
<tr>
<th></th>
<th>Able-bodied (°)</th>
<th>Para-athletes (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top hand side Ankle flexion ROM</td>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td>Bottom hand side Ankle flexion ROM</td>
<td>16</td>
<td>10</td>
</tr>
</tbody>
</table>

When examining the relationship between the paddling force and leg movement (knee and ankle flexion ROM in both legs) when paddling on a va’a ergometer in male athletes with full trunk function and impaired leg function (either bilateral or unilateral above, below or through knee amputation or having a general leg impairment resulting from e.g. an incomplete spinal cord injury) the result showed that there was no significant correlation between leg movement and paddling force (Spearman’s rho=0.379, p=0.133). The results therefore demonstrate that paddling force is not significantly influenced by the leg movement and therefore not affected by the leg impairment if athletes have full trunk function (Figure 3).
Figure 3. Force and the sum of knee and ankle flexion ROMs from both legs in male athletes with leg impairment and full trunk function during paddling on a va’a ergometer.

The revised minimal eligibility criteria for the legs is a loss of 10 points or more in one leg or a loss of 11 points or more over two legs in the leg test. This corresponds, for example, to an athlete with above knee amputation with no function in the ankle or the knee (will score 18 points including leg press test) or an athlete with partial leg function in both legs. In addition to the minimal eligibility criteria for the legs, a minimal eligibility criterion for the trunk has also been established to include para-athletes with an impairment that affects the trunk more than the legs. The athletes need to have a loss of 7.5 points or more on the dynamic trunk test and in addition they need to have a loss of 8 points or more on the leg test to be eligible.

Non-eligible impairments
Athletes with the impairment types: limb deficiency, impaired range of movement and impaired muscle strength meeting the minimal eligibility criteria, will be eligible to compete in the Paralympic Games in para-va’a. Since no athletes with upper limb impairment participated in this study, conclusions about how to classify athletes with this type of injury could not be drawn. Therefore, no athletes with only upper limb impairments will be eligible in the Paralympic Games in the proposed revised classification system for para-va’a. Athletes who meet the new proposed minimal eligibility criteria and also have an upper limb impairment will only be classified on their trunk and/or lower limb impairment, thus the upper limb impairment will not be considered.
Revised class allocation

The current total scores for eligible athletes of the classification tests vary with 6 points for the on-water test, 12 points for the dynamic trunk test and 18 points for the leg test. In the overall calculation of Sport Class, it was preferred to have the three tests weighted equally. This was done by multiplying 3 to the on-water test scores and 1.5 to the trunk test scores (Figure 4). Therefore by a simple mathematical calculation each test score is factored to equal 18. The total sum for the three tests was then calculated (maximum total sum score=54 points) (Figure 4). The total sum was calculated for all athletes classified in para-va’a in order to examine how many points athletes with different impairments have.

<table>
<thead>
<tr>
<th>TEST</th>
<th>Raw Score</th>
<th>Transformation Factor</th>
<th>Transformed Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leg</td>
<td>0-18</td>
<td>1</td>
<td>0-18</td>
</tr>
<tr>
<td>Trunk</td>
<td>0-12</td>
<td>1.5</td>
<td>0-18</td>
</tr>
<tr>
<td>On-water</td>
<td>0-6</td>
<td>3</td>
<td>0-18</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>Final Overall Score</strong> 0-54</td>
</tr>
</tbody>
</table>

**Figure 4.** Scoring template for transformation of raw scores.

Numerous results from the research indicate that trunk movement is an important factor for va’a performance. The research showed that the trunk movements during paddling are highly correlated with force production (trunk compartment vs. force production: r=0.78). The importance of the trunk is also demonstrated in the results of a partial correlation analysis which examined if the leg function affects the correlation between trunk movement and force production. The already strong correlation between trunk movement and force production was minimally affected by the leg function (for males r=0.649, p<0.001, for females r=0.709, p=0.002) demonstrating that the leg function is inferior to the trunk function. This is also shown in Figure 3 where it is demonstrated that athletes with a greater leg impairment can produce more force compared to athletes with less leg impairment when the athletes have full trunk function. In the revised classification system athletes will therefore mainly be allocated a class based on their trunk function assessed during the dynamic tasks of the trunk test; no dynamic trunk function, partial dynamic trunk function and good dynamic trunk function (Figure 5).

The athletes allocated in the lowest functioning class, VL1 (Figure 5), should therefore have no dynamic trunk function which is defined as not being able to sit upright on a bench with the legs hanging whilst the thighs and/or pelvis are secured and not moving the
trunk in flexion, extension, rotation and lateral flexion. This corresponds to having 0 points on the dynamic tasks in the trunk test. These athletes should also not have any leg function (0 points on leg test). Since they have no dynamic function in trunk or legs they should therefore also have an on-water score of 0. These athletes should therefore have a total point of 0. Furthermore, during competition and the on-water part of the classification the VL1 athletes should have a non-elastic quick release strap\(^2\) around the trunk to secure the athlete in position.

The athletes with the highest function will be allocated the VL3 class (Figure 5) and will include the athletes with full dynamic trunk function or almost full dynamic trunk function (15-18 points) and can score 18 points or below on the leg test and on-water test. The exception to this rule will for an example be athletes who score 13.5 points or lower on the trunk test but have a high leg score. In order to define exactly the characteristics of these athletes and if they should be allocated the VL2 or VL3 class, a cluster analysis was conducted on three variables, i.e. the scores from the three classification tests; trunk, leg and on-water tests. The cluster analysis showed that athletes scoring a total of 27 points or lower grouped into one cluster and athletes scoring a total of 28 points or over grouped into another cluster. It was therefore decided that athletes who score 13.5 points or lower in the trunk test but have a total score of 28 points or over are also allocated the VL3 class. Furthermore, athletes scoring between 1.5 and 13.5 points on the trunk test and have a total score of 27 points or lower are allocated the VL2 class (Figure 5).

\(^2\) A detailed description of the strap restriction and placement will be provided in the near future.
**Figure 5.** Class allocation description of the revised Paralympic evidence-based classification system for para-va’a.
References


Appendix 2
Proposed Paralympic Classification System for para-kayak

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In collaboration with the classifier team
John Edwards, Member Board of Directors, Chair Paracanoe
Julie Gray, Head of classification
Diego Doga, technical classifier
Fatima Fernandes, medical classifier
Background

In November of 2010 the International Paralympic Committee (IPC) included Paracanoe as a new sport for the Paralympics 2016. In recent years, IPC has highlighted the importance of an evidence based classification system for all athletes with physical impairments to control the impact of impairment on the outcome of competition (Tweedy & Vanlandewijck, 2011). The International Canoe Federation (ICF) has therefore initiated a research project aimed to evaluate, develop and present a proposal to the IPC relating to a validated and evidence based classification system for paracanoers. The overall purpose of a new evidence based selective classification system for Paracanoe is to achieve the purpose of promoting participation in sport by people with disabilities by minimizing the impact of eligible types of impairment on the outcome of competition. The purpose of the research is to identify how much impairment of varying type, location and severity impact on the kayak paddling performance by;

Defining eligibility: to be eligible to compete in para-canoe athletes must have an impairment that:

- Is one of the three eligible types of impairment (impaired muscle power, impaired range of motion, limb deficiency),
- Is permanent in nature (i.e. will not resolve in the foreseeable future regardless of physical training, rehabilitation, or other therapeutic interventions),
- Causes a sufficient level of activity limitation: the athlete must have an impairment defined by the minimum disability criteria.

Minimizing the impact of impairment on the outcome of competition:

- The athletes should succeed because they have the most favorable combination of anthropometric, physiological and psychological attributes. Athletes who succeed will do so because they are stronger in these areas, rather than because they have an impairment that causes less activity limitation.

To achieve these purposes, three research studies have been conducted by our research group to define the sport specific range of movement (RoM) and power output during kayak paddling in elite level able-bodied kayakers and para-kayakers to enable comparisons between the two groups, and assess how the para athletes’ loss of RoM and loss of strength affect their ability to paddle, and to develop, validate and use a trunk test to determine the function of trunk musculature in para-athletes. The results of these studies will help in determining how many classes, how they will be defined, the minimal eligibility criteria and the assessment tests that will be used in para-kayak.
Study 1 and 2 Sport specific range of movement on the kayak ergometer

Introduction
The paddling movement is complex with three dimensional (3D) upper-body movements during water and aerial phase time. The requirements for movement control are high due to its complexity and the interplay between reaction forces in different directions. A 3D kinematic analysis during the kayak paddling was therefore chosen as a method to analyse the sport specific RoM. It is necessary to define the sport specific RoM for kayak to ensure that physical assessment actually assess the relevant RoM required for the sport.

The purpose of the first study was to define the sport specific RoM in the upper limbs (bilaterally: shoulder, elbow, wrist), lower limbs (bilaterally: hip, knee and ankle) and trunk in elite level able-bodied kayakers during kayak ergometer paddling. The purpose of the second study was to establish the sport specific RoM (c.f. above) in elite level para-kayakers with varying types of impairments (impaired muscle power, impaired range of motion, limb deficiency) to enable comparisons between the reference group of able-bodied athletes and the group of para-athletes.

Method
Participants

Elite able-bodied kayakers
Ten elite international level able-bodied athletes (four women and six men) volunteered for the study (22 ± 3.5 years, 78.3 ± 10.2 kg, 1.79 ± 0.06 m). The athletes trained on average 6.9 ± 1.7 sessions per week with a total exercising time of 15.4 ± 3.9 hours per week.

Elite para-kayakers
50 international or national level para-kayak athletes (17 women and 33 men) from 12 different countries from 4 continents also volunteered for the study (34 ± 9.4 years, 70.4 ± 12.8 kg, 1.73 ± 0.1 m). The para-athletes trained on average 5.3 ± 1.4 sessions per week with a total exercising time of 14.8 ± 6.9 hours per week. A detailed description of the para-kayak athletes are presented in Appendix 1 (injury, physical and technical assessment, kayak experience, sport class).
Equipment
The kayak paddling was performed on a kayak ergometer (Dansprint, I Bergmann A/S, Denmark). The resistance on the ergometer could be adjusted by regulating the air intake on the flywheel from 1 (lightest) to 10 (heaviest). For this study the resistance was set at 8 for able-bodied females and 10 for able-bodied males. The resistance was set at 4 for the para-athletes. 3D kinematic data were recorded using a 12-camera optoelectronic system (Oqus4, Qualisys AB, Sweden) at a sampling frequency of 150 Hz. Fifty-four reflective markers (12 mm diameter) were attached on anatomical landmarks in order to construct a whole-body model consisting of 14 segments (Figure 1) and three markers were placed on the kayak paddle shaft. The marker placement was adjusted for the para-athletes with limb deficiency.

Figure 1. Whole body model consisting of 14 segments.
The markers were attached at the following positions for the
a) *hand and arm segments*: 8 markers were attached bilaterally on the wrist and hand and 2 markers were placed on the lateral and medial part of the elbow. A cluster of 4 markers were placed on the upper arms and a cluster of 3 were placed on the forearms. For the able-bodied participants and 27 of the para-athletes the cluster on the forearms and upper arms consisted of one marker
b) *trunk segment*: 6 markers were placed in a diamond shape, 3 over the spine at C7, T5 and T12 level and one on the left and right acromion, and one marker attached on the center of the sternum,
c) *pelvis segment*: 4 markers were attached on the left and right anterior superior iliac spinae (ASIS) and on the left and right posterior superior iliac spinae (PSIS). One additional marker was placed on the sacrum level of the spine if any of the other markers were not visible,
d) *leg and foot segments*: A cluster of 4 markers were attached bilaterally on the thigh (femur), 2 markers were placed bilaterally on the lateral and medial part of the knee joint, a cluster of 4 markers were placed bilaterally on the lower leg and 2 markers were placed on the lateral and medial part of the ankle and foot. On the foot an additional 3 or 4 markers were placed as tracking markers. In addition; 3 markers were attached on the paddle and 2 markers were attached on both edges of each force transducer.

Piezoelectric force transducers (Type 311B, Kistler Instruments AG, Switzerland) were connected with the rope from the ergometer flywheel close to each end of the ergometer
paddle to continuously measure force during the stroke cycles at a sampling frequency of 1500 Hz. Two additional markers were placed on each end of the force transducers. The transducers were connected to an amplifier (Type 5073, Kistler Instruments AG, Switzerland) and signals were A/D converted (Kistler Instruments AG, Switzerland).

**Data collection procedure**

Before the test, the athletes were introduced to the test procedure and performed a five minute warm-up on the kayak ergometer at a self-chosen low intensity. Thereafter the athletes were asked to paddle at incremental intensities with a three-minute break between each test. The athletes started at 25 W if they were a para-athlete and at 50 W if they were an able-bodied athlete. This level is defined as low intensity (L_{int}). The para-athletes were then asked to paddle at 50 W. The athletes were asked to maintain each intensity level as stable as possible during at least 20 stroke cycles (one stroke cycle is defined from left catch to left catch). After the athletes had paddled at 50 W the intensity was increased with 50 W increments up to the sub-maximal intensity (S-M_{int}), i.e. the highest predetermined level that the athlete could stably maintain with a good technique for 20 stroke cycles. The athletes were then asked to paddle at maximal intensity (M_{int}). During the M_{int} level the athletes were first instructed to slowly increase the intensity during 15 kayak stroke cycles up to M_{int}. When reaching M_{int} after 15 cycles, they were instructed to execute 20 all out maximal stroke cycles. The athletes were verbally encouraged to maintain maximal intensity throughout the test. Synchronized kinematic and kinetic data were collected for each test. Between each test the force transducers were calibrated.

**Data analysis**

**Kinematic data analysis**

Kinematic and kinetic analysis were performed in Visual3D (version 4, C-Motion, Inc., USA) and MATLAB (The MathWorks, Inc., USA). Kinematic data were smoothed with a second-order, bi-directional, low-pass Butterworth filter with a cutoff frequency of 7 Hz.

The coordinate systems were defined as right handed coordinate systems with X axis directed laterally to the right, Y axis directed forward (anteriorly) and the Z axis directed upward (superiorly). This allows the Eulerian sequence about the axes X, Y and Z to correspond to forward flexion, abduction and axial rotation (Rab, Petuskey & Bagley 2002).
Joint definition

When defining the shoulder joint, Rab et al., (2002) suggest that researchers use the method that conveys meaningful data in an understandable form. The shoulder joint was defined according to the definition for shoulder joint in the RAB upper extremity model (Rab et al., 2002) for 39 para-athletes and 9 able-bodied athletes. For 11 para-athletes and 1 able-bodied athlete the shoulder was instead defined as a functional shoulder joint. For the participants where the functional shoulder model was used, the RAB model demonstrated non-meaningful data. With the shoulder abducted 90°, the Z (axial rotation) axis of the humeral segment coincides with the X (flexion-extension) axis of the shoulder in its initial position. In this position, the decomposition of the initial angle of the rotation sequence (in this case, flexion) becomes indeterminate (gimbal lock). Rab et al., (2002) found that when analyzing the angles of the linked model in the 89–91° range of abduction it yielded unreliable estimates for initial flexion angle. This was also seen for the participants in this study who reached >89° abduction. If this was apparent when using the shoulder joint definition from the RAB upper extremity model, the functional shoulder joint was used instead. The functional joint calculation used in Visual 3D has been adapted from Schwartz & Rozumalski (2005). The calculation of the functional shoulder joint requires movement of one segment relative to another segment (c.f. Visual 3D manual/Functional Joints). Since the shoulder joint is modelled with all 3 degrees of freedom, the movement trial contained movements around the joint about all the three axes of rotation as suggested by Schwartz & Rozumalski (2005).

The elbow joint was defined as 100% inferior of the existing upper arm segment in the axial axis. The wrist joint, knee joint and ankle joints were created by default in Visual 3D and is assumed to exist between the distal end of a segment and an extremely close proximal end of another segment (c.f. Visual 3D manual/Standard anatomical conventions). The hip joint landmarks are automatically created when creating a CODA pelvis segment. The location of the landmarks are defined as: Right hip joint = (0.36*ASIS_Distance,-0.19*ASIS_Distance,-0.3*ASIS_Distance) and Left hip joint = (-0.36*ASIS_Distance,-0.19*ASIS_Distance,-0.3*ASIS_Distance).

Segment definition
In Table 1 the upper limb, trunk and lower limb segments are defined.
Table 1
Segment definition of upper arm, forearm, hand, trunk, pelvis, thigh, shank and foot.

<table>
<thead>
<tr>
<th>Segment</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper arm</td>
<td>Shoulder joint and medial and lateral elbow.</td>
</tr>
<tr>
<td>Forearm</td>
<td>Elbow joint and radial and ulnar wrist.</td>
</tr>
<tr>
<td>Hand</td>
<td>Radial and ulnar wrist and metacarpal 1 and 5.</td>
</tr>
<tr>
<td>Trunk</td>
<td>Left and right acromion and left and right ASIS.</td>
</tr>
<tr>
<td>Pelvis</td>
<td>A CODA pelvis segment was created of the left and right ASIS and PSIS.</td>
</tr>
<tr>
<td>Thigh</td>
<td>Hip joint and medial and lateral knee.</td>
</tr>
<tr>
<td>Shank</td>
<td>Medial and lateral knee and ankle.</td>
</tr>
<tr>
<td>Foot</td>
<td>Medial and lateral ankle and metatarsal 1 and 5.</td>
</tr>
</tbody>
</table>

Joint angle definition
In Table 2 the joint angles between the moving segment and the reference segment are defined for the upper limb, trunk and lower limb.
Table 2  
Joint angle definitions (X, Y and Z to correspond to forward flexion, abduction and axial rotation).

<table>
<thead>
<tr>
<th>Moving segment</th>
<th>Reference segment</th>
<th>Designated joint movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper arm</td>
<td>Trunk</td>
<td>Shoulder: flexion/extension, abduction/adduction and external/internal rotation</td>
</tr>
<tr>
<td>Forearm</td>
<td>Upper arm</td>
<td>Elbow: flexion/extension</td>
</tr>
<tr>
<td>Hand</td>
<td>Forearm</td>
<td>Wrist: dorsal flexion/ palmar flexion, ulnar deviation/radial deviation</td>
</tr>
<tr>
<td>Trunk</td>
<td>Pelvis</td>
<td>Trunk: bending, rotation</td>
</tr>
<tr>
<td>Trunk</td>
<td>Global Coordinate System (GCS)</td>
<td>Trunk: flexion/extension and rotation</td>
</tr>
<tr>
<td>Thigh</td>
<td>Trunk</td>
<td>Hip: flexion/extension</td>
</tr>
<tr>
<td>Shank</td>
<td>Thigh</td>
<td>Knee: flexion/extension</td>
</tr>
<tr>
<td>Foot</td>
<td>Shank</td>
<td>Foot: dorsal flexion/ plantar flexion</td>
</tr>
</tbody>
</table>

Range of Movement (RoM) variables  
Maximal and minimal peak (MaxP and MinP) flexion and extension and total RoM were calculated for the wrist, elbow, shoulder, trunk, hip, knee and ankle joints. Additionally, MaxP, MinP and the RoM were calculated for shoulder abduction and rotation, for trunk rotation and lateral bending and for ulnar and radial deviation.

Kinetic data analysis  
The calculated power output based on 3D analyses (P3D) was defined as a product of paddle forces and velocity of the markers attached on the force transducers. The total power and the power for each side were calculated which enabled calculations of side differences. For both the power and angle calculations, 10 stroke cycles for each intensity level were used. For the L_{int} and S-M_{int} the 10 strokes were calculated in the middle of each trial and for the
$M_{\text{Int}}$ level the ten first strokes on the maximal level were calculated. The strokes were defined using the markers on the paddle or the markers on the hands (metacarpal 5) if the markers on the paddle could not be used.

**Statistics**

The statistics was carried out in Statistica 12 (StatSoft, USA). All parameters are presented as mean values and standard deviation (SD).

To detect joint angle differences between the body sides and intensities during paddling, MaxP and MinP joint angle values for each joint were analysed in the able-bodied group using a two way analysis of variance (ANOVA), with two within subject factors: *body side* (left and right) and *intensity* ($L_{\text{Int}}$, $S-M_{\text{Int}}$ and $M_{\text{Int}}$). In the presence of significant main effects, Tukey's post hoc test was applied. For this report only differences between body sides were of interest.

To define which joint angles correlated with power output, Person's correlation coefficient was calculated between power output and the separate joint angles for able-bodied and para-athlete men and women. The joint angles were obtained from the kayak ergometer test conducted at the $S-M_{\text{Int}}$ level, i.e. the highest level the athlete was able to stably paddle on, with good technique, during at least 20 stroke cycles. The joint angles that correlated significantly ($p \leq 0.05$) with power output are presented. The joint angles that significantly correlated with power output were divided in different compartments (trunk, leg and sport specific compartment). The joint angles included in each compartment were sum to a total compartment angle.

To get an overview of how para-athletes with different impairments perform during kayaking; within the para-athlete group and compared to able-bodied athletes, a cluster analysis was performed for each compartment. K-Means Clustering method based on the calculation of squared Euclidian distances between cluster centroids was used to perform cluster analyses. In order to avoid a subjective manipulation and to automatically determine the “right” number of clusters, the v-Fold Cross-Validation algorithm was applied. In the latter algorithm the minimum and maximum number of possible clusters and smallest percentage decrease were set to 2, 25 and 10% respectively.
**Result**

*Sport specific range of movement in able-bodied athletes*

There were no significant differences between left and right side RoM in the able-bodied group. In peak joint angles exceptions were seen with a greater MaxP for left knee flexion ($p=0.013$) and greater MinP for left hip flexion ($p=0.039$). However, the differences in joint angles were less than 5 degrees, and therefore the peak joint angles and RoM data of the able-bodied group are presented as mean values of left and right body sides (Table 3).

The sport specific joint angles obtained in the able bodied group during kayaking will be used as reference values in the assessment of muscle strength/muscle power in parakayak athletes. In Table 4 the anatomical joint angle values normally used when assessing passive range of movement are presented together with the sport specific joint angles.

**Table 3**

Peak joint angles and range of movements (RoM) of able-bodied athletes presented as means and standard deviations (SD) of left and right body sides. Values were calculated for shoulder, elbow, wrist, trunk, hip, knee and ankle joints at low (L$_{int}$), sub-maximal (S-M$_{int}$) and maximal (M$_{int}$) intensities.

<table>
<thead>
<tr>
<th>Joint</th>
<th>L$_{int}$</th>
<th>S-M$_{int}$</th>
<th>M$_{int}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean SD</td>
<td>Mean SD</td>
<td>Mean SD</td>
</tr>
<tr>
<td>Shoulder</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion</td>
<td>93.3 9.4</td>
<td>103.6 7.1</td>
<td>102.7 8.9</td>
</tr>
<tr>
<td>Flexion</td>
<td>2.5 12.0</td>
<td>14.2 9.6</td>
<td>16.3 11.9</td>
</tr>
<tr>
<td>RoM</td>
<td><strong>90.8</strong></td>
<td><strong>89.4</strong></td>
<td><strong>86.4</strong></td>
</tr>
<tr>
<td>Abduction</td>
<td>56.0 5.4</td>
<td>47.5 8.2</td>
<td>48.4 6.0</td>
</tr>
<tr>
<td>Abduction</td>
<td>9.5 4.8</td>
<td>7.2 3.2</td>
<td>9.7 2.9</td>
</tr>
<tr>
<td>RoM</td>
<td><strong>46.4</strong></td>
<td><strong>40.3</strong></td>
<td><strong>38.7</strong></td>
</tr>
<tr>
<td>Rotation</td>
<td>41.7 11.7</td>
<td>26.5 13.6</td>
<td>20.3 11.5</td>
</tr>
<tr>
<td>Rotation</td>
<td>29.2 12.4</td>
<td>43.5 11.6</td>
<td>47.1 10.0</td>
</tr>
<tr>
<td>RoM</td>
<td><strong>70.9</strong></td>
<td><strong>70.0</strong></td>
<td><strong>67.4</strong></td>
</tr>
<tr>
<td>Elbow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion</td>
<td>115.8 11.3</td>
<td>105.6 13.8</td>
<td>102.2 12.6</td>
</tr>
<tr>
<td>Flexion</td>
<td>22.4 10.6</td>
<td>22.7 8.3</td>
<td>22.7 7.9</td>
</tr>
<tr>
<td>RoM</td>
<td><strong>93.4</strong></td>
<td><strong>82.8</strong></td>
<td><strong>79.5</strong></td>
</tr>
<tr>
<td>Wrist</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion</td>
<td>7.5 8.4</td>
<td>9.0 4.9</td>
<td>4.0 4.5</td>
</tr>
<tr>
<td>Flexion</td>
<td>23.0 4.4</td>
<td>28.7 3.8</td>
<td>32.0 5.9</td>
</tr>
<tr>
<td>RoM</td>
<td><strong>30.5</strong></td>
<td><strong>37.7</strong></td>
<td><strong>36.0</strong></td>
</tr>
<tr>
<td>Deviation</td>
<td>4.3 5.0</td>
<td>8.9 4.3</td>
<td>9.8 4.8</td>
</tr>
<tr>
<td>Deviation</td>
<td>20.4 5.3</td>
<td>21.7 5.4</td>
<td>20.8 5.2</td>
</tr>
<tr>
<td>RoM</td>
<td><strong>24.7</strong></td>
<td><strong>30.6</strong></td>
<td><strong>30.5</strong></td>
</tr>
</tbody>
</table>
Table 4

Anatomical joint angle values from Hislop and Montgomery (1995). The sport specific joint angles (mean ± 1 SD) are based on the mean able-bodied athletes’ (n=10) joint angles during paddling on the ergometer at the S-Mint.

<table>
<thead>
<tr>
<th>Joint movement</th>
<th>Anatomical joint angles</th>
<th>Sport specific joint angles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulder flexion</td>
<td>180°</td>
<td>110°</td>
</tr>
<tr>
<td>Shoulder extension</td>
<td>50°</td>
<td>-5°</td>
</tr>
<tr>
<td>Shoulder abduction</td>
<td>180°</td>
<td>55°</td>
</tr>
<tr>
<td>Shoulder adduction</td>
<td>40°</td>
<td>-5°</td>
</tr>
<tr>
<td>Shoulder internal rotation</td>
<td>80°^°</td>
<td>55°</td>
</tr>
<tr>
<td>Shoulder external rotation</td>
<td>60°^°</td>
<td>40°</td>
</tr>
<tr>
<td>Elbow flexion</td>
<td>150°</td>
<td>130°</td>
</tr>
<tr>
<td>Elbow extension</td>
<td>0°</td>
<td>-10°</td>
</tr>
<tr>
<td>Wrist palmar flexion</td>
<td>80°</td>
<td>15°</td>
</tr>
<tr>
<td>Wrist dorsal flexion</td>
<td>70°</td>
<td>35°</td>
</tr>
<tr>
<td>Wrist ulnar deviation</td>
<td>35°</td>
<td>25°</td>
</tr>
<tr>
<td>Wrist radial deviation</td>
<td>25°</td>
<td>15°</td>
</tr>
<tr>
<td>Trunk flexion</td>
<td>80°</td>
<td>9°^°</td>
</tr>
<tr>
<td>Trunk extension</td>
<td>25°</td>
<td>5°^°</td>
</tr>
<tr>
<td>Trunk lateral bending</td>
<td>20°</td>
<td>7°</td>
</tr>
<tr>
<td>Trunk rotation</td>
<td>45°</td>
<td>30°</td>
</tr>
<tr>
<td>Hip flexion</td>
<td>120°</td>
<td>110°</td>
</tr>
<tr>
<td>Hip extension</td>
<td>20°</td>
<td>-75°^°</td>
</tr>
<tr>
<td>Knee flexion</td>
<td>135°</td>
<td>55°</td>
</tr>
<tr>
<td>Knee extension</td>
<td>0°</td>
<td>0°</td>
</tr>
<tr>
<td>Ankle plantar flexion</td>
<td>45°</td>
<td>40°</td>
</tr>
<tr>
<td>Ankle dorsiflexion</td>
<td>20°</td>
<td>0°</td>
</tr>
</tbody>
</table>

^a In literature range varies between 0° and 90° due to variation in shoulder elevation.
^b Anatomical trunk extension and flexion is measured in a supine position with extended legs. The reference data is based on trunk extension and flexion values obtained in sitting position and angles are calculated against the vertical plane.
^c In paddling the hip does not extend due to the seated position.
Methodological consideration
After discussions with Dr. Peter Van de Vliet at IPC it was decided to consult the coaches and classifiers about the para-athletes’ experience level, level of competition and training program. The purpose with this additional information was to identify if any outliers found in the results were due to kayaking inexperience. The para-athletes were therefore scored from 0-2 in experience. A score of 0 indicated that the athlete was inexperienced with less than one year of kayaking experience. A score of 1 indicated that the athlete was competing on national level with more than one year experience and had an established training program. A score of 2 indicated that the athlete was competing on international level. Four athletes were inexperienced kayakers (score of 0) and therefore excluded from further analysis. Due to the insufficient number of tested para-athletes with upper limb impairment (n=2) it was also decided after recommendations from Dr. Van de Vliet to exclude these two athletes. A total of 44 para-athletes were therefore included in the final analysis (14 women and 30 men, 35 ± 9.0 years, 70.2 ± 12.4 kg, 1.74 ± 0.1 m) and they trained on average 5.3 ± 1.4 sessions per week with a total exercising time of 14.4 ± 6.7 hours per week.

As a result of the large variation of existing impairments in the para-athlete group, presentation of a group mean value for each joint angle will not be representative for the whole group. Therefore, the sport specific joint angles and RoM values are presented as group means values after the para-athletes were placed in one of the proposed Paralympic classes, KL1, KL2, or KL3 (c.f. in the paragraph “Developing the new Paralympic classification system for para-kayak”, page 25) (Table 5).
#### Table 5
Peak joint angles and ranges of motion (RoM) of para-athletes presented as means and standard deviations (SD) of left and right body sides when divided in the proposed Paralympic classes, KL1, KL2 or KL3. Values were calculated for the trunk, hip, knee and foot joints at sub-maximal intensity (S-MInt).

<table>
<thead>
<tr>
<th></th>
<th>KL1</th>
<th></th>
<th>KL2</th>
<th></th>
<th>KL3</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td><strong>Trunk</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion (GCS) (maximum)</td>
<td>-13.5</td>
<td>6.2</td>
<td>-2.9</td>
<td>6.9</td>
<td>4.7</td>
<td>7.2</td>
</tr>
<tr>
<td>Flexion (GCS) (minimum)</td>
<td>-19.8</td>
<td>7.0</td>
<td>-9.8</td>
<td>6.6</td>
<td>-2.8</td>
<td>7.5</td>
</tr>
<tr>
<td><strong>RoM</strong></td>
<td>6.3</td>
<td>2.6</td>
<td>6.9</td>
<td>2.1</td>
<td>7.6</td>
<td>1.9</td>
</tr>
<tr>
<td>Rotation (GCS) (left)</td>
<td>26.3</td>
<td>8.9</td>
<td>31.9</td>
<td>7.7</td>
<td>35.4</td>
<td>7.9</td>
</tr>
<tr>
<td>Rotation (GCS) (right)</td>
<td>25.0</td>
<td>15.7</td>
<td>31.8</td>
<td>5.7</td>
<td>36.1</td>
<td>6.3</td>
</tr>
<tr>
<td><strong>RoM</strong></td>
<td>52.5</td>
<td>20.5</td>
<td>63.7</td>
<td>12.9</td>
<td>71.5</td>
<td>12.0</td>
</tr>
<tr>
<td>Rotation (left)</td>
<td>22.5</td>
<td>7.6</td>
<td>25.9</td>
<td>5.6</td>
<td>25.1</td>
<td>6.0</td>
</tr>
<tr>
<td>Rotation (right)</td>
<td>18.4</td>
<td>12.4</td>
<td>25.4</td>
<td>5.9</td>
<td>24.2</td>
<td>4.6</td>
</tr>
<tr>
<td><strong>RoM</strong></td>
<td>42.9</td>
<td>15.2</td>
<td>51.3</td>
<td>9.4</td>
<td>49.3</td>
<td>8.4</td>
</tr>
<tr>
<td>Bending (left)</td>
<td>9.8</td>
<td>5.4</td>
<td>12.1</td>
<td>4.5</td>
<td>9.2</td>
<td>4.8</td>
</tr>
<tr>
<td>Bending (right)</td>
<td>9.9</td>
<td>4.8</td>
<td>12.7</td>
<td>5.8</td>
<td>7.0</td>
<td>6.8</td>
</tr>
<tr>
<td><strong>RoM</strong></td>
<td>19.7</td>
<td>7.8</td>
<td>24.8</td>
<td>7.1</td>
<td>16.1</td>
<td>6.1</td>
</tr>
<tr>
<td><strong>Hip</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion (maximum)</td>
<td>83.3</td>
<td>8.8</td>
<td>87.0</td>
<td>20.8</td>
<td>101.6</td>
<td>17.1</td>
</tr>
<tr>
<td>Flexion (minimum)</td>
<td>74.9</td>
<td>8.9</td>
<td>78.1</td>
<td>18.7</td>
<td>86.2</td>
<td>14.4</td>
</tr>
<tr>
<td><strong>RoM</strong></td>
<td>8.5</td>
<td>3.4</td>
<td>8.9</td>
<td>5.4</td>
<td>15.5</td>
<td>6.3</td>
</tr>
<tr>
<td><strong>Knee</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion (maximum)</td>
<td>36.6</td>
<td>13.3</td>
<td>30.3</td>
<td>22.8</td>
<td>39.2</td>
<td>12.9</td>
</tr>
<tr>
<td>Flexion (minimum)</td>
<td>27.8</td>
<td>11.9</td>
<td>21.9</td>
<td>21.8</td>
<td>16.8</td>
<td>10.6</td>
</tr>
<tr>
<td><strong>RoM</strong></td>
<td>8.8</td>
<td>6.8</td>
<td>8.4</td>
<td>8.4</td>
<td>22.4</td>
<td>11.1</td>
</tr>
<tr>
<td><strong>Foot</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion (dorsi)</td>
<td>-41.0</td>
<td>15.5</td>
<td>-27.7</td>
<td>19.5</td>
<td>-25.6</td>
<td>18.7</td>
</tr>
<tr>
<td>Flexion (plantar)</td>
<td>46.9</td>
<td>15.9</td>
<td>32.2</td>
<td>21.0</td>
<td>35.4</td>
<td>17.2</td>
</tr>
<tr>
<td><strong>RoM</strong></td>
<td>5.9</td>
<td>3.9</td>
<td>4.5</td>
<td>3.8</td>
<td>9.8</td>
<td>5.7</td>
</tr>
</tbody>
</table>

**Correlations**

The joint angles that significantly correlated with power output are presented in Table 6. Since no participants with upper limb impairment were included in the data, the upper limb angles were not included in further analysis.

The joint angles that significantly correlated with power output were divided in three different compartments a) the trunk compartment, containing the sum of the angles of the trunk that significantly correlated with power (trunk rotation GCS RoM and the maximal trunk flexion angle, which indicates the trunk position (flexion/extension) the athletes are sitting in, b) the leg compartment, containing the sum of the angles of the lower limbs that
correlated significantly with power (hip, knee and ankle RoM), and c) the sport specific compartment, containing the sum of the angles from the trunk and leg compartments.

Correlations between compartments and power output for men and women were performed and are presented in Table 7.

**Table 6**
Significant correlations between joint angle values and power output during sub-maximal intensity (S-M\textsubscript{int}) for both male and female able-bodied athletes and para-athletes during kayak ergometer paddling. No significant correlations were found for elbow, wrist angles or the trunk rotation.

**Power vs. joint angles**

<table>
<thead>
<tr>
<th></th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pearson r</td>
<td>p-value</td>
</tr>
<tr>
<td><strong>Arm</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shoulder flexion RoM</td>
<td>-0.43</td>
<td>0.018</td>
</tr>
<tr>
<td>Shoulder abduction RoM</td>
<td>-0.42</td>
<td>0.020</td>
</tr>
<tr>
<td>Shoulder rotation RoM</td>
<td>-0.44</td>
<td>0.015</td>
</tr>
<tr>
<td><strong>Trunk</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trunk Flexion Max</td>
<td>0.83</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Trunk Rotation GCS RoM</td>
<td>0.66</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Trunk Bending RoM*</td>
<td>-0.48</td>
<td>0.007</td>
</tr>
<tr>
<td><strong>Leg</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip Flexion RoM</td>
<td>0.71</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Knee Flexion RoM</td>
<td>0.69</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Foot Flexion RoM</td>
<td>0.38</td>
<td>0.039</td>
</tr>
</tbody>
</table>

*The trunk bending angle was negatively correlated with power output and was therefore not included in the trunk compartment.

**Table 7**
Significant correlations between trunk, leg and sport compartments and mean power output for male and female able-bodied athletes and para-athletes during kayak ergometer paddling.

**Power vs. compartment**

<table>
<thead>
<tr>
<th></th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pearson r</td>
<td>p-value</td>
</tr>
<tr>
<td><strong>Compartment</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trunk</td>
<td>0.82</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Leg</td>
<td>0.71</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Sport Specific</td>
<td>0.80</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
Cluster analysis

The results of the cluster analyses from the trunk, leg and sport specific compartments are presented in Figure 2 – 4, respectively. For all of the compartments, the athletes with the highest impairments are included in cluster 1. The number under each circle represents the athlete’s identification number (c.f. Appendix 1).

Figure 2

Five clusters were identified for the trunk compartment. The number under each circle represents the athlete’s identification number (c.f. Appendix 1).
Figure 3

Five clusters were identified for the leg compartment. The number under each circle represents the athlete’s identification number (c.f. Appendix 1).
Five clusters were identified for the sport specific compartment. The number under each circle represents the athlete’s identification number (c.f. Appendix 1).
Study 3 Trunk Muscle Function

Introduction

As previously mentioned, kayak paddling is a complex activity that involves most of the upper-body musculature. This has been demonstrated for the muscles around the shoulder joint in able-bodied athletes (Trevithick et al., 2006). Corresponding data for the trunk muscles are lacking, but it is evident from a mechanical point of view that there has to be a link transferring the forces from the paddle via the shoulders to the kayak. Moreover, the paddling movement is complex with alternating three-dimensional upper body movements during the pull, lift and push phases. The complex interplay between the forces in different directions, and the construction of the kayak, places marked demands on sitting balance control and postural stability, particularly in medio-lateral direction. Thus, evaluating trunk muscle function and sitting balance control is crucial in para-kayak athletes since kayaking requires dynamic postural control. Also, the results from Study 1 and 2 in this report suggested a more detailed understanding of the trunk function during paddling is warranted.

Currently there are no established clinical methods for examining motor function in the trunk muscles in individuals with impaired muscle power, for example following a spinal cord injury (SCI). However, it has been incorporated into classification of trunk function for Paralympic athletes such as in wheelchair rugby and Nordic skiing. Since individual abdominal muscles receive innervation from different thoracic segment levels the assessment of different abdominal muscles should help to further increase the accuracy in identifying the level and completeness of the trunk impairment in the para-athlete. Recent research have examined the accuracy of using manual examination to determine abdominal muscle function in persons with impaired muscle power (i.e. individuals with SCI) and found that EMG provide a sensitive, accurate technique to detect small muscle activation levels of preserved motor function in the abdominal muscles (Bjerkefors et al., 2014).

The purpose of the third study was to a) develop and use a test to determine the trunk function in para-athletes, b) assess if the results from the manual muscle test correlates with the results from the functional assessment scale, c) to correlate the results obtained from the trunk test with the trunk compartment values obtained from the kayak ergometer test in Study 1 and 2, d) validate the trunk test by comparing the results from the manual muscle test to neurophysiological measures of trunk muscle activity using electromyography (EMG).
Method
Participants
Sixty five international or national level para-canoe athletes (para-kayak and para-va'a) (19 women and 46 men, 35 ± 9 years; 73.0 ± 13.0 kg, 1.74 ± 0.1m) from 12 different countries from 4 continents volunteered for the study. A description of the para-athletes are presented in Appendix 2.

Experimental design and procedure
Participants were instructed to perform six different trunk muscle tasks: trunk flexion, trunk rotation to the left and right, trunk lateral flexion to the left and right and trunk extension. Athletes’ abdominal muscles were individually scored on a scale from 0-5. Scores could range from zero activity (0), trace (1), poor (2), fair (3), good (4) to normal (5) activity. Scoring criteria were task specific. The load of the exercise could be adjusted by changing the position of the arms (Figure x). If the subject could only complete the tasks according to the criteria for 0-2 points the clinician palpated the key abdominal muscles (transversus abdominis (TrA)/obliquus internus (OI), obliquus externus (OE), rectus abdominis (RA), erector spinae (ES) at T7 and T12 level)). The following instruction was given for all exercises: breathe out (2s), go up to the target position (2s), hold the position (2s) and then relax. Participants performed two trials of each task, with a 30s rest between trials.

Figure 5
Trunk flexion in supine with a) hands clasped behind head (score 5), b) arms crossed over chest (score 4), and c) arms out-stretched in full extension above plane of body (score 3).

After the manual trunk muscle test was performed, the EMG electrodes were removed and the subjects performed the functional assessment test. The athletes were asked to complete different functional tasks while sitting unsupported. The examination included a) static tasks; sitting upright with arms across chest (Figure 6a) and with arms outstretched in 4 directions,
b) dynamic tasks; moving trunk through a range of motion in 6 directions (Figure 6b), c) perturbation tasks; push and recovery from 6 directions (Figure 6c) and d) perturbation tasks while athlete was sitting on a wobble cushion; push and recovery from 6 directions. If the athlete failed to complete a task, no further tasks were needed to be performed. The tasks were graded from 0-2; 0=clearly fails, 1=in doubt, 2=succeed.

![Figure 6 a-c](image)

The functional assessment of the trunk included a) static tasks; sitting upright with arms across chest, b) dynamic tasks; moving trunk through a range of motion in 6 directions, and c) perturbation tasks; push and resistance.

c) perturbation task (left; push, right; resistance)

The Guideline for the Manual Trunk Muscle Test and Functional Assessment is attached in Appendix 3.

**Equipment**

Muscle activity was recorded with surface EMG bilaterally from: TrA/OI, OE, RA (Figure 7) and from erector spinae (ES) at T7 and T12 level. Prior to placing the electrodes, the skin was cleaned with alcohol and, if needed, shaved. Pairs of electrodes (34 mm diameter, Ambu AS, Denmark) were attached with approximately 2cm inter-electrode separation. EMG data were collected at 1500Hz (MyoSystem 1400A, Noraxon, Scottsdale, USA) and digitally sampled using Master Edition MR-XP 1.07 (Noraxon, Scottsdale, USA) amplified (500 times) and band-pass filtered between 10 and 500Hz, before processing off-line (Spike2, CED, Cambridge, UK).
Data analysis and statistics

EMG data was analyzed by an experimenter who was blind to the results of the manual muscle examination. EMG data recorded during voluntary tasks was high-pass filtered at 30Hz and root mean square (RMS) amplitude was calculated over a 500ms time period for each muscle and task during rest and voluntary contraction. For the EMG data, if the average RMS amplitude of the two contraction trials for a given muscle and task exceeded 2SD above the mean resting value (calculated from all trials), the value was defined as “present” for the given technique and was included in the frequency analysis. For each task, only the appropriate muscles were included to determine presence of response (flexion: bilateral RA; rotation: ipsilateral TrA/OI and contralateral OE; lateral bending: ipsilateral OE).

The scores from the manual muscle test (MMT) and the scores from the functional assessment test (FAS) were summed separately, and the scores for all tests were summed to a total score (Total Sum Score). To assess if the results from the manual muscle test correlates with the results from the functional assessment scale, Spearman rank order correlation were calculated. To examine if the score obtained on the trunk test correlates with the values from the trunk compartment and the scores from the trunk test, Spearman rank order correlation were calculated. To validate the trunk test the frequency of muscle responses detected by manual examination were compared to detection by EMG (treated as the gold standard) in order to calculate measures of sensitivity, specificity, overall agreement, as well

Figure 7

Electrode positions were as follows: obliquus internus (OI)/transversus abdominis (TrA): approximately 2cm medial to the anterior superior iliac spine (ASIS) (black circles); obliquus externus (OE): approximately 2cm below the lowest point of the rib cage (white circles); and rectus abdominis (RA): approximately 3cm lateral and 2cm caudal to the umbilicus (grey circles).
as positive and negative likelihood ratios. In addition, 95% confidence intervals are reported. Sensitivity was calculated as the number of true positives divided by the sum of true positives plus false negatives, multiplied by 100. Specificity was calculated as the number of true negatives divided by the sum of false positives plus true negatives, multiplied by 100. Overall percent agreement was calculated as the sum of true positives plus true negatives divided by the total number of cases, multiplied by 100.

Result
A new test for evaluating trunk muscle function and functional performance in sitting has been developed and used in 65 para-canoe athletes. The results from the athletes are presented in Figure 8. Scores on the manual muscle test were predictive of functional balance control in para-canoe athletes ($r=0.82$, $p<0.001$). The results suggest that the trunk test is a valid test to assess sport specific trunk function in para-athletes ($r=0.69$, $p<0.001$). Minimal levels of function were accurately detected and were confirmed using EMG (Figure 9). A detailed presentation of the results from the sensitivity, specificity, and overall agreement for the trunk test will be presented in a separate report during next year.

Figure 8
Three clusters were identified for the total score of the trunk test. The number under each circle represents the athlete’s identification number (c.f. Appendix 2). Please note that in this figure the scores in the manual muscle test has been changed to range from 0 to 2 and the total value for the trunk test is therefore 84.
Figure 9
Example of electromyography recordings from three abdominal muscles (from the top: Left Internal Oblique, Right Internal Oblique, Left External Oblique, Right External Oblique, Left Rectus Abdominis, Right Rectus Abdominis) during trunk lateral bending to the left in supine position in one athlete with full trunk muscle function (left) (manual muscle test score (MMT 35 points) and one athlete with partial trunk muscle function (right) (spinal cord injury T11) (MMT 13 points). Dashed line indicates the contraction onset. The red circle indicates that the muscle activation was task specific, i.e. the targeted muscle (Left External Oblique) was activated and the antagonist muscle (Right External Oblique) was silent (black circle).
Conclusion of the research from Study 1, 2 and 3

- The range of movement values from the able-bodied group can be used as reference values in a sport specific classification for para-kayak athletes.
- During kayaking, sitting in a position of forward trunk flexion and having a greater range of movement in trunk rotation correlates with producing a greater power output (Male $r=0.88$, Female $r=0.74$).
- Having a greater range of movement in hip, knee and foot flexion during kayaking correlates with producing a greater power output (Male $r=0.71$, Female $r=0.86$).
- A greater total score in the trunk tests correlated with a greater angle value in the Trunk compartment ($r=0.69$).
- The new test battery developed to assess trunk muscle function in para-kayak and para-valxa athletes was successful in defining if the athletes had no, partial or full trunk function.
Development of a proposed evidence based Paralympic classification system

Implementing the results from the research

This implementation was conducted in a number of steps. The first step was to re-score all the tests included in the physical and technical assessment so that all tests had the same scoring range. The second step was to create a scoring system for the on-water test and to define what each score implies. The third step was to analyse if the results from the research correlates with the updated scores from the physical and technical assessment tests to validate the tests. The fourth step was to identify groups/clusters within the para-athlete group for each test, and to identify differences between the para-athlete group and the able-bodied group to define minimal eligibility. The fifth step was to set boundaries between each group/cluster for each test. The sixth step was to identify the number of existing combinations for trunk, leg and on-water tests in the para-athlete group. The final step was to propose a new Paralympic classification system including a) evidence based physical and technical assessment tests, b) minimal eligibility criteria, and c) excluding athletes with only upper limb impairments.

1. Re-scoring the trunk and leg test

The first part in the development of the new proposed classification was to re-score current physical assessment from the scores of 0-5 to 0-2 so that all tests had the same scoring range. The scoring range of 0-2 was chosen after recommendations from Dr. Van de Vliet who suggested that this type of scoring system was easier to implement in sport performance. The items that were re-scored from the current physical assessment were the leg strength test and the squat test. The total score ranged between 0 and 26. The trunk test was re-scored from 0-5 to 0-2 and the total score could therefore range between 0 and 84.

2. Scoring system for on-water test

The technical on-water observation has previously included 13 items which have not been scored. This was changed to there being six items that were scored 0-2. The scored items were left leg movement, right leg movement, balance, trunk posture, trunk rotation and trunk side flexion. The total score for the on-water test could therefore range between 0 and 12.

3. Correlations between research results and tests

To examine if the physical and technical assessment correlates with the results from the trunk, leg and sport specific compartment from the research, Spearman rank order correlation were
calculated between a) the values from the trunk compartment and the scores from the trunk test, b) the values from the leg compartment and the scores from the leg and squat test, and c) the values from the sport specific compartment and the scores from the on-water test (Table 6). All the assessment tests were significantly correlated with the research.

Table 6
Spearman’s correlation between the assessment tests and the research compartments (trunk, leg and sport specific).

<table>
<thead>
<tr>
<th>Assessment tests vs. research compartments</th>
<th>Test</th>
<th>Spearman’s Rho</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trunk test vs. Trunk compartment</td>
<td>0.69</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Leg test vs. Leg compartment</td>
<td>0.72</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>On-water test vs. Sport specific compartment</td>
<td>0.81</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

4. Clusters and minimal eligibility

Cluster analyses of the trunk (Figure 10), leg (Figure 11) and on-water (Figure 12) tests were conducted. K-Means Clustering method based on the calculation of squared Euclidian distances between cluster centroids was used to perform cluster analyses and the v-Fold Cross-Validation algorithm was applied. In the latter algorithm the minimum and maximum number of possible clusters and smallest percentage decrease were set to 2, 25 and 15 % respectively. After examining the cost sequence graph four clusters were examined to be the appropriate number of clusters.

5. Setting boundaries between clusters

The boundaries between each cluster were set from the results of the cluster analyses for each test. However, to set the exact value between each cluster an in-depth analysis of the para-athletes that scored the highest and the lowest in respective cluster was performed. On page 27-29 the boundaries and clusters are presented including information about these athletes.
**Trunk test**

For the trunk test the score range for each cluster were 0 to 16 for no trunk function, 17 to 68 for partial trunk function and 69 to 84 for full trunk function. The athletes with the highest score in cluster 1 (16 points) are able to sit upright during the trunk test but fails to sit upright when exposed to internal perturbation (arm movements). All the athletes in this cluster will therefore have to use a special seat or a high backrest in the kayak for trunk support. The athlete with the lowest trunk score in cluster 2, had a score of 35, scored 1 in all the sitting balance tests when external perturbations was applied, and was not able to sit on a wobble cushion. The athlete with the highest score in cluster 2, had a score of 64, was able to sit on a wobble-cushion but failed the wobble-cushion task if external perturbations were applied. The athlete with the lowest score in cluster 3, had a score of 71, was able to partially perform the wobble-cushion task with applied external perturbations.

![Trunk test](image)

**Figure 10**

Cluster analysis of the total score from the trunk test resulting in 3 clusters. The number of athletes was 64, not including able-bodied athletes. One athlete was excluded due to a high thigh amputation that affected the performance on the wobble cushion resulting in a misleading low trunk score. The number under each circle represents the athlete’s identification number (c.f. Appendix 2).
**Leg test**

For the leg test the score range for each cluster were 0 to 2 for no or limited leg function, 3 to 17 for partial leg function and 18 to 24 for “full” leg function (i.e. “full” leg function will be a term used to define the para-athletes with highest leg function). The athletes in cluster 1 should exhibit no or limited leg function. The athlete with the lowest score in cluster 2 scores two points and has only full function in left hip flexion. The athletes with the highest scores in cluster 2 have a total score of 16 to 17 and have bilateral below knee amputations or single above knee amputation thus missing strength in two joints in the lower limbs. In addition to the amputations, the athletes also have only partial function in one or both hip joints which makes them eligible for this cluster group. The four athletes with the lowest score in cluster 3 have all single leg above knee amputations with full hip function. The two athletes with the highest score in cluster 3 (23 points) have impaired muscle power in the ankle joint/s.

**Figure 11**

Cluster analysis of the total score from the leg test resulting in 3 clusters. The number of athletes included in this analysis was 51, including able-bodied athletes. Three athletes were excluded in cluster 2 and 3, one due to neurological degenerative disorder and two due to undated physical assessment. The number under each circle represents the athlete’s identification number (c.f. Appendix 1).
**On-water test**

For the on-water test the score range for each cluster were 0 to 3 for cluster 1, 4 to 8 for cluster 2, and 9 to 12 for cluster 3. The athlete with the highest score in cluster 1 did not exhibit any leg movement and no trunk rotation, but could sit upright (most likely due to the seat) and did not exhibit any trunk side flexion. The athlete with the lowest score in cluster 2 had a score of 4 points and did not have any leg movement but was able to rotate the trunk partially, sit in an upright position and had partially good balance. The athletes with the highest score in cluster 2 had either no leg movement and full trunk movements or partial leg and trunk movements. The four athletes with the lowest score in class 3 (9 points) had different combinations of function, that were; full trunk function, partial leg movement in both legs and partial balance control (n=1), full trunk function, full leg function in one leg, partial leg function in the other leg, and full balance control (n=2), partial trunk function, full function in one leg and no function in the other leg, and full balance control (n=1).

**Figure 12**

Cluster analysis of the total score from the on-water test resulting in 3 clusters. The number of athletes was 51 including able-bodied athletes. Three athletes were excluded, one due to neurological degenerative disorder and two due to undated physical assessment. The number under each circle represents the athlete’s identification number (c.f. Appendix 1).
6. **Identifying the number of existing combinations in test performance**

From these cluster analyses the athletes were scored 1, 2 or 3 on each test. To further divide the athletes into classes, the number of combinations the athletes could have was examined. The total score from each test were summed into a total classification score, ranging from 3 to 9. Since trunk was determined to be the key factor of performance in kayak, the combinations were sorted in 1) trunk test, 2) leg test and 3) on-water test. Figure 13 shows the different combinations observed in the para-athlete group and the number of athletes that exhibited each combination. As shown in Figure 13, there are eleven different combinations. In five of them only one athlete exhibited that combination.

**Number of existing combinations in the para-athlete group**

![Diagram showing combinations and athletes](image)

**Figure 13**

The different combinations that existed in the para-athlete group sorted from the results from the trunk score (cluster 1 to the left, cluster 2 in the middle, and cluster 3 to the right). 41 athletes are included in this chart, 3 outliers were excluded; one due to neurological degenerative disorder, and two due to undated physical assessment. The number (n) indicates how many athletes had that combination. The athlete with a combination of 2-3-3 had a high single above knee amputation (no prosthesis) and was not able to sit on the wobble cushion. The athlete with the combination of 3-2-2 was an athlete with bilateral below knee amputation not using prostheses.
7. Proposed new Paralympic classification system

The three largest combinations shown in red in Figure 13, were the ones with no trunk or leg function (n=9, total score of 3), partial trunk and leg function (n=5, total score of 6) and full trunk and partial leg function (n=9, total score of 9). It therefore seemed appropriate to divide the athletes into three different classes. The athletes in the no trunk or leg function class have a total score of 3 points (KL1). The athletes in the class with no/partial/full trunk and/or no/partial leg function will be the biggest group (n=14) and can have a score ranging from 4 to 7 (KL2). The last group will be athletes with partial or full trunk function and "full" leg function and can have a score ranging from 8 to 9 (KL3). Typical characteristics of the athletes in each group are described in Figure 14. In the future, with more research and a larger number of competing athletes, it is anticipated that the middle class will likely be split into two classes, thus there being a total of four classes.

Proposed Paralympic classification for kayak
3 classes

Figure 14
Definitions of the new proposed Paralympic classes for para-kayak.

a) New proposed assessment tests

Physical assessment

It is proposed that in the new Paralympic classification system, the physical assessment will consist of a trunk test and a leg test. The trunk function will be assessed using the trunk test (manual muscle test and functional assessment) (Figure 15). The leg test will assess muscle power/muscle strength in hip, knee and foot flexion/extension in sport specific RoM. It will
also consist of a seated single leg press for both legs. The scores will range between 0 and 2 for all tests. The total score of the trunk test will therefore range between 0 and 84. The total score for the leg test will range between 0 and 28.

**Technical assessment**

For the technical assessment it is proposed that the ergometer test will be an observation test only, and that six items will be scored on the on-water test. The items will be scored from 0 to 2, and the total score of the on-water test will range between 0 and 12 (Figure 15). The items that will be scored on the on-water test are based on the variables that were demonstrated from the research studies in the report to be correlated with producing a greater power output. The items are: left leg movement, right leg movement, balance control, trunk posture, trunk rotation and trunk side flexion.

**Figure 15.**

A chart of the new proposed Paralympic classification system for para-kayak.
b) **New proposed minimal eligibility criteria**

The previous minimal eligibility criteria has been at least full loss of 3 fingers on one hand, or at least a tarsal metatarsal amputation of the foot, or the permanent loss of at least ten points on one limb or fifteen points across two limbs. The new proposed minimal eligibility criterion is at least loss of 4 points in one leg in the physical assessment leg test.

c) **Upper limb impairments**

Since only two athletes with upper limb impairment participated in this study, conclusions about how to classify athletes with this type of injury could not be drawn. Therefore, no athletes with only upper limb impairments will be included for Paralympics 2016. Athletes who meet the new proposed minimal eligibility criteria and also have an upper limb impairment will only be classified on their lower limb impairment, thus the upper limb impairment will not be considered.
References


Appendix 3
Guidelines for the Trunk test
for Paracanoe Athletes

Information

Please note that the purpose of the pictures is to show the position of the athlete and classifier. The classifier’s job is to assess function and not position, the scores may therefore be different during a classification even though the position is similar to what is shown in the manual.
Equipment

- Treatment bench with adjustable height
- Wobble cushion
- Protocol

Manual Muscle Test (MMT)

- Athlete will perform seven trunk muscle tasks
  - trunk flexion
  - trunk rotation to the right (R) and to the left (L)
  - trunk side bending/flexion to the R and L
  - trunk lumbar extension
  - trunk lumbar extension and hip extension

- The tests will be performed on a 0-2 scale.
- Total number of points available for this section = 14
MMT Trunk flexion Score 2

- **Position of Athlete:** Supine with arms crossed over chest.
- **Position of Classifier:** Standing beside the athlete and stabilize the legs and pelvis. Classifiers should check if the scapulae clear the table during the test.
- **Test:** Athlete flexes trunk through range of motion. A curl-up is emphasized, and trunk is curled until scapulae clear table.
- **Instruction:** “Tuck your chin and lift your head and shoulders to curl up off the table.”
- **Score 2:** Athlete completes range of motion and raises trunk until scapulae are off the table.

---

MMT Trunk flexion Score 1

- **Position of Athlete:** Supine with arms stretched towards toes.
- **Position of Classifier:** Standing beside the athlete and stabilize the legs and pelvis. Classifiers should check if the scapulae clear or partially clear the table during the test. The hands used for palpation is placed at the midline of the thorax over the linea alba, and one hand is used to palpate the Rectus Abdominus.
- **Test:** Athlete attempts to flex trunk.
- **Instructions:** “Tuck your chin and lift your head and shoulders to curl up off the table.”
- **Score 1:** Athlete completes partial range of motion and the examiner must be able to detect contractile muscle activity.

*extra tests can be found in the end of the guideline.
MMT Trunk flexion Score 0

- **Position of Athlete**: Supine with arms stretched towards toes.
- **Position of Classifier**: Standing beside the athlete and stabilize the legs and pelvis. Classifiers should check if the scapulae partially clear the table during the test. The hands used for palpation is placed at the midline of the thorax over the linea alba, and one hand is used to palpate the Rectus Abdominus.
- **Test**: Athlete attempts to flex trunk.
- **Instructions**: “Tuck your chin and lift your head and shoulders to curl up off the table.”
- **Score 0**: The athlete is unable to lift the shoulders from the table, and no or very limited activity is visible or palpable during attempted contraction.

*extra tests can be found in the end of the guideline.

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MMT Trunk rotation Score 2

- **Position of Athlete**: Supine with arms crossed over chest.
- **Position of Classifier**: Standing beside the athlete supporting the legs and pelvis. Classifiers should check if the scapulae clears the table during the test.
- **Test**: Athlete flexes trunk and rotates to one side. And then the other.
- **Instruction**: “Lift your head and shoulders from the table, taking your left elbow toward your right knee.” Repeat on opposite side.
- **Score 2**: The inferior angle of the scapula on the opposite side to the rotation clears the table.
MMT Trunk rotation Score 1

- **Position of Athlete:** Supine with arms at sides.
- **Position of Classifier:** Standing beside the athlete and supporting the legs and pelvis. Classifier palpates the External and Internal Oblique on each side.
- **Test:** Athlete attempts to raise body and rotate to one side. Repeat on the other side.
- **Instruction:** “Lift your head and shoulders from the table, taking your left hand towards your right knee.” Repeat on opposite side.
- **Score 1:** Athlete completes partial range of motion and the classifier must be able to detect contractile activity.

*extra tests can be found in the end of the guideline.*

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MMT Trunk rotation Score 0

- **Position of Athlete:** Supine with arms at sides.
- **Position of Classifier:** Standing beside the athlete and supporting the legs and pelvis. Classifier palpates the External and Internal Oblique on each side.
- **Test:** Athlete attempts to raise body and rotate to one side. Repeat on the other side.
- **Instruction:** “Try to lift your head and shoulders from the table, taking your left hand towards your right knee.” Repeat on opposite side.
- **Score 0:** The athlete is unable to lift the shoulder from the table, and no or very limited activity is visible or palpable during attempted contraction.

*extra tests can be found in the end of the guideline.*
MMT Trunk side flexion Score 2

- **Position of Athlete:** Supine with arms crossed over chest.
- **Position of Classifier:** Sitting at level of athlete’s pelvis to provide support. Stabilize the pelvis with body and arm. Place one hand on the ipsilateral shoulder of the athlete.
- **Test:** Athlete laterally bends the trunk. Repeat on the other side.
- **Instruction:** “Push towards my hand by bending your trunk to the side.”
- **Score 2:** The athlete can overcome resistance and can bend to the side.

Trunk test guidelines for Paracanoe

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MMT Trunk side flexion Score 1

- **Position of Athlete:** Supine with arms crossed over chest.
- **Position of Classifier:** Sitting at level of athlete’s pelvis to provide support. Stabilize the pelvis with the body. With one hand classifier palpates the External Oblique on the ipsilateral side with the hand placed on the lateral part of the trunk between the distal part of the rib cage and the pelvis.
- **Test:** Athlete laterally bends the trunk. Repeat on the other side.
- **Instruction:** “Bend your trunk to the side.”
- **Score 1:** The athlete is able to move without resistance and the classifier must be able to detect contractile activity.
MMT Trunk side flexion Score 0

- **Position of Athlete:** Supine with arms crossed over chest.
- **Position of Classifier:** Sitting at level of athlete’s pelvis to provide support. Stabilize the pelvis with the body. With one hand classifier palpates the External Oblique on the ipsilateral side with the hand placed on the lateral part of the trunk between the distal part of the rib cage and the pelvis.
- **Test:** Athlete attempts to laterally bend the trunk. Repeat on the other side.
- **Instruction:** “Try to bend your trunk to the side.”
- **Score 0:** The athlete is unable to bend sideways and no or very limited activity is visible or palpable during attempted contraction.

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MMT Trunk Lumbar Extension Score 2

- **Position of Athlete:** Prone with hands close to head or by their sides.
- **Position of Classifier:** With hands holding just close to ischeal tuberosities.
- **Test:** Athlete extends the lumbar spine until the entire sternum is raised from the table.
- **Instruction:** “Raise your head, shoulders, and chest from the table as high as you can.”
- **Score 2:** The athlete can achieve the end position.
MMT Trunk Lumbar Extension Score 1

- **Position of Athlete:** Prone with their arms placed by their sides.
- **Position of Classifier:** Support high on the thighs. Classifier palpates the Erector Spinae on both sides.
- **Test:** Athlete extends the trunk.
- **Instruction:** “Lift your head and chest as high as possible”.
- **Score 1:** Athlete completes partial range of motion and the classifier must be able to detect contractile activity.

Trunk test guidelines for Paracanoe

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MMT Trunk Lumbar Extension Score 0

- **Position of Athlete:** Prone with their arms placed by their sides.
- **Position of Classifier:** Support high on the thighs. Classifier palpates the Erector Spinae on both sides.
- **Test:** Athlete extend the trunk.
- **Instruction:** “Lift your head and chest as high as possible”.
- **Score 0:** The athlete is unable to lift the trunk off the table and no or very limited activity is visible or palpable during attempted contraction.

Trunk test guidelines for Paracanoe
MMT Trunk and hip extension Score 2

- **Position of Athlete:** Prone with their hands placed by the head or by their sides.
- **Position of Classifier:** Standing at the side of the athlete to observe the trunk movement and position of the pelvis.
- **Test:** Athlete extend the trunk.
- **Instruction:** “Lift your head and chest as high as possible”
- **Score 2:** The sternum clears the table, and the pelvis remains flat on the bench.

MMT Trunk and hip extension Score 1

- **Position of athlete:** Prone with their arms placed by their sides.
- **Position of Classifier:** standing at the side of the athlete to observe the movement of the trunk and the position of the pelvis
- **Test:** Athlete extend the trunk.
- **Instruction:** “Lift your head and chest as high as possible”
- **Score 1:** Athlete completes partial range of trunk extension. If the hip flexor muscles are stronger than the hip extensor muscles, the athlete’s pelvis will lift from the bench.
MMT Trunk and hip extension Score 0

- **Position of athlete**: Prone with their arms placed by their sides.
- **Position of classifier**: standing at the side of the athlete to observe the movement of the trunk and the position of the pelvis
- **Test**: Athlete extend the trunk.
- **Instruction**: “Lift your head and chest as high as possible”
- **Score 0**: The athlete is unable to lift the trunk of the table and no or very limited activity is visible or palpable during attempted contraction.

Functional Assessment Score

Athletes will be asked to complete functional tasks while sitting. Athletes should look at the classifier during all functional assessment tests. Athletes should not stabilize themselves by locking the legs under the bench.

The examination includes:
- static tasks (sitting upright with arms outstretched in 4 directions), scores a maximum of 10 points
- dynamic tasks (moving trunk through a range of motion), scores a maximum of 12 points
- resistance and perturbation from 6 directions, scores a maximum of 24 points
- resistance and perturbation from 6 directions while athlete is sitting on a wobble cushion, scores a maximum of 24 points

There are a maximum of 70 points for the Functional assessment. These are added to the Manual Muscle Test score for a maximum of 84 points.
Position of classifier

Athlete with above knee amputation might need this type of support

Athlete needing more support

Trunk test guidelines for Paracanoe

Static test

Upright Sitting

- **Description:** Athlete sits with legs hanging over the edge with feet unsupported. Athlete crosses arms to prevent support. Classifier brings athlete into upright position, one hand on sternal bone and one hand on back, then slowly lets go of support.
- **Instruction:** “Sit up tall.”
- **Evaluation:** Observe sitting position after removing the support:
  - straight/upright
  - flat belly
  - kyphotic/quad/para belly
- **Score 2:** Sits straight upright, without marked kyphosis, and with flat belly for 3 seconds or more.
- **Score 1:** Can only manage upright sitting for less than 3 seconds and compensates with head movement.
- **Score 0:** Sits with marked kyphosis due to a compensation of not having/having limited trunk function or with quad belly.

Trunk test guidelines for Paracanoe
Static test
Upright Sitting with shoulder flexion/extension

- **Description:** Athlete sitting on the plinth with legs hanging over edge of plinth with the feet unsupported. The classifier may need to place his/her hands close to the hips, to fix both legs to the plinth.
  
  **Flexion:** Athlete is instructed to lift both arms to 90° shoulder flexion, hold for 2 seconds and slowly go back to the initial position.
  
  **Extension:** Athlete is instructed to lift both arms to about 30° shoulder extension, hold for 2 seconds and slowly go back to the initial position.

- **Evaluation:** Observe movement quality and range standing lateral to the athlete.

- **Score 2:** Athlete performs shoulder flexion to at least 90° with a straight upright position.

- **Score 2:** Athlete performs shoulder extension to at least 30° with a straight upright trunk position.

- **Score 1:** Athlete attempts to flex/extend shoulders to 90°/30° but can only maintain a straight upright trunk momentarily before compensating by kyphosis or lordosis.

- **Score 0:** Athlete is unable to maintain an upright posture to lift the arms, either into flexion or extension.

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Score 2
Shoulder flexion
Score 0

Shoulder extension

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Trunk test guidelines for Paracanoe
Static test
Upright Sitting with abduction

- **Description:** Athlete sitting on the plinth with legs hanging over edge of plinth with the feet unsupported. The classifier may need to place his/her hands close to the hips, to fix both legs to the plinth.
  - *Abduction:* Athlete is instructed to lift one arm to 90° shoulder abduction, hold the position for 2 seconds and slowly go back to the initial position. The other arm is crossed over the chest.
- **Evaluation:** Observe movement quality and range standing lateral to the Athlete.
- **Score 2:** Athlete performs shoulder abduction to at least 90° with a straight upright position.
- **Score 1:** Athlete lifts shoulder to 90°, but is unable to maintain upright posture throughout the test without compensation.
- **Score 0:** Athlete is unable to lift the shoulder to 90° and compensates with kyphosis/lordosis. May need support to resume straight position.

Dynamic test
Active Trunk Flexion/Extension

- **Description:** Athlete sits on the plinth with legs hanging over the edge, with the feet unsupported. Athlete crosses the arms in front of his/her chest, to prevent support for sitting balance from the arms. The classifier may need to place his/her hands close to the hips, to fix both legs to the plinth.
- **Evaluation:** Observe movement quality and range standing lateral to the Athlete.
- **Score 2:** Athlete performs trunk flexion to at least 20° line between pelvis and C7 and vertical, and maintains position for 2 seconds before returning to upright position, and performs at least 15° trunk extension and maintains position for 2 seconds before returning to upright position.
- **Score 1:** Athlete flexes to less than 20° and extends to less than 15°, and is unable to maintain the position for 2 seconds. May compensate to resume straight position.
- **Score 0:** Athlete cannot flex or extend without compensation by kyphosis/lordosis or cannot resume straight position without support.
Dynamic test
Active Trunk Flexion

Score 2
Score 2
Score 0

Trunk test guidelines for Paracanoe

Dynamic test
Active Trunk Extension

Trunk test guidelines for Paracanoe
Dynamic test
Active Trunk Rotation

- **Description:** Athlete sits on the plinth with legs hanging over edge, with the feet unsupported. Athlete crosses the arms in front of his/her chest, to prevent support for sitting balance from the arms. The classifier may need to place his/her hands close to the hips, to fix both legs to the plinth.

- **Evaluation:** Observe movement quality and range standing lateral to the Athlete.

- **Score 2:** Athlete stays in upright position and rotates 20° or more to both sides, measured in straight line between both shoulders and line between ASIS on both sides. Classifier sits in front of athlete to observe if the athlete rotates below the waist and palpate the ASIS to make sure that the trunk rotation also includes rotation of the pelvis.

- **Score 1:** Athlete rotates mainly with the upper trunk less than 20°, or cannot remain upright whilst rotating. Athletes might need pelvis stabilization from the classifier.

- **Score 0:** Athlete does not rotate, or cannot maintain upright position while rotating (e.g. assumes kyphotic posture) even whilst receiving pelvis support.

Trunk test guidelines for Paracanoe
Dynamic test - kayak
Active Trunk Side Flexion

- **Description:** Athlete sits on the plinth with legs hanging over edge, with the feet unsupported. Athlete crosses the arms in front of his/her chest, to prevent support for sitting balance from the arms. The classifier may need to place his/her hands close to the hips, to fix both legs to the plinth.

- **Evaluation:** Observe movement quality and range standing in front of the athlete.

- **Score 2:** Athlete stays in upright position and performs **side flexion** at least with suprasternal notch in vertical line above the ASIS to both sides and can maintain this position for 2 seconds before resuming the upright position.

- **Score 1:** Athlete cannot side flex to the level of the suprasternal notch, or can only maintain position momentarily.

- **Score 0:** Athlete cannot side flex, or cannot maintain an upright position while performing side flexion (e.g. kyphotic posture).
Dynamic test – va’a

Active Trunk Side Shift

- **Description:** Athlete sits on the plinth with legs hanging over edge, with the feet unsupported. Athlete crosses the arms in front of his/her chest, to prevent support for sitting balance from the arms. The classifier may need to place his/her hands close to the hips, to fix both legs to the plinth.

- **Evaluation:** Observe movement quality and range standing in front of the athlete.

- **Score 2:** Athlete stays in upright position and performs side shift with suprasternal notch in vertical line above the ASIS to both sides and can maintain this position for 2 seconds before resuming the upright position.

- **Score 1:** Athlete cannot side shift to the level of the suprasternal notch, or can only maintain position momentarily.

- **Score 0:** Athlete cannot side shift, or cannot maintain an upright position while performing side shift (e.g. kyphotic posture).
**Trunk Resistance**

- Trunk Flexion, Trunk Extension, Trunk Rotation, Trunk Side Flexion

**Description:** Athlete sits on the plinth with legs hanging over the edge, with the feet unsupported. Athlete crosses the arms in front of his/her chest, to prevent support for sitting balance from the arms.

Classifier applies prolonged force to the trunk in six directions by placing the hand in six different locations; anterior, over the mid sternum, posterior, over the thoracic spine midway between the superior and inferior angles of the scapula, and right and left rotation, over the frontal aspect of the acromial process, and right and left side flex, over the lateral aspect of the acromial process.

**Instruction:** “Hold, do not let me push you over!”

**Evaluation:**
- **Trunk flexion:** RA, both sides of umbilicus
- **Trunk extension:** ES, both sides spine
- **Trunk rotation to the L:** OE R and OI L
- **Trunk rotation to the R:** OE L and OI R
- **Trunk lat. bending to the L:** QL R
- **Trunk lat. bending to the R:** QL L

**Score 2:** Athlete is able to adequately resist the constant force to the trunk.

**Score 1:** Athlete resists the initial push but is unable to maintain upright posture, or can only resist a very gentle force

**Score 0:** Athlete is not able to recover from the constant force.
Trunk Perturbation
- Trunk Flexion, Trunk Extension, Trunk Rotation, Trunk Side Flexion

- **Description:** Athlete sitting on the plinth with legs hanging over edge of plinth with the feet unsupported. Athlete crosses the arms in front of his/her chest, to prevent support for sitting balance from the arms.
  Classifier applies an unexpected/sharp force to the trunk in six directions by placing the hand in six different locations; anterior, over the mid sternum, posterior, over the thoracic spine midway between the superior and inferior angles of the scapula, and right and left rotation, over the frontal aspect of the acromial process, and right and left lateral, over the lateral aspect of the acromial process.

- **Instruction:** “Remain still when I’m trying to push you!”

- **Evaluation:** Trunk flexion: RA, both sides of umbilicus, Trunk extension: ES, both sides spine, Trunk rotation to the L: OE R and OI L, Trunk rotation to the R: OE L and OI R, Trunk lat. bending to the L: QL R, Trunk lat. bending to the R: QL L.

- **Score 2:** Athlete is able to adequately resist the trunk push.

- **Score 1:** Athlete attempts to resist the push, or can only resist a very gentle push.

- **Score 0:** Athlete is not able to apply any resistance to the push.

Trunk test guidelines for Paracanoe
All Dynamic and Perturbation tasks will be performed on the wobble cushion on a 3 graded scale.

Succeed = 2, In doubt = 1, Clearly fails = 0
EXTRA TESTS – trunk flexion

• Trunk flexion between 0 and 1 - raise arms with shoulder flexion in 90° and elbows extended and push against classifiers arms. Classifier palpates if there is activity in the Rectus Abdominis.

EXTRA TEST – trunk rotation

• Trunk rotation between 0 and 1 - raise arm with shoulder flexion in 90° and elbows extended and push against classifiers arms. Classifier palpates External Oblique.
EXTRA TEST – Trunk extension

• Trunk extension between 0 and 1 - athlete lifts head and classifier provides resistance to neck extension and palpates Erector Spinae to confirm activation in muscles. To further confirm if there is activity, ask athlete to extend shoulders and palpate erector spinae and latisimus dorsi to feel for contraction. Watch for lifting of the pelvis as this indicates some active hip flexors.
Guidelines for the Leg test
for Para-va’a Athletes

Information

Please note that the purpose of the pictures is to show the position of the athlete and classifier. The classifier’s job is to assess function and not position, the scores may therefore be different during a classification even though the position is similar to what is shown in the manual.
Equipment

• Treatment bench with adjustable height
• Goniometer (if athlete has limited range of motion, the range of motion has to be measured and recorded on the scoring sheet)
• Protocol

Leg test guidelines for Paracanoe

Hip flexion

• **Position of Athlete:** the athlete lies in supine, with the hip flexed to 60° and lower leg supported by classifier
• **Position of Classifier:** place a hand above the athlete’s knee to give resistance. The lower leg can be supported under the calf if needed
• **Test:** the athlete should pull to flex the hip from 60° to 100°
• **Instruction:** “pull your thigh against my hand”
• **Grade 2:** the athlete can overcome resistance and flex the hip
• **Grade 1:** the athlete can flex the hip without resistance. If the athlete cannot perform the test in supine, reposition the athlete into sidelying and repeat the test with gravity eliminated.
• **Grade 0:** the athlete can’t perform the movement
Hip extension

- **Position of Athlete**: the athlete lies in supine, with the hip flexed to 100° and lower leg supported by classifier
- **Position of Classifier**: place a hand below the athlete’s knee to give resistance and one hand under the calf for support
- **Test**: the athlete should push to extend the hip from 100° to 60°
- **Instruction**: “push your thigh against my hand”
- **Grade 2**: the athlete can overcome resistance and extend the hip
- **Grade 1**: the athlete can extend the hip without resistance. If the athlete cannot perform the test in supine, reposition the athlete into sidelying and repeat the test with gravity eliminated.
- **Grade 0**: the athlete can’t perform the movement

Knee flexion

- **Position of Athlete**: the athlete sits with the knee flexed to 20°. The athlete can hold on to the supporting surface to stabilize themselves. Some athletes may need support from a coach to maintain the seated posture
- **Position of Classifier**: position one hand behind the athlete’s ankle to give resistance and the athlete’s thigh should be supported by the classifier’s forearm
- **Test**: the athlete should pull to flex the knee from 20° to 60°
- **Instruction**: “bend your knee”
- **Grade 2**: the athlete can overcome resistance and flex the knee.
- **Grade 1**: to test the function against gravity, reposition the athlete into prone position and ask the athlete to flex the knee. If the athlete cannot perform the test in prone position, reposition the athlete into sidelying and repeat the test with gravity eliminated.
- **Grade 0**: the athlete can’t perform the movement
Knee extension

- **Position of Athlete:** the athlete sits with the knee flexed to 60°. The athlete can hold on to the supporting surface to stabilize themselves. Some athletes may need support from a coach to maintain the seated posture.
- **Position of Classifier:** position one hand behind the athlete's ankle to give resistance and the athlete's thigh should be supported by the classifier's forearm.
- **Test:** the athlete should push from 60° to 20°.
- **Instruction:** “straighten your knee”
- **Grade 2:** the athlete can overcome resistance and extend the knee.
- **Grade 1:** the athlete can extend the knee without resistance. If the athlete cannot perform the test in seated position, reposition the athlete into sidelying and repeat the test with gravity eliminated.
- **Grade 0:** the athlete can’t perform the movement.

Plantarflexion

- **Position of Athlete:** the athlete lies in supine, with the knees and hips extended and with the ankles positioned over the end of the bench. The feet are in plantarflexion (10°).
- **Position of Classifier:** One hand is placed under the sole of the forefoot and the other is placed around the heel.
- **Test:** the athlete should push from 10° plantarflexion to 45° plantarflexion. The classifier must take care to observe that the plantarflexion is taking place at the ankle, NOT the forefoot.
- **Instruction:** “point your foot down towards me”
- **Grade 2:** the athlete can overcome resistance and plantarflex the foot. If the classifier is unsure whether the athlete scores 2, the classifier can ask the athlete to stand up on one leg and push up to tiptoes.
- **Grade 1:** the athlete can plantarflex the foot without resistance. If the athlete cannot perform the test in supine position, reposition the athlete into sidelying and repeat the test with gravity eliminated.
- **Grade 0:** the athlete can’t perform the movement.
## Dorsiflexion

- **Position of Athlete:** the athlete lies in supine, with the knee and hip extended and with the ankles positioned over the end of the bench. The feet are in a plantarflexed position (45°)
- **Position of Classifier:** the classifier’s hand is placed over the front of the foot
- **Test:** the athlete should pull the foot from 45° plantarflexion to 10° plantarflexion. Make sure that the movement is performed without supination or pronation
- **Instruction:** “pull your foot up”
- **Grade 2:** the athlete can overcome resistance to dorsiflex the foot
- **Grade 1:** the athlete can dorsiflex the foot without resistance. If the athlete cannot perform the test in supine position, reposition the athlete into sidelying and repeat the test with gravity eliminated
- **Grade 0:** the athlete can’t perform the movement

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## Leg press

- **Position of Athlete:** athlete sits over the edge of the bench with one leg with hip and knee flexed supported by the classifier. The athlete can hold on to the supporting surface to stabilize themselves. Some athletes may need support from a coach to maintain the seated posture
- **Position of Classifier:** the classifier half kneels in front of the athlete to resist and control direction of movement. The classifier supports the athlete’s foot around the heel and under the knee
- **Test:** the athlete should push to extend the hip from 100° and the knee from 60° downwards
- **Instruction:** “push down against my hands to straighten your leg”
- **Grade 2:** the athlete can overcome resistance and extend the hip and knee
- **Grade 1:** the athlete can extend the hip and knee without resistance
- **Grade 0:** the athlete cannot perform the movement
When range of motion is the limiting factor

- Score 2: If strength is 2 and range of motion is more than 50 % of the sport specific range.
- Score 1: If strength is 2 or 1 and range of motion is less than 50 % of the sport specific range.
- Score 0: If strength is 2 or 1 and range of motion is outside the sport specific range.

Leg amputation

**Hip flexion/extension:**
Score 0: the athlete has a hip disarticulation or hemipelvectomy.
Score 1 and 2: use the same scoring system as for the hip flexion/extension tests if the athlete has an above knee amputation regardless of the length of the residual limb.

**Knee flexion/extension:**
Score 0: the athlete has a through knee amputation or there is no active movement in the residual limb.
Score 1 and 2: if the athlete has a below knee amputation and have an intact tibial tubercle, the knee flexion/extension can be scored 1 or 2 depending on the function. If the amputation affects the tibial tubercle, but the extensor muscle is inserted to some point on the remaining residual limb, the function can be scored 1.

**Plantar flexion/ dorsiflexion**
Score 0: the athlete has a tarsal level amputation.
Score 1 and 2: the athlete has a metatarsal amputation or below.

**Leg press:**
Score 0: the athlete has an above knee amputation, regardless of wearing a prosthesis or not.
Score 1: the athlete has a through or below knee amputation and can perform the movement without resistance.
Score 2: the athlete has a below knee amputation, regardless of wearing the prosthesis or not.
Guidelines for the On-water test
for Paracanoe Athletes

Introduction

- The on-water technical assessment is conducted to assess the sport specific performance of the paddler.
- The on-water technical assessment must be conducted in the type and model of boat that will be used by the athlete and with the specific adaptive equipment to be used during the competition.
- The classifiers have the responsibility to ensure that the conditions (e.g. weather, the availability of the on-water classification area) allow the athlete to perform at their full capacity. The classifiers may adapt or postpone the on-water test if the conditions inhibits the athletes to perform at their fullest.
- The classifiers have to ensure that the classification follow the safety standards (e.g. a safety boat should always be present).
### Equipment

**Classifiers’ equipment**
- Video camera (filming from the dock, we suggest using a tripod)
- Action camera (can be attached on the front of the cockpit)
- Scoring sheet
- Athlete’s equipment passport
- Tape measure
- Stop watch
- Table of paddling times

**Athletes’ equipment**
- Boat used during competition
- Adaptive equipment positioned at the same place as during competition
- Tight and light/bright coloured clothing

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### On-water pre-test procedure

- After the medical assessment the classifiers explain the on-water procedure and inform that the athlete should wear appropriate clothing and can only have one person (and one translator) at the dock except during transferring into and out of the boat.
- Classification should occur at a dock/pontoon that is restricted for classification purposes.
- On the dock the classifiers verify that the boat and the adaptive equipment matches the equipment passport.
- Spray decks shall not be permitted during on-water tests.
- The classifiers film the athlete when transferring into the boat.
- The classifiers ask the athlete to warm up.
**Considerations during the test**

- Adaptations ought to optimize functional ability not restrict it.
- Medical classifiers video the athlete so that the technical classifier can instruct and observe.
- Make sure the quality of the videos will be good (eg. lighting should not impact the quality of the video).
- Inform the athlete that maximal performance is required. If the classifier observes that the athlete is not performing maximally the athlete will be requested to repeat the test until maximal performance is achieved or the classification will be stopped. (*see Appendix 1: Time Factor Guidelines*)
- The athlete should be loudly encouraged throughout the tests to perform maximally.

**Procedure**

- After the warm up the athlete paddles to the classifier for instruction
- The athlete paddles to buoy 1
- TEST 1: From buoy 1 the athlete performs a maximal start and paddles at maximum speed to buoy 2
  - 2 min rest
  - TEST 2: From buoy 2 the athlete performs a maximal start and paddles at maximum speed to buoy 1
  - 2 min rest, return to classifier
  - TEST 3: From the dock the athlete performs a maximal start and paddles at maximum speed to buoy 3
  - 2 min rest, return to classifier
  - TEST 4: From the dock the athlete performs a maximal start and paddles at maximum speed to buoy 4
  - 2 min rest, return to classifier
  - TEST 5: From the dock the athlete performs a maximal start and paddles at maximum speed to buoy 5
  - 2 min rest
  - TEST 6: From buoy 5 the athlete performs a maximal start and paddles at maximum speed to the dock
Considerations after the test

• The on-water technical assessment shall take into consideration the medical assessment which is conducted prior to the technical assessment.
• Scoring between the medical and technical tests should be consistent, if not classifiers are encouraged to re-do tests.

Va’a On-water scoring
Leg movement score 2
Athlete has the ability to dynamically flex and extend the knee joint of one leg.

Leg movement score 1
Athlete has the ability to partially move one leg dynamically.
**Leg movement score 0**

The athlete has passive, involuntary or no leg movement.

*Note: Athletes may use adaptations and strapping to prevent involuntary movements of impaired limbs or non-functioning residual limbs to aid stability in the boat.*

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**Trunk rotation score 2**

Athlete has the ability to fully rotate their trunk through all the phases of the canoe stroke (catch, power and recovery). The athlete has the ability to produce coordinated movement of the pelvis and hips with the trunk, which increases the movement, and therefore, the stroke range.

*Note: Athletes may use adaptations which improve connection to the boat, but which limit the movement at pelvis and hips.*
Trunk rotation score 1

Athlete has the ability to partially rotate the trunk by using their upper trunk only (thoracic region) in all phases of the canoe stroke (catch, power and recovery). The athlete is unable to use the pelvis and hips to produce maximum rotation.

Note: Pay attention if the observed function is coming from the shoulders and scapulae or from the trunk. If unsure, discuss with medical classifier.
Athlete may use some modification to stabilize their lower trunk (lumbar spine)

Trunk rotation score 0

Athlete is not able to achieve trunk rotation and only uses arms and shoulders in all phases of the canoe stroke (catch, power and recovery)

Note: Pay attention if the observed function is coming from the shoulders and scapulae or from the trunk. If unsure, discuss with medical classifier.
Athlete may use adaptation to stabilize their trunk at the pelvis and use an adapted seat required for support into the thoracic region of the spine.
Trunk flexion score 2

The athlete can actively lean forward with the trunk and dynamically move his/her trunk during each paddle stroke.

*Note: Athlete usually does not require adaptation*

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Trunk flexion score 1

Athlete may be able to partially flex the trunk, but should not be able to actively lean forwards using anterior tilt of the pelvis or flexion at the hips.

*Note: Pay attention if the observed function is coming from the shoulders and scapulae or from the trunk. If unsure, discuss with medical classifier.

*Athlete may use some adaptation to stabilize their lower trunk (lumbar spine)*
Trunk flexion score 0

Athlete does not show any trunk movement, the only active movement seen is at the shoulders and scapulae. (The trunk can be vertical, c-shaped, or forwards depending on how the adaptive equipment is being used to support them).

*Note: Pay attention if the observed function is coming from the shoulders and scapulae or from the trunk. If unsure, discuss with medical classifier. Athlete may use adaptation to stabilize their trunk at the pelvis and use an adapted seat required for support into the thoracic region of the spine.*

### Consistency Checklist

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trunk rotation</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>VL1</td>
<td>✓</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>VL2</td>
<td>×</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>VL3</td>
<td>×</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Trunk flexion</td>
<td>✓</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>VL1</td>
<td>✓</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>VL2</td>
<td>✓</td>
<td>✓</td>
<td>×</td>
</tr>
<tr>
<td>VL3</td>
<td>×</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Leg movement</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>VL1</td>
<td>✓</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>VL2</td>
<td>✓</td>
<td>✓</td>
<td>×</td>
</tr>
<tr>
<td>VL3</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

* × = warning, check with medical*
EXTRA TESTS

• You may want to assess the athlete’s paddle and functional ability further by:
  • Have the athlete paddle backwards
  • Have the athlete attempt to shoot their boat after accelerating
  • Have the athlete use their paddle to stop suddenly after accelerating
  • Have the athlete draw water on both sides
  • Have the athlete hold their paddle parallel to the water and rotate
  • Have the athlete turn the boat in a tight/small area
  • Observe the athlete informally for transfers; required support

APPENDIX 1

<table>
<thead>
<tr>
<th>EVENT</th>
<th>20m Time</th>
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<tbody>
<tr>
<td>KL1 W</td>
<td>6.96 secs</td>
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<tr>
<td>KL2 W</td>
<td>6.15</td>
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<tr>
<td>KL3 W</td>
<td>6.14</td>
</tr>
<tr>
<td>VL1 W</td>
<td>10.14</td>
</tr>
<tr>
<td>VL2 W</td>
<td>7.60</td>
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<tr>
<td>VL3 W</td>
<td>7.66</td>
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<tr>
<td>KL1 M</td>
<td>5.71</td>
</tr>
<tr>
<td>KL2 M</td>
<td>5.10</td>
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<tr>
<td>KL3 M</td>
<td>4.78</td>
</tr>
<tr>
<td>VL1 M</td>
<td>6.00</td>
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<tr>
<td>VL2 M</td>
<td>6.34</td>
</tr>
<tr>
<td>VL3M</td>
<td>5.98</td>
</tr>
</tbody>
</table>

**Time Factor Guidelines for 20 meters**
These are guidelines to assess athletes’ giving maximum effort. They are established as 120% of the average times of 2017 World Final results for 1st and 3rd place. Slower times will be a result of either a non-high performance paddler or a low level of effort.