The aim of classification in Paralympic sport is to minimize the impact of impairment on the outcome of competition. The aim of this thesis was to investigate the impact of different types of impairments on para-cycling performance to develop an evidence-based classification system in the para-cycling C (bicycling) and T (tricycling) divisions.

This thesis is based on four articles. The first article examined differences in race performance between para-cycling classes by comparing track race results. The second article evaluated leg strength measures and the association with para-cycling performance in para-cyclists with musculoskeletal impairments. The third article investigated leg coordination and leg strength and the association with para-cycling performance in para-cyclists with hypertonia, ataxia, or athetosis. The fourth article aimed to gather consensus on para-cycling classification issues and to identify research priorities within para-cycling, by consulting a panel with expertise within para-cycling and para-sport.

This thesis has identified performance characteristics in para-cyclists with musculoskeletal and coordination impairments, and suggested tests with potential to be used in para-cycling classification to assess muscle strength and coordination. The results indicate that the classes for athletes with the least impairments, as well as the classes for athletes with impaired coordination, need to be further investigated.

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TOWARDS EVIDENCE–BASED CLASSIFICATION IN PARA–CYCLING
Towards evidence–based classification in para–cycling

Johanna Liljedahl
Thank you to all athletes, team managers, and coaches that have participated in and supported this project.
Abstract

Para–sports are performed by athletes with impairments that impact sports performance. To achieve fair competition, the classification process allocates athletes to different sport classes based on the impairment’s impact on sport performance. To ensure that success is achieved by the athletes with the most favorable combination of physiological and psychological traits, as opposed to the athletes with the least impairment, the aim of classification in para–sports is to minimize the impact of impairment on the outcome of competition. The International Paralympic Committee (IPC) requires all para–sports that are part of the Paralympic movement to provide evidence–based classification systems.

In para–cycling, athletes compete in four different divisions (bicycling, tricycling, handcycling, or tandem) depending on impairment. This thesis will focus on classes C1–C5 in the C (bicycling) division, and classes T1–T2 in the T (tricycling) division. The para–cycling classification system has not been scientifically scrutinized to ensure compliance with the requirements of the IPC. Therefore, the aim of this thesis was to investigate the impact of different types of impairments on para–cycling performance, in order to provide knowledge for the development of the classification system in the para–cycling C and T–divisions.

Study I investigated differences in performance in the C–division. The top five track race results of the men’s C1–C5 classes were obtained from major para–cycling events between 2011 and 2018. Corresponding data of non–impaired track cyclists were used for reference. The results showed that para–cyclists in C5 reached 90% of the race speed of non–impaired cyclists, indicating that cycling performance was hindered by impairments. The least impaired classes C4 and C5 did not differ in race speed, indicating that the current class cut–off between C4 and C5 needs to be reevaluated.

For Study II, data of 56 para–cyclists were collected to evaluate leg strength measures in athletes with musculoskeletal impairments competing in the C–division. Data of leg muscle strength, cycling sprint power, and race speed were collected. The results showed that the currently used Manual Muscle Test (MMT) to assess leg muscle strength in classification was associated with isometric and dynamic leg muscle strength. Furthermore, the isometric and dynamic leg muscle strength tests were correlated with each other and associated with cycling sprint power and race speed. The results indicate that leg muscle strength is important for para–cycling performance in
this group of athletes, and that MMT, but also the isometric and dynamic strength tests, have potential be used in classification to assess muscle strength.

Study III investigated data of 29 para–cyclists with coordination impairments (CI) (hypertonia, ataxia, and/or athetosis) competing in the C and T–divisions. Data of twelve para–cyclists without leg impairments were used for reference. Data of leg coordination, leg muscle strength, cycling sprint power, and race speed were collected. The results showed that athletes with CI performed less taps in a tapping test and less isometric strength compared to athletes without leg impairments. Leg coordination and leg muscle strength were associated with cycling sprint power but not with race speed, indicating that additional factors determine race speed in athletes with CI. When comparing classes, the most impaired athletes in T1 performed lower results in a cadence test and less cycling sprint power compared to athletes in the less impaired classes T2, C1/C2, and C3/C4. The results indicate that athletes in T1 distinguish themselves from athletes in the less impaired classes and that the cadence test has potential to be used in classification to assess leg coordination. Additionally, there was no difference in performance in leg coordination, isometric and dynamic leg muscle strength, or cycling sprint power between classes T2, C1/C2, and C3/C4, which indicates that these athletes may be able to compete on similar terms and that a reevaluation of these classes might be needed.

Study IV was a Delphi study which investigated current issues in para–cycling classification with three rounds of questionnaires being sent out to a chosen panel of persons with experience in para–cycling or in para–sport. The aim of Study IV was to reach consensus on para–cycling classification issues in order to guide the development of the current classification system, and to prioritize future para–cycling research. The results presented agreement in the panel that the current manual muscle test to assess muscle strength in classification should be simplified into a 0–2 points scale compared to the current 0–5 points scale, that athletes riding the bicycle with only one leg should compete separately from athletes riding with two legs as opposed to current practice, and that athletes with coordination impairments should compete separately from athletes with musculoskeletal impairments as opposed to current practice. According to the results of the Delphi study, future research should prioritize the minimum impairment criteria to be eligible to compete in para–cycling, as well as define the cut–off between the C and T–divisions for athletes with coordination impairments.

This thesis has identified performance characteristics of para–cyclists with musculoskeletal or coordination impairments, and suggested tests with potential to assess strength and coordination in para–cycling classification. The results of this thesis imply that the cut–offs between the least impaired C–division classes and the least impaired classes consisting of athletes with coordination impairments need to be further investigated.

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Abbreviations

AK Above knee
BK Below knee
C1 Bicycling class 1 (most impaired)
C2 Bicycling class 2
C3 Bicycling class 3
C4 Bicycling class 4
C5 Bicycling class 5 (least impaired)
CI Coordination impairment
CP Cerebral palsy
IPC International Paralympic Committee
MIC Minimum Impairment Criteria
MMT Manual Muscle Test
PROM Passive Range of Movement
T1 Tricycling class 1 (most impaired)
T2 Tricycling class 2 (least impaired)
UCI Union Cycliste Internationale (International Cycling Federation)
1 Introduction

Para–sports are performed by athletes with physical, visual, or intellectual impairments. The concept of para–sport has its origins in England in 1948 when a competition for wheelchair athletes was organized. The International Paralympic Committee (IPC) was founded in 1989 and the movement has grown to include 28 sports which are part of the Paralympic summer and winter games.

According to IPC, the aim of para–sport is to enable para–athletes to achieve sporting excellence. To ensure fair competition, the impairments of para–athletes are assessed in the classification process and athletes are allocated to different sport classes based on the impairment severity and the impairment’s impact on the sport in question. To be able to achieve this aim, the IPC requires all para–sports that are part of the Paralympic movement to provide evidence–based classification systems.

Para–cycling is performed by athletes with physical impairments that impact the cycling activity. Para–cycling consists of four disciplines (bicycling, tricycling, handcycling, and tandemcycling) and this thesis will focus on bicycling and tricycling. The C–division (bicycling) consists of classes C1–C5 of which C5 is the least impaired. The T–division (tricycling) consists of classes T1–T2 of which T2 is the least impaired. Athletes with musculoskeletal and coordination impairments compete in the C–division, while only athletes with coordination impairments compete in the T–division. The classification system in para–cycling is currently based on expert–opinion and has not been scientifically scrutinized.

The aim of this thesis was to investigate the impact of impairments eligible for the para–cycling C and T–divisions, in order to provide knowledge for the development of the para–cycling classification system. This was done by examining performance in the current classes, and by investigating the impact of impairments on key performance determinants of cycling and their association with cycling performance. Additionally, a Delphi study was performed to reach consensus on research–based para–cycling classification issues, and to guide future para–cycling research needs.
2 Background

2.1 Para–sport

The aim of para–sport is “to enable Para–Athletes to achieve sporting excellence and inspire and excite the world” (IPC; International Paralympic Committee, 2015). Para–athletes are athletes with physical, visual, or intellectual impairments that limit their ability to perform a sport activity when compared to non–impaired athletes. Impairments can be congenital or acquired.

The concept of para–sport has existed for around 100 years with the aim of rehabilitation and re–education of people with impairments. The Paralympic movement has its origins in England in 1948 when Dr Ludwig Guttmann, a German–British neurologist, established the Stokes Mandeville Games; a competition for wheelchair athletes. The first official Paralympic Games took place in Rome in 1960, in which eight different para–sporting events were included. In 1989, the IPC was founded in Germany and is currently the organization responsible for the Paralympic movement. The movement has grown to include 28 para–sports of which 22 are summer Paralympic sports and six are winter Paralympic sports.

2.2 Classification in para–sport

The classification systems used in para–sports aim to define who is eligible to compete and, by grouping athletes into sport classes, to minimize the impact of impairments on the outcome of competition (IPC, 2015). The classification system strives to ensure that success in para–sport is determined by the same factors as in sports for non–impaired athletes, i.e., the athlete with the most optimal set of physical and mental attributes reaches success.

All para–sports within the Paralympic Movement need to comply with the guidelines stated by the IPC, which is to ensure that the classification system in each sport is evidence–based (IPC, 2015). The term ‘evidence–based classification’ is defined as a classification system in which scientific evidence indicates that the methods used for assigning the classes will achieve the stated purpose (Tweedy and Vanlandewijck, 2011). Currently, the classification systems of several para–sports have developed out of expertise knowledge, and thus, have not been rooted in scientific evidence.

To conduct research in para–sport to develop sport–specific and evidence–based classification systems, a stepwise process was described by Tweedy and Vanlandewijck (2011) (Figure 1). The first step is to identify the sport and the impairment type(s) eligible for the sport to identify the impairment types that are to be classified. The second step is to develop models of determinants of performance to identify the key characteristics of sport performance. The third step is to develop measures of impairment for the impairments eligible for the sport, and to develop measures of sport performance. Measures of impairment must be impairment–specific and training–resistant (Tweedy & Vanlandewijck, 2011). That a measure is impairment–specific means that it assesses only the effect of one impairment type, i.e., the measure should not be impacted by other impairment types which the athlete might also have. Additionally, a measure should assess impairments that will have an impact on sport performance. Training–resistance means that the assessment methods should not be affected by the training status of the athlete, as it would disfavor well–trained athletes. The fourth step is to assess the relationship between impairment and sport performance, and the fifth step to determine the minimum impairment criteria and class profiles. After finishing the fifth step, the translational phase is started in which potential changes are implemented into the classification system and thereafter, the monitoring phase aims to periodically evaluate the classification system (Mann et al., 2021). If additional changes to the classification system are needed, the process starts again from the second step.

Classification in para–sport is multifaceted and several factors might affect classification outcomes. A valid classification system is dependent on educated classifiers that conduct the same assessments and make the same class allocation of an athlete in order to increase the reliability of classification. In classification, the communication between international athletes and classifiers might affect the assessment, as a common language is needed to make the correct observations of an athlete. Furthermore, athletes from different countries have different prerequisites for competing in terms of sports equipment and technical rules are needed in an attempt to make competitions fair for everyone. Additionally, for para–sport classification to work it is vital that athletes perform to the best of their efforts during the classification procedure.
2.3 Para–cycling

Para–cycling is one of the sports of the Paralympic Movement and is governed by the international cycling federation Union Cycliste Internationale (UCI) in conjunction with the IPC. Athletes with physical impairments that impact on the activity of cycling can compete in para–cycling. The impairment types that are eligible for para–cycling have been specified by IPC and include: impaired strength, impaired passive range of movement (PROM), limb deficiency, leg length difference, hypertonia, ataxia, athetosis, and visual impairments (IPC, 2015). Para–cycling covers four disciplines: bicycling, tricycling, handcycling, and tandem, of which the latter is for visually impaired athletes. This thesis will focus exclusively on the disciplines of bicycling and tricycling, which consist of athletes with physical impairments.

In the bicycling discipline (C–division), athletes compete on standard road or track bicycles. The bicycles may have adaptations to better fit the needs of the athletes, and are controlled by the technical regulations of para–cycling (UCI, 2022). The C–division covers five classes ranging from C1 to C5, of which C1 is the class for athletes with the greatest impairments. Athletes with impaired strength, impaired PROM, limb deficiency, leg length difference, hypertonia, ataxia, or athetosis are eligible to compete in the C–division.

The tricycling discipline (T–division) consists of classes T1 and T2 of which T1 is the class for athletes with the greatest impairments. Athletes with coordination impairments (CI) caused by hypertonia, ataxia, or athetosis are eligible to compete. In the T–division, athletes compete on a three–wheeled tricycle, hereafter referred to as a trike. Trikes are commonly made from standard road race bicycle frames that have been adjusted to fit two rear wheels instead of one. The trike offers increased stability for athletes with CI incapable of riding a two–wheeled bicycle because the impairment affects balance. Trikes used in para–cycling competition need to comply with the technical regulations of para–cycling (UCI, 2022).

2.4 Classification in para–cycling

The aim of para–cycling classification is to assess athlete impairments to allocate athletes to the correct sport class. Class allocation is determined by the severity of the impairment in order to facilitate fair competition in which athletes with the same level of activity limitation compete against each other. Thus, it is possible for athletes with different impairment types to compete in the same class. Para–sport classification is a
selective classification process in which specified characteristics (i.e., impairments) have been defined to constitute the classes (Tweedy & Vanlandewijck, 2011).

In classification, two certified classifiers (one medical and one technical) meet the athlete to conduct the classification assessments. Before the classification process can start, the impairment type needs to be eligible for para-cycling, and if so, the impairment impact on cycling is assessed to ensure that the minimum impairment criteria (MIC) are fulfilled. The MIC are set to ensure that the impairment affects the extent to which the athlete is able to execute the specific tasks required for cycling. The impairment type determines which tests are to be performed in classification. Thirdly, the impairment severity will determine which class the athlete will be allocated to.

An issue when classifying two or more impairment types that compete in the same classes, which is the case in the C-division, is that different assessment methods are used. In order to meaningfully compare the impairment types, knowledge of the relative importance of each impairment for cycling performance is required. For example, classifying athletes with different impairment types that compete against each other means that an athlete with impaired strength will be evaluated in relation to an athlete with impaired coordination, or that measures in different units are aggregated in the case of athletes with a combination of impairment types. In the para-cycling classification system, this issue has not been scientifically investigated.

2.4.1 Impaired muscle strength
Athletes with impaired muscle strength have a decreased ability to voluntarily activate certain muscles which can be caused by trauma to the body or by health conditions such as spinal cord injury or muscular dystrophy. Impaired muscle strength is assessed in classification with the clinical scale Manual Muscle Test (MMT) (Hislop & Montgomery, 2007) (Table 1). The MMT scale has not been validated for use in para-cycling classification. Muscle function is assessed on a 0–5 point scale, where 0 is absence of muscle function and 5 is full (normal) muscle function. The relevant muscle groups, determined by the impairment of the athlete, are tested, i.e., muscles that are or might be affected by the impairment. The MMT is performed within the ranges of movement specific to cycling which means that impaired muscle strength outside of the cycling-specific ranges of movement will not be eligible for para-cycling. After scoring the muscle groups on the 0–5 point scale, the scores are reversed into a 3–0 point scale where 3 is absence of muscle function, and 0 is full muscle function. The scores of 3–0 are thereafter multiplied with the “Factor of importance” that has been added to stress the relevance of certain muscle groups specific to cycling (Table 2). Classifiers may use additional assessments such as squats, heel-raises, or jumping in place to verify the result of the MMT.

<table>
<thead>
<tr>
<th>MMT score</th>
<th>Original description</th>
<th>Modified description for para-cycling classification</th>
<th>Classification score</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Total lack of voluntary contraction.</td>
<td>Total lack of voluntary contraction.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Faint contraction without any movement of the limb.</td>
<td>Faint contraction without any movement of the limb.</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>Contraction with very weak movement through full range of motion when gravity is eliminated.</td>
<td>Active movement against gravity but not through full available range/reference range of cycling.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Contraction with movement through full range of motion against gravity.</td>
<td>Active range of movement against gravity through the reference range with no added resistance OR active movement against gravity with some added resistance but not through full reference range of cycling.</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Contraction with movement through full range of motion against gravity and some resistance.</td>
<td>Active movement against gravity with slight to moderate (but not full) resistance through the reference range OR active movement against gravity with full resistance possible through only part of the reference range.</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>Contraction of normal muscle strength through full range of motion against full resistance.</td>
<td>Normal muscle power through the range of movement required for cycling.</td>
<td>0</td>
</tr>
</tbody>
</table>

The MIC for impaired muscle strength in the lower limbs is the inability to perform a one-legged heel-raise in one of the legs, or comparable strength impairments. The MIC for impaired muscle strength in the upper limbs is the inability to form and maintain a cylindrical grip similar to gripping the handlebars while riding a bicycle, or an activity limitation comparable to the inability to form a cylindrical grip.
2.4.2 Impaired passive range of movement (PROM)

PROM is a restriction in passive movements in one or more joints that are caused by joint contractures resulting from chronic joint immobilization or trauma affecting a joint. PROM is measured manually with a goniometer. The classifier moves the limb through the cycling specific ranges, and if the limb can be passively moved through the ranges, it will not be enough to be eligible for para-cycling. If the limb cannot be passively moved, e.g., because of a joint contracture, the movement will be scored on a 0–3 point scale depending on how much of the range can be moved through. Three points mean that there is a complete absence of movement and 0 points is full movement required for cycling. The assessment method of PROM has not been validated for use in para-cycling classification. The MIC for impaired PROM in the lower limbs is the same as for impaired muscle strength, i.e., the inability to perform a one-legged heel–raise as described in the second paragraph under 1.3.1. The MIC for impaired PROM in the upper body is full loss of grip in one hand, inability to form and maintain a cylindrical grasp, or no functional hand movement due to impaired PROM.

2.4.3 Limb deficiency

Limb deficiency is partial or total absence of bones or joints resulting from trauma, illness, or congenital limb deficiency. Limb deficiencies in para-cycling are most often limb amputations but can also be deformation of limbs where the limb is no longer functional. Both lower and upper body amputations can be eligible. Limb deficiencies are one of the most straightforward impairments to assess in classification as it is a matter of which joints are affected, and at what joint level the amputation is (e.g., below or above the knee, or below or above the elbow). The length of the residual limb is measured with a tape measure. The MIC in the lower body is amputation through the foot at metatarsal level and the MIC in the upper body is amputation through the hand at metacarpal level.

2.4.4 Leg length difference

Leg length difference is the result of disturbance of limb growth or trauma. Leg length difference is assessed by measuring both legs with a tape measure, and a difference in leg length of 7 cm or more will pass as an eligible impairment. Consequently, the MIC for leg length difference is a minimum of 7 cm difference.

2.4.5 Hypertonia, ataxia, and athetosis

In classification, CI is assessed with different clinical scales in addition to neurological assessments and assessment of the athlete’s functionality on the bicycle/trike. To compete in the T-division, the coordination impairment must cause activity limitation severe enough to make the athlete “unable to ride a bicycle due to lack of balance and/or severe restriction in pedaling due to spasticity, ataxia, athetosis, or dystonia” (UCI, 2022). The scales used in classification to assess CI are clinical scales to assess function which have not been validated for use in classification. No clear cut-off score or exact definitions have been written regarding the assessments of CI, and the scales are mainly used in classification for guidance.

Hypertonia is an increase in muscle tension causing a reduced ability to stretch the muscle. It is caused by damage to the central nervous systems and health conditions that can cause hypertonia and be eligible for para-cycling are cerebral palsy, traumatic injury, and stroke. Hypertonia is assessed with the Australian Spasticity Scale which is used to assess muscle "catches" when the tester is rapidly moving the affected limbs. The MIC for hypertonia is spasticity grade 1 or more in one lower or upper limb, clear neuromuscular signs to include a positive Hoffman or Babinski test, noticeably brisk reflexes or clear differences in reflexes left versus right.

Ataxia is uncoordinated movement that affects control of voluntary movements and is caused by damage to the central nervous system. Examples of health conditions that can cause ataxia and be eligible for para-cycling are cerebral palsy, traumatic brain injury, stroke, and multiple sclerosis. In classification, ataxia is assessed using the Scale for the Assessment and Rating of Ataxia. The MIC for ataxia is occasional and mild or subtle signs of ataxia.

Athetosis is continual and slow involuntary movements caused by involuntary muscle contractions. Underlying health conditions that can cause athetosis and are eligible for para-cycling are cerebral palsy, traumatic brain injury, and stroke. Furthermore, athetosis must be evident in abnormal posturing and present at rest and in activity. Athetosis is
assessed in classification using a modification of the clinical scale Dyskinesia Impairment Scale. The MIC for athetosis is occasional signs of athetosis with mild or subtle intensity of posturing or amplitude of movement.

2.5 Research in cycling and para–cycling

Leg muscle strength is one of the most important determinants for success in cycling (Raymond et al., 2005), and muscle volume and muscle coordination are also factors that will determine individual success in cycling (Blake & Wakeling, 2012; Kordi et al., 2019).

Muscle volume, specifically the thigh cross–sectional area, is directly related to sprint cycling peak power output (Kordi et al., 2019), and peak power output is correlated with average power output during prolonged (90 minutes) cycling exercise (Bentley et al., 2001). Therefore, maintaining high power output over time is an important determinant of cycling performance. The distributed power produced by the hip, knee, and ankle joint during pedaling have been described to be 40%, 40%, and 15%, respectively (Elmer et al., 2011). Cycling performance will likely be decreased in para–cyclists with impaired leg muscle strength (and consequently decreased leg muscle volume) or leg amputation compared to non–impaired cyclists. To date, no studies have evaluated the differences in muscle strength in impaired and non–impaired cyclists, which stresses the importance of studying performance characteristics in para–cyclists.

The impact of the upper body (trunk and arms) has been researched to a lesser extent compared to the lower body (legs). One study has indicated that 5% of the power during cycling comes from the involvement of the upper body (Elmer et al., 2011). The upper body also contributes to cycling standing out of the saddle, e.g., when sprinting and climbing (Chen et al., 2016; Costes et al., 2016; Duc et al., 2008; Turpin et al., 2017). Additionally, Baker and Davis (2009) compared ergometer cycling with and without hand–grip function and showed a significant difference in peak power output when the participants performed the sprint test without a hand–grip, as well as a significant correlation between peak power output and grip strength. As there is limited research describing the effect of the upper body on cycling, it remains difficult to conclude the effect of upper body impairments on cycling. However, based on the studies that have been conducted, the cycling technique and power output are influenced by the upper body and therefore, the impact of upper body impairments on cycling performance need to be determined to develop the para–cycling classification system.

Muscle coordination refers to the ability to apply forces to the pedals as well as the interaction between agonist and antagonist muscles and the interaction between the upper and lower body. Although applicable to all para–cyclists, para–cyclists with CI in particular are disadvantaged by impaired muscle coordination. Research in competitive para–cyclists with CI is lacking, however, research in cycling has been conducted in other populations with health conditions that affect coordination. Lauer et al. (2008) showed that leg kinematics measured with electromyography during recumbent cycling differed between adolescents with and without cerebral palsy (CP). In general, persons with CP presented increased leg muscle frequency and earlier muscle activation onset and later muscle activation offset, compared to persons without CP. Similar findings have been observed in another study in adolescents with CP in which co–contraction of agonist and antagonist muscles were seen during recumbent cycling (Johnston et al., 2007). It is reasonable to believe that the abilities to apply only positive forces to the pedals and to recruit the required muscle groups are decreased also in well–trained para–cyclists with coordination impairments. However, CI can be congenital (by birth) or acquired (by trauma) and it has not been established whether the activity of cycling and thus, cycling performance is affected differently depending on if the athlete has a congenital or acquired brain injury. Research is warranted to investigate the impact of different types of coordination impairments on cycling.

Research has shown that cycling can be used for rehabilitation purposes in persons with health conditions such as spinal cord injury (van der Scheer et al., 2021), muscular dystrophy (Sveen et al., 2008), Charcot–Marie–Tooth disease (El Mhandi et al., 2008), and CP (Armstrong et al., 2019). However, research on the impact of health conditions on competitive cycling is limited and have mostly been conducted in persons with leg amputations (Childers et al., 2011a, 2011b, 2014; Dyer, 2016a; Koutney et al., 2013; Watanabe et al., 2020), of which two studies have been literature reviews (Dyer, 2016b; Poonsiri et al., 2018). Several of these studies are case studies or studies with few participants (Dyer, 2016; Koutney et al., 2013; Watanabe et al., 2020). Only two studies have been conducted in elite para–cyclists with CI: sprint cycling performance and neuromuscular characteristics in five para–cyclists with CP (Runciman et al., 2014), and a case study on torque production (Brickley & Gregson, 2011). A few studies have been conducted in para–cycling race performance (Borg et al., 2021; Dyer, 2018; Noojien et al., 2021; Wright, 2016). Borg et al. (2021) showed that each consecutive class in the men’s road races significantly differed in race speed, while in women, a difference in race speed was only found between C1 and C2 and between C3 and C4. Regarding the T–division, both men’s and women’s race speeds differed significantly between T1 and T2 (Borg et al., 2021). Noojien et al. (2021) showed that sprint power is a determinant of race performance in the C and T–divisions. Dyer et al. (2018) showed that in C4, athletes with or without lower leg prosthetics did not significantly differentiate in race speed in a 1 km track time trial. Wright (2016) described pacing strategies of C1–C3 in track time trials, which were similar to pacing strategies of non–impaired cyclists. Wright (2016) also showed that athletes in C2 more often tend
to have the slowest split time in the beginning of the races which could possibly be explained by C2 comprising athletes with above knee amputations who cannot stand out of the saddle to accelerate from a stand-still start.

Currently, very little is known about the impact of different impairments on fundamental activities in cycling. Research in para–cyclists is vital to understand the impact of impairments on cycling performance and consequently, the development of an evidence–based and fair classification system. No research has been conducted to evaluate the validity of any of the tests used in para–cycling classification. Therefore, the assessment used in classification is prone to subjectivity and inconsistency.

Isometric strength measures have been recommended for the purpose of assessing strength in para–sport classification, as it has been suggested to be the most training–resistant strength measures (Beckman et al., 2017). However, to conduct sport–specific and easily administered in–field tests, as classification is often performed at the race venues in conjunction to a competition, a dynamic bicycle test is also of interest to para–cycling classification. Additionally, the dynamic tests can be compared to the recommended isometric tests to investigate the relationship between different strength measures.

Para–sport classification research has often conducted open–chain coordination tests to measure coordination in athletes with CI (Maia et al., 2021; Hogarth et al., 2018; Connick et al., 2015). The tests are usually performed by instructing the participants to tap as fast as possible while maintaining accuracy. As cycling performance is partly determined by the ability to coordinate leg movement patterns (Chapman et al., 2009; Raymond et al., 2005), it appears motivated to conduct these tests in para–cyclists with impaired coordination in order to investigate the reliability of such tests. However, cycling is a closed–chain activity as the athlete is connected to the bicycle by the feet, seat, and hands and therefore, it is possible that coordination assessments for the purpose of classification in para–cycling should be assessed with closed–chain tasks.

When performing classification research, measures of impairments need to be investigated in relation to sports performance (Tweedy & Vanlandewijck, 2011). By correlating coordination and strength measures with cycling performance measures, the impact of each impairment measure on cycling performance can be identified. This in turn will assist in explaining the variance in performance.

2.6 The development of evidence–based classification in para–cycling

In 2017, UCI reached out to two research schools to investigate evidence–based classification in para–cycling. The Swedish School of Sport and Health Sciences (GIH) was recruited to conduct the research in the cycling and trike disciplines and the Vrije Universiteit Amsterdam (VU) was recruited to conduct the research in hand cycling. The aim of the research was to develop a new classification system in para–cycling. As the current para–cycling classification system has not been researched to use valid assessment methods for para–cycling classification, the focus of the research was to develop a new, evidence–based classification system rather than improving the current one.

The collaboration between the two schools has been close throughout the four years of researching, for example, the visits at para–cycling events to collect data were conducted together with research teams from both schools. Additionally, UCI, GIH, and VU have met annually to follow up the research as well as plan ahead. An advice report that summarizes the research conducted to date was sent to UCI in 2022 to allow UCI to begin revising the current para–cycling classification system. The deadline for finishing the initial steps of the para–cycling research has been set to just before the Paralympic Games in 2024. The implementation of a new classification system includes education of the classifiers in para–cycling, re–classification of athletes, and providing information about the new system to athletes and the national federations. The deadline will allow UCI to implement any major changes to the para–cycling classification system after the Paralympic Games in 2024, to provide a revised classification system for the Paralympic Games in 2028.
3 Aims

This thesis was written as part of a larger, UCI–supported project for the development of the para–cycling classification system into an evidence–based system. The overall aim of the thesis was to provide evidence for the development of an evidence–based classification system in para–cycling, by investigating the current sport classes and the impact of different impairments on para–cycling performance. Based on these results, a further aim was also to gather consensus on topics related to para–cycling classification.

Study I: To investigate the differences in race performance between para–cycling C–division classes at recent major international competitions, and to compare the results to race performance of able–bodied cyclists.

Study II: To evaluate three types of leg strength measures for the purpose of para–cycling classification; the MMT that is currently used in classification, isometric strength, and dynamic strength, to determine the para–cycling performance characteristics.

Study III: To evaluate the relationships between lower limb coordination, muscle strength, and para–cycling performance in para–cycling athletes with CI, to determine the para–cycling performance characteristics.

Study IV: To gather consensus on classification issues based on Study I–III in the para–cycling C and T–divisions, and to identify research priorities that are of fundamental importance to the para–cycling classification system.

4 Methods

Data for Study I was obtained from publicly available para–cycling race results. Data for Study II and III were collected at international UCI sanctioned para–cycling events; two World Cups (Emmen, The Netherlands 2018 and Ostend, Belgium 2019) and two World Championships (Maniago, Italy 2018 and Emmen, The Netherlands 2019). Data for Study IV was collected via online questionnaires on classification issues based on Studies I–III answered by a qualified panel of people involved in para–cycling and para–sports.

4.1 Participants

4.1.1 Study I

The top five track race results of the men’s C1–C5 classes between 2011 and 2018 were obtained from publically available result lists (UCI.org). The race results were obtained from 1 km time trials from five UCI World Championships (Montichiari, 2011; Aquascalientes, 2014; Apeldoorn, 2015; Los Angeles, 2017; Rio de Janeiro, 2018), and two Paralympic Games (London, 2012; Rio de Janeiro, 2016) (no para–cycling World Championship was held in 2013). Additionally, data from non–impaired track cyclists were used for reference by obtaining the top five 1 km time trial results from the Track World Championships from the same years (Apeldoorn, 2011; Melbourne, 2012; Cali, 2014; Montigny–le–Bretonneux, 2015; London, 2016; Hong Kong, 2017; Apeldoorn, 2018). Ethical approval was not required for Study I.

4.1.2 Study II and III

A total of 120 unique para–cyclists (30 females) partook in data collection in the para–cycling seasons of 2018 and 2019 (Table 3), of which 97 were C–division cyclists (20 females) and 23 were T–division cyclists (10 females) (Table 4 and 5). Table 2, 3, and 4 describes the participant characteristics of all athletes that participated in data collection. The participant characteristics of athletes that fulfilled the inclusion criteria of Study II and III are described in the detailed presentations of the studies. Inclusion criteria were
impairments affecting the lower limbs, and minimum of 18 years of age. Exclusion criteria in 2018 were impairments of hypertension, ataxia, or athetosis while in 2019, these impairments were included as well. Prior to the competitions, athletes agreed to participate in the research in an online booking system provided by the research team and distributed to the national federations through UCI. Onsite, athletes received written and verbal information about the research and signed a consent form before beginning the data collection. The consent form included information about the participation being voluntary, that the participant could stop at any time without stating a reason and decline specific assessments should they feel discomfort or pain, and that participation was anonymous. The data collection protocol consisted of physical tasks but contained no strenuous exercises to not affect race performance in the upcoming competitions. Total time of data collection was approximately 60 minutes. Ethical approval for Study II and III was granted by The Swedish Ethical Review Authority (approval no: 2018/1004–31/4).

Table 3. Participant characteristics of all athletes (C and T-divisions) participating in data collection in 2018 and 2019 (mean ± standard deviation).

<table>
<thead>
<tr>
<th></th>
<th>Females (n = 30)</th>
<th>Males (n = 90)</th>
<th>Total (n = 120)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>32 ± 11</td>
<td>33 ± 10</td>
<td>33 ± 10</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>162.7 ± 6.0</td>
<td>176.2 ± 7.6</td>
<td>172.8 ± 9.3</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>57.1 ± 8.6</td>
<td>69.9 ± 10.3</td>
<td>66.8 ± 11.3</td>
</tr>
<tr>
<td>Training level (hours/week)</td>
<td>13.6 ± 6.2</td>
<td>14.5 ± 5.1</td>
<td>14.3 ± 5.4</td>
</tr>
<tr>
<td>Competitive experience* (years)</td>
<td>3.8 ± 3.2</td>
<td>4.6 ± 4.8</td>
<td>4.4 ± 4.5</td>
</tr>
</tbody>
</table>

*On an international level

Table 5. Participant characteristics of all T-division athletes participating in data collection in 2018 and 2019 (mean ± standard deviation).

<table>
<thead>
<tr>
<th></th>
<th>Females (n = 10)</th>
<th>Males (n = 13)</th>
<th>Total (n = 23)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>39 ± 13</td>
<td>34 ± 11</td>
<td>36 ± 12</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>163.1 ± 6.4</td>
<td>175.1 ± 6.4</td>
<td>169.9 ± 8.8</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>58.5 ± 12.8</td>
<td>70.5 ± 12.4</td>
<td>65.6 ± 13.7</td>
</tr>
<tr>
<td>Training level (hours/week)</td>
<td>9.9 ± 3.6</td>
<td>10.9 ± 3.9</td>
<td>10.5 ± 3.7</td>
</tr>
<tr>
<td>Competitive experience* (years)</td>
<td>4.9 ± 3.2</td>
<td>4.9 ± 3.2</td>
<td>4.9 ± 3.1</td>
</tr>
<tr>
<td>T1</td>
<td>6</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>T2</td>
<td>4</td>
<td>8</td>
<td>12</td>
</tr>
</tbody>
</table>

*On an international level

4.1.3 Study IV

Participants were recruited by emailing the national para–cycling federations and asking for nominations of individuals whom they believed fulfilled the inclusion criteria. The inclusion criteria were: a good understanding of the English language, a minimum of five years of experience in para–cycling or other para–sports. The first inclusion criterion was to ensure that the participant had reading and writing skills in the English language in order to be able to respond to the questionnaires. The second inclusion criterion was to ensure that participants had at a minimum a basic knowledge and experience of para–cycling or other para–sports. After receiving the nominations, an invitation to be a member of the expert panel in the Delphi study was sent to 71 people, considering an equal spread of gender, age, geographic origin, role in para–cycling/para–sports, and experience in para–cycling/para–sports. 61 people accepted the invitation and were asked to complete a short digital interview to ensure compliance with the inclusion criteria. Fifty-nine participants satisfied the inclusion criteria and received the informed consent form together with the questionnaire of Round 1. The consent form required an electronic signature to proceed to the next stage and the start of Round 1 (Appendix 1). 51 participants signed the consent form and responded to Round 1, and thus were enrolled in the Delphi study panel. Ethical approval was granted by The Swedish Ethical Review Authority (approval no: 2018/1004–31/4, modified application no: 2019–03733).
4.2 Data collection procedures

4.2.1 Race performance data (Study I)
Median race speed (km/h) with interquartile range (IQR) was calculated from the official race time results of men’s classes C1 to C5 for all included events combined. In order to analyze only top performances, the five fastest results of each class at each event were included. To assess whether results were not influenced by including results of the same athletes at multiple events, a sensitivity analysis was conducted. The sensitivity analysis was performed by including only the fastest race time result of each athlete participating multiple times, and performing the same statistical tests as in the original analysis to assess whether the results remained the same. Additionally, the para-cycling results were expressed as a percentage of the median race speed of able-bodied cyclists.

4.2.2 Manual Muscle Test (MMT) data (Study II, III)
Data from the classification database of participants who had (during previous classification sessions) given consent to share their classification data for research purposes were shared by UCI with the research team. For Study II, data of the most recent MMT result of each participant who had gone through an MMT assessment in classification was obtained.

4.2.3 Isometric strength measures (Study II, III)
The isometric tests were performed using a custom–built strength set–up constructed upon the base of a kayak ergometer (Dansprint ergometer; Dansprint ApS, Hvidovre, Denmark). Reliability was tested and satisfied in a non–impaired population prior to data collection (Ekman et al., 2021). Two unilateral isometric strength tests (leg push and leg pull) were conducted with two trials per test (Figure 2). The participants built up muscle force for 2 s until they reached maximal voluntary contraction which was maintained during a minimum of 3 s. The push test evaluated the positive force applied onto the footrest while in the pull test, the foot was strapped onto the footrest and the negative force applied to the footrest was evaluated. The isometric strength data were sampled and analyzed using Spike2 (version 7.0, CED, Cambridge, UK). Peak isometric force (N/kg body mass) was defined as the average value of the highest force produced during 2 s when the least variability in force was produced.

4.2.4 Dynamic strength measures (Study II, III)
The dynamic strength tests consisted of a leg push and pull to allow comparison with the isometric leg push and pull strength results. The tests were performed on the participant’s personal road bicycle mounted on a cycling ergometer (Cyclus2, RBM Electronics, Germany). Athletes competing on trikes used a bicycle (Scott Speedster 20) made available by the research team as trikes were not supported by the ergometer. Participants were seated on the bicycle with the tested leg clipped to the pedal, which was positioned at the top position of a pedal revolution (0°). The participant pushed the pedal in a downstroke motion to the bottom position (180°) to assess the dynamic push. The dynamic pull was performed by pulling the pedal in an upstroke motion from the bottom position at 180° to the top position of 360°. Both tests were performed from a static start. Data from the dynamic strength tests and the sprint test were exported to Microsoft Excel and the peak power (W/kg body mass) produced during each test and trial was used for further analysis.
4.2.5 Coordination measures (Study III)
An open-chain tapping test was conducted in which four circle-shaped cardboard markers were placed on the floor in a rectangle shape to mark the tapping areas. One cycle was defined as: right foot to the right front target, left foot to the left front target, right foot to the right back target, left foot to the left back target. Participants were instructed to complete as many cycles as possible during 20 s, tapping as fast as they could without reducing accuracy. The highest number of taps achieved of two trials was used for further analysis. A closed-chain cadence test was performed on the participant’s own bicycle or the Scott Speedster 20, mounted on the Cyclus2 ergometer. During the test, participants pedaled as fast as they could with no resistance in the pedals during 6 s to reach their peak cadence. The outcome variable was peak RPM registered by the ergometer.

4.2.6 Performance measures (Study II, III)
The Cyclus2 pre-programmed Isokinetic Maximum Strength Test was used to perform a 20 s seated sprint test on the participant’s personal road bicycle or the Scott Speedster 20, mounted on the Cyclus2 ergometer. The test was performed from a flying start and participants were given verbal encouragement throughout the test. Data from the sprint test were exported to Microsoft Excel and the average power output (W/kg body mass) produced during 20 s was used for further analysis.

The second measure of performance was race speed. Official and publicly available race results from the individual road time trials at the event at which the participant partook in data collection were obtained (https://www.rsstiming.com/Resultats/UCIParacycling.htm). Race results were expressed as average race speed (km/h) to facilitate comparisons between participants as the competed distances varied depending on sex, class, and event. To ensure that the test measures and race performances at the time of testing were comparable in regard to the athletes’ physical status, the data collections were conducted in close connection to the para-cycling race events (the days prior to the races).

4.2.7 Delphi questionnaire data collection (Study IV)
Data collection in the Delphi study was conducted by sending out three rounds of online questionnaires to the expert panel (Appendix 1). The panel responded to the questionnaires within a set time limit and the results were reported as percentage of agreement on a topic. As the aim of the Delphi study was to reach consensus on certain para-cycling topics, a consensus level was set to ≥ 75%, which was defined as a clear majority of the panel expressing the same opinion in the topic of interest. There is no general agreement on the threshold for the level of consensus, and this depends on the number of questionnaire rounds, the available time, and the type of Delphi study performed (Keeney et al., 2011). If consensus was reached and the participants did not bring up new issues regarding the topic, it was considered resolved. If consensus was not reached, the question was reformulated based on the comments from the panel to consider the panel’s different views. Responses of “Not able to answer” were removed when calculating consensus.

4.3 Statistical methods
All statistical analyses were performed in IBM SPSS Statistics for Windows (version 26.0, Armonk, New York, USA). An overview of the statistical tests used can be seen in Table 6. For each study, normal distributions were examined using Shapiro–Wilk’s test and thereafter, statistical methods were chosen depending on if the data were normally distributed or not. Shapiro–Wilk’s test was chosen as the sample sizes investigated were small (the largest sample size investigated being n = 56). P-values above an α-level of .05 were considered normally distributed. For all studies, outlying data points were
defined as points exceeding the interquartile range times three, however, no outliers were observed in any of the data sets. The isometric and dynamic strength tests and the cycling sprint power test were investigated for impact of body mass using Spearman’s correlation (isometric push and dynamic pull were non-normally distributed) as it can be assumed that leg and body mass would impact the test outcomes to some extent. Spearman’s rho reported correlations between body mass and test outcomes between $\rho = .47$ and $\rho = .71$ ($p < .001$), which was considered to be moderate to strong correlations and therefore, the strength tests and cycling sprint power test were adjusted for body mass.

Table 6. Overview of the statistical methods used in Studies I–III. No statistical methods were used in Study IV.

<table>
<thead>
<tr>
<th>Statistical method</th>
<th>Study I</th>
<th>Study II</th>
<th>Study III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient of multiple comparisons</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Cohen’s $d$</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Games–Howell test</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Kruskal–Wallis test</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mann–Whitney U test</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multiple linear regression</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Shapiro Wilk’s $W$</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Spearman’s rho correlation</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Welch test</td>
<td></td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>

The statistical method used in Study I to assess differences in race speed between consecutive classes was the Kruskal–Wallis test for non-normally distributed data. A resulting $p$–value less than .05 indicated a statistically significant difference between one or more classes. To investigate which classes significantly differed in race speed, the Mann–Whitney $U$ post hoc test was performed. $P$–values less than .05 were reported as significantly different race speeds, whereas $p$–values equal to or larger than .05 conveyed statistically similar race speeds between classes.

In Study II (athletes with musculoskeletal impairments) and Study III (athletes with CI), multiple linear regression analyses were used to determine the associations of impairment measures: MMT (Study II), and isometric and dynamic strength (Study II and III) with cycling performance measures (cycling sprint power and race speed). Dependent variables (cycling sprint power and race speed) were examined to satisfy the assumptions of regression analysis as follows (Flatt & Jacobs, 2019; Gignac, 2019).

Normal distribution of residuals was tested with the Shapiro–Wilks test (accepted when $p > .05$) and by examining Cook’s distance for influential cases (values accepted when smaller than 1.00). The Shapiro–Wilks test was performed on the residuals to examine normal distribution of residuals. Cook’s distance values are calculated by SPSS by observing how much the values in the regression model change when the $n_{th}$ data point is removed. A Cook’s value greater than 1 would indicate that one case has a large influence on the regression results.

Absence of measuring errors across time was controlled with the Durbin–Watson statistic (values of 1.50–2.50 were accepted). The Durbin–Watson statistic ranges from 0 to 4, 0 indicating a positive correlation and 4 indicating a negative correlation in the size of the residuals across time. In the data analyses performed in Study I and II, there is a possibility of measuring errors if technical appliances are not regularly calibrated and therefore, the Durbin–Watson statistic was important to examine.

Homoscedasticity (or homogeneity of variance of residuals) was investigated visually by plotting the standardized predicted values to the standardized residuals, and tested statistically with Spearman’s correlation coefficient between the standardized predicted values and absolute standardized residuals (homoscedasticity was assumed when $p > .05$). Homoscedasticity indicates that the regression equation is equal for all values of the dependent variable.

Linearity was examined visually by plotting the dependent variable by the independent variable to identify non–linearity. Linearity indicates that the dependent and independent variables display an equal association across all levels of the independent variable. Multicollinearity between variables was assessed by examining the variance inflation factors (absence of multicollinearity assumed when values were < 5.00 and the average variance across all variables was > 1.00). Multicollinearity indicates correlation between independent variables which could cause inflation in the regression results.

In Study II, Spearman’s correlation was used to assess the relationships between isometric and dynamic strength measures as the isometric pull reported non–normal distribution also when adjusted for body mass.

In Study III, Welch’s $t$-test was used to assess differences between athletes with and without CI, and Cohen’s $d$ effect sizes were reported. Welch’s $t$-test was used as the two sample sizes of athletes with and without CI were unequal (n = 29 and n = 12, respectively), which is not an assumption of the Welch test. To assess differences between classes T1, T2, C1/C2, and C3/C4 on multiple dependent variables, the Games–Howell post hoc test was used (Noumanis & Myers, 2016). The assumptions of independence, normality, homogeneity of variance, and absence of multicollinearity to perform statistics of analysis of variance (ANOVA) were evaluated and satisfied, however, Games–Howell is a one–step procedure and does not need to be preceded by ANOVA tests. The Games–Howell test is recommended when working with small sample sizes to reduce the risk of Type I errors. Adjusted $p$–values for multiple comparisons were reported to reduce the risk of Type II errors.

In Study IV, no statistical analyses were performed. Results of the Delphi questionnaires were presented in percentages.
5 Results and discussion

This thesis has examined the average race speed of the current classes of the para–cycling C–division, investigated performance characteristics for para–cycling in the C and T–divisions, and identified majority opinions expressed by experienced people involved in para–cycling and para–sport, as well as identified future research priorities. The main results of this thesis will be presented and discussed in greater detail in the next paragraphs.

5.1 Study I: Race performance in current classes

Study I showed that significantly different race speed could be observed between each consecutive C–division class in the men’s track races ($p < .010$), except between C4 and C5 where the difference in median race speed was 1.4 km/h, which was not statistically different ($p = .05$). In a valid classification system, one would expect each class to perform differently from each other to ensure that the classification system can distinguish between the impacts of impairments in the least impaired athletes of C4 and C5. Furthermore, Study I also showed that athletes in C5 reached 90% of the race speed of non–impaired athletes. The result that the least impaired para–cyclists did not reach the same race speed as non–impaired cyclists would be expected, as the impairments of para–cyclists should hinder cycling performance in order to be eligible for para–cycling.

Borg et al. (2021) evaluated race speed in the men’s road races where the difference between C4 and C5 was 0.76 km/h ($p = .006$), indicating a statistically significant difference between the two classes. Additionally, there were significant differences between all consecutive classes of the men’s C1 to C4 ($p < .001$ for each comparison). Borg et al. (2021) also found significant differences between women’s classes of C1–C2 ($p = .001$) and C3–C4 ($p < .001$), while no significant differences were found between women’s C2–C3 ($p = .870$) and C4–C5 ($p = .078$). For the T division, Borg et al. (2021) found significant differences in race speed between both men’s and women’s T1–T2 classes ($p < .001$).

The difference between men’s C4–C5 classes was not evident in the study of Borg et al. (2021), however, the track race results found no significant difference between the two classes (Study I). It is possible that the road and track races explored required different performance characteristics as the track races were shorter sprints while the road races were longer distances, resulting in different study outcomes regarding the men’s C4 and C5 classes. However, the same classification methods are currently used to evaluate athletes in both track and road racing, and it is possible that certain impairment types are more disadvantaged in one race type compared to another. For example, track races are typically shorter in duration compared to road races, and road races might include additional factors such as ascending, descending, and technically challenging courses (e.g., cornering, accelerating, changing gears). Furthermore, the women’s C2–C3 and C4–C5 classes need to be further explored as these classes did not present a significant difference in race speed.

Table 7 presents an overview of cycling sprint power in the C and T–divisions (results from the data collection conducted for Study II and III) with a comparison to race sprint performance in non–impaired elite cyclists for reference. Male para–cyclists in C5 reached 72% of the sprint power produced by non–impaired male cyclists, and female para–cyclists in C5 reached 79% of the sprint power produced by non–impaired female cyclists. These results imply that the performances of para–cyclists are impacted by impairments.

In current para–cycling classification system, classifiers sometimes correct an athlete’s class after observing the athlete’s race performance. The results of Study I could possibly be a consequence of athletes being allocated to classes that correspond to their race performance. Therefore, the para–cycling classes might appear to be more evenly divided than they would have been if the initial classifications had not been corrected based on athlete race performance. Race observations are part of the technical para–cycling classification, however, the race performance protocol is not evidence–based. There are several risks with classifying based on race performance. For example, the athlete might get classified based on their training status rather than the severity of the impairment, which will lead to disadvantages for well–trained athletes and advantages for lesser trained athletes. In para–sport classification, training status is related to cardiovascular status which is not related to the impairment, and thus, an athlete should not be disadvantaged for high cardiovascular function. As an athlete’s training status might also impact the athlete’s functional ability, there is also a risk of disadvantaging athletes that have put a lot of effort into overcoming the impairment. Furthermore, an athlete with more expensive or better adapted equipment may get moved to a less impaired class, while athletes with badly adapted equipment or less competitive experience may get moved to a class with more severely impaired athletes. As the classification methods are not yet fully developed, there is a risk that classification affects the individual’s chance of success and medal–winning, but might also create a general disbelief in the classification methods. By performing studies that explore different impairment types and different combinations of impairments and how they associate with cycling perfor-
mance, a classification system that takes the mentioned issues into account could be developed.

Table 7. Overview of sprint cycling peak power output (POmax) measured in W/kg (mean ± standard deviation) in para–cyclists (males and females). Race data of non-impaired cyclists (males and females) are presented for reference.

<table>
<thead>
<tr>
<th>Para–cyclists, males (n = 71)</th>
<th>Para–cyclists, females (n = 23)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1 (n = 4) 5.7 ± 1.2</td>
<td>T1 (n = 3) 4.3 ± 1.5</td>
</tr>
<tr>
<td>T2 (n = 5) 9.9 ± 1.0</td>
<td>T2 (n = 4) 5.0 ± 1.0</td>
</tr>
<tr>
<td>C1 (n = 7) 7.7 ± 1.2</td>
<td>C1 (n = 0) –</td>
</tr>
<tr>
<td>C2 (n = 16) 8.1 ± 1.7</td>
<td>C2 (n = 4) 7.2 ± 1.5</td>
</tr>
<tr>
<td>C3 (n = 13) 9.7 ± 3.2</td>
<td>C3 (n = 2) 6.2 ± 2.1</td>
</tr>
<tr>
<td>C4 (n = 14) 11.4 ± 1.7</td>
<td>C4 (n = 3) 9.7 ± 2.4</td>
</tr>
<tr>
<td>C5 (n = 12) 12.6 ± 3.1</td>
<td>C5 (n = 7) 11.0 ± 2.0</td>
</tr>
<tr>
<td>Cyclists, males (n = 6) 17.4 ± 1.7</td>
<td>Cyclists, females (n = 7) 13.9 ± 1.3</td>
</tr>
</tbody>
</table>

*Peak power performed during 20 s sprint test with a flying start.

Table 7. Overview of sprint cycling peak power output (POmax) measured in W/kg (mean ± standard deviation) in para–cyclists (males and females). Race data of non-impaired cyclists (males and females) are presented for reference.

5.2 Study II: Evaluation of musculoskeletal impairments

5.2.1 Muscle strength impairments

The results of Study II showed that MMT exercises including hip, knee, and ankle extension were associated with isometric push (R² = .49) and dynamic push (R² = .35). MMT exercises including hip, knee, and ankle flexion were associated with dynamic pull (R² = .28). Additionally, both isometric and dynamic strength were associated with cycling sprint power. Furthermore, Study II presented a significant correlation between isometric and dynamic leg push (ρ = .68, p < .001) and pull (ρ = .57, p < .001) strength, which corresponds to the findings of McGuigan et al. (2010).

Isometric strength testing has been recommended to assess strength in classification as isometric testing has been described to be the least training–respondent method (Beckman et al., 2017). However, studies have shown that isometric strength improves as an effect of muscle strength training in un–trained individuals (Lehnert et al., 2015; Peltonen et al., 2018), and that isometric strength is correlated to cycling sprint power in

cyclists (Stone et al., 2004) and to vertical jump performance and 1–repetition maximum in recreationally trained individuals (McGuigan et al., 2010). It is possible that both isometric and dynamic strength could be used to assess strength in para–cycling classification, however, assessment methods considered for classification purposes need to be evaluated in terms of training–resistance to be valid for use in classification.

MMT has been critiqued for being subjective and for being ordinal–scaled, i.e., 4 points do not equal the double of 2 points which can make comparisons of measurement outcomes more difficult to interpret (Beckman et al., 2017; Tweedy et al., 2010). Furthermore, all assessed muscle groups in the MMT are weighted equally, e.g., knee extension and finger extension would both be graded 5 points when there is full function, however, for a sport like para–cycling, impaired finger extension would not have the same impact on cycling performance as impaired knee extension. In para–cycling classification, this issue has been overcome by adding a factor of importance to each muscle group to grade muscles important to cycling higher than muscles with less importance (Table 2). However, the added factors have not been verified in research and thus, the MMT and the factors used in para–cycling classification need validation.

Study II showed that hip and knee MMT measures were significantly associated with isometric and dynamic leg strength. It has been recommended that tests for classification purposes need to be as simple as possible to be manageable in the field, and should be validated through comparison with laboratory tests (Mann et al., 2021). The association of isometric strength with MMT means that MMT could potentially be used in classification after revision. This was also confirmed in the para–cycling Delphi study; 76% agreed that MMT should continue to be used in para–cycling classification (Study IV). However, before confirming its use in classification, the MMT and the factors used in para–cycling classification need validation.

The MMT data in para–cyclists showed that para–cycling athletes scoring 4 or 5 points in MMT in unilateral hip and knee extension and flexion scored overlapping results in the objective and ratio–scaled isometric and dynamic leg strength measures (Appendix 1). This indicates that 4 and 5 points might be difficult for raters to distinguish between, or that a score of 4 does not significantly impact cycling performance. When presenting these results in the form of graphs to the Delphi expert panel it resulted in an agreement level of 88% that 4 and 5 points could be regarded as the same score (Study IV). Therefore, the 0–5 point scale could potentially be adjusted to cover fewer points to better explain muscle strength impairments, which is similar to results shown in para–va’a (Rosén et al., 2019).
5.2.2 PROM impairments
In cycling, the required movement in the hip joint is approximately 40° range in hip flexion, 60° range in knee flexion, and 20° range in ankle plantarflexion (Ericson et al., 1988; Chapman et al., 2009; da Silva et al., 2016). Impaired PROM is one of the impairments eligible for para-cycling, however, as the ranges of movement of the leg joints are limited as the foot is constrained to follow the pedal movement, impaired PROM in the hips and knees are not common in para-cycling. That makes it more difficult to develop an evidence-based classification system for this impairment type; of the athletes included in this thesis, only one had impaired PROM in the hip (limiting the athlete to adopt an aerodynamic position on the bicycle). In the ankle joint, impaired PROM is more common and several athletes in para-cycling have impaired passive or active ROM in the ankle. However, research has shown that the ankle joint is not as important as the hip and knee joints when it comes to contributing to power output: 15% of the power output can be derived to ankle joint work (Elmer et al., 2011). Accordingly, Study IV showed that 86% of the Delphi panel agreed that the muscles of the ankle should be rated as “supporting muscle groups” and be given lower importance in classification compared with the importance of the hip and knee muscle groups. Impaired PROM in the ankle warrants further investigation to conclude the effects on cycling performance.

5.3 Study III: Evaluation of coordination impairments
In study III, athletes with CI presented significantly lower values in leg coordination (tapping test) and isometric leg muscle strength when compared to athletes without leg impairments and without CI. Furthermore, athletes with coordination impairments in the men’s classes T1–T2 and C1–C4 were evaluated regarding leg coordination, leg muscle strength, and cycling performance. The results showed that T1, the combined classes C1/C2, and the combined classes C3/C4 did not differ in any of the performed tests (tapping test, maximal cycling cadence, isometric strength, dynamic strength, sprint power, and race speed). Additionally, T1 performed significantly poorer results compared to all other classes in the maximal cadence test and sprint power.

So far, only open–chain coordination tests have been conducted in para–sport research (Connick et al. 2015; Hogarth et al. 2018; Van der Linden et al. 2018; Reina et al. 2020; Maia et al. 2021). Open–chain means that the distal segment of the body can move freely in space, which is the case in tapping coordination tests. In cycling, a closed–chain is created by the rider’s contact with the handlebars, saddle, and pedals. Therefore, the use of open–chain coordination to assess impairment severity in a sport that is not performed in an open–chain may not be the most accurate or relevant measure. The data protocol that was used for this thesis included both an open–chain tapping test and a closed–chain maximal cadence test.

That athletes with CI presented lower values in the coordination and strength tests compared to athletes without impairments in the legs could possibly be explained by the athletes with CI experiencing higher levels of co–contraction as well as increased difficulty to voluntarily activate the muscle groups at the right moment, as was shown by Lauer et al. (2008) and Johnston et al. (2007). Even though athletes across T1–T2 to C1–C4 displayed similar values of isometric and dynamic leg strength, T1 presented significantly lower results in the coordination test of maximal cadence, as well as significantly lower sprint power. One possible explanation is that T1 athletes have significantly more severe coordination impairments compared to athletes in T2 and C1–C4. Another explanation is that the current methods used in para–cycling classification cannot discern between athletes with different levels of coordination impairments, as the current system has not been validated.

An issue with a non–researched classification system is that it becomes unreliable to interpret test measures with regards to class. The results of Study III are important as they indicate that either classes T2 and C1–C4 are composed of athletes with similar performance characteristics (implying that these athletes could compete in the same class), or that the athletes have different performance characteristics but have been incorrectly classified. The results also indicate that athletes in T1 exhibit a significant activity limitation compared to athletes with coordination impairments allocated to the less impaired classes. These differences could not be observed when evaluating the tapping test, isometric or dynamic strength tests, or race speed. For classification purposes, these results can be used to guide which methods could be used for a valid assessment of coordination impairments.

The studies within this thesis are the first to begin exploring the performance characteristics within this group of athletes, and further studies are needed to develop tests of impairment for a complete and evidence–based classification of coordination impairments in para–cycling.

5.4 Study IV: Consensus on research–based para–cycling results
The results of Study IV show that the panel agrees that the MIC of both the lower and upper body in para–cycling need to be further investigated. The MIC of the lower and upper body have been described in the introduction of this thesis. The panel believed that the current MIC of the lower body does not explicitly include different types of
impairment which makes the rules for eligibility unclear. Furthermore, the panel expressed that the MIC for the upper body might be too low, including impairments with very minor impact on cycling performance.

The panel was in agreement regarding a development of the current methods to assess impaired muscle strength in para-cycling classification. The panel agreed that the assigned “Factor of importance” to the adjusted MMT used in para-cycling classification needs to be further researched in order to ensure its use to grade muscle groups in classification. Additionally, the panel agreed that the current 0-5 points MMT scale could be adjusted into a 0-2 point scale. The panel believed that it would simplify the classification process. Furthermore, the data presented to the panel showed that athletes with 4 or 5 points in the MMT displayed similar strength results in objectively measured strength tests, which led the panel to agree that the score could be adjusted to cover less points.

The panel presented consensus regarding separate classes for athletes cycling with only one leg, compared to athletes cycling with two legs. The comments from the panel implied that it is not fair for athletes with one leg to race against athletes with two legs, as the one-legged athlete will have disadvantages when it comes to power production and position on the bicycle (e.g., athletes cycling with one leg cannot stand out of the saddle in a climb or in a sprint).

The results showed that the cut-off between the C and T-division, i.e., the cut-off between riding a trike and riding a bicycle, provided differing opinions. The current classification system does not clearly define this cut-off which leads to athletes with the skills to ride a bicycle being able to compete on a trike. However, the classification system does also not define whether the C and T-division should be seen as two different disciplines between which athletes can choose the division to compete in, or whether the C and T-divisions should be seen as a continuum in which athletes are allocated to either division exclusively based on their evaluation in classification. Currently, T2 includes athletes that may have the skills to ride a bicycle but prefer to compete on a trike. According to the comments of the Delphi panel (which consisted of athletes and coaches highly involved in para-cycling racing), these reasons range from feelings of insecurity when riding a bicycle to a calculated decision to compete in T2 in order to increase medal success. However, these comments cannot be verified but should be taken into consideration when developing new methods to assess coordination impairments in classification.

The issue of a non-defined cut-off between the C and T-divisions has led to insecurity in the para-cycling community as to whether competitiveness in T2 is fair. The opinions of the Delphi panel were divided during the first and second round of questionnaires. Some panel members believed that athletes with the skills to ride a bicycle under any circumstance should not be eligible for the T-division. Others believed that as long as the athlete has been allocated to the T-division, they can ride a bicycle outside of competition without it affecting their T-division allocation, which is a disputed area. After completing the third round of the Delphi questionnaire, the panel agreed on a statement that said “It is better for an athlete to not be eligible for the T-division because they can ride a bicycle in training”, which 84% agreed with, compared to “It is better for an athlete to be eligible for the T-division in spite of being able to ride a bicycle in training”, which 16% agreed with. However, other statements were not agreed upon by a majority of the panel, and in summary, this issue raises larger matters that cannot be solved only by research, but also require appraisal of the definitions of what para-sport should be.

The aim of Study IV was to reach consensus on research-based results of impairments and performance and identify research areas within para-cycling that warrants further research in order to develop and establish an evidence-based classification system for para-cycling. This was achieved through a Delphi study which has recently been a growing concept in para-sports (Ravensbergen et al., 2016; Ravensbergen et al., 2018; Krabben et al., 2019; Fliess-Douer et al., 2021; Runswick et al., 2021). A strength of Study IV was that it was conducted after the initial data collection and result analyses of Studies I-III, providing actual para-cycling research results and suggestions on how to approach the continued work with the current classification system on which the panel could take a stand.

5.5 Methodological considerations and study limitations

5.5.1 Participant considerations

During the four events at which data collection were conducted, 34% of the competitive athletes were female athletes. In Study II, 21% of the participants were female athletes, and in Study III, 38% of the participants were female athletes. These numbers were considered low in order to perform meaningful separate regression analysis of men and women, however, it is an actual representation of the division of male and female athletes in para-cycling. Because of the low number of female athletes, the strength tests and cycling sprint power test were adjusted to body mass and men and women were analyzed together. Furthermore, the variable Sex was included in the regression analyses to control for differences between men and women; however, the variable was not significant in any of the regression models for the coordination and strength tests performed in Studies II and III.

The participant samples of Study II and III were relatively heterogeneous when considering impairment types, and when taking out the subsamples of different impairment types, the sample sizes become small and further statistical analysis would not be mean-
ingful. Therefore, conducting analyses on athletes with different impairment types is difficult and further research is warranted to determine the performance differences between specified impairment types.

In Study IV, there was a smaller sample size of participants from Africa, Asia, and South America, while most of the participants were from Europe. While this is a limitation to the study, it is also a relatively accurate reflection of the current division of active para-cyclists’ origins.

5.5.2 Impact of the upper body on performance
Research of the function of the upper body in cycling has been less researched than the lower body. As there is limited data on the role of, for example, trunk function, shoulder stabilization, and hand grip function, it becomes more complex to understand the activity limitation in cycling that is caused by upper body impairments. Furthermore, as the upper body contributes to power production in standing cycling and in sprinting, it could create unfair competition in para–cycling races with several hills as well as in technical races that might demand more phases of acceleration after deceleration. In track sprint racing, it has been shown that C2, in which athletes using only one leg to pedal the bike compete, presented slower accelerations during the first 125 m of the race (Wright, 2016). It was concluded that it is possible that athletes with one leg have slower accelerations because they cannot ride standing, which is required to produce more power short–term (Bouillod et al., 2018; Millet et al., 2002). If this is the case, research is needed to investigate whether this will cause a significant disadvantage for athletes riding with one leg when competing in short–duration track races.

Some tests conducted during data collection included involvement of the upper body: maximal cadence, dynamic push, dynamic pull, sprint power, and race speed. The tests of tapping, isometric push, and isometric pull were not dependent on upper body function. As the tapping test was performed without a back rest in the seated position, it is possible that a level of trunk stability was needed. However, during testing, all participants were able to perform the tapping test without noticeable difficulties staying upright. A limitation of the study of strength and performance in athletes with musculoskeletal impairments was therefore that upper body impairments were not regarded. It is possible that athletes with arm or hand amputations, impaired grip strength, or coordination impairments in the arms would have troubles with using the handlebars as a lever to maximize the power produced by the legs on the pedals. However, by having the athletes perform the cycling tests using their own bicycle, their individualized handlebar adaptations decreased the impact of any upper body impairments. Research is needed to determine the effect of different hand, arm, and trunk impairments on para–cycling performance.

5.6 Future research
In reference to the suggested research model presented by Mann et al. (2021), the research in para–cycling currently covers Step 1 (identifying the sport and impairment types) and Step 2 (identifying determinants of sport performance). However, for Step 2 to be completed, the determinants of the upper body for cycling performance need to be clarified.

Step 3a (developing measures of impairment) is partly covered by Study II and III regarding musculoskeletal impairments and coordination impairments, however, further research is needed to investigate measures of PROM, limb deficiency, and leg length difference. Furthermore, Step 3a is not complete as tests with the potential for assessing strength in classification (i.e., MMT) and tests with the potential for assessing coordination in classification (i.e., the cadence test) need to be further investigated to ensure training–resistance. Additionally, after identifying determinants of the upper body for cycling performance (Step 2), Step 3a needs to be repeated in order to develop measures of impairments for the upper body regarding strength, PROM, limb deficiencies and coordination.

Step 3b (developing measures of performance) has been addressed by Study II and III by identifying the cycling sprint power test as a measure of performance, which has been shown to be a relevant indicator of para–cycling performance (Nooijen et al., 2021). However, Study II and III investigated the lower body and further research is needed to address Step 3b regarding the eligible impairments of the upper body.

Step 4 (assessing the impairment–performance relationship) has been addressed by Study II and III by investigating the relationship between lower body muscle strength and performance, and between lower body coordination and performance. However, Step 4 needs to be addressed regarding impaired PROM and limb deficiency, and regarding the eligible impairments of the upper body.

Step 5 (determine minimum impairment criteria and class profiles) has been started by investigating current class profiles (Study I) and by addressing the class profiles of athletes with impaired coordination in the C and T–division (Study III). However, further research is needed to define evidence–based class profiles. Additionally, Study IV showed that there was an agreement on the need to redefine the MIC of the lower and upper body research is needed to identify the MIC of each eligible impairment to ensure that para-cyclists are disadvantaged in non–impaired cycling.

A more detailed description of prioritized para–cycling research is presented below.
5.6.1 MIC and class profiles
The MIC of the lower body is the inability to perform a one–legged heel raise. The results of Study IV showed that 97% of the panel believed that the MIC of the lower body does not accurately represent the level of impairment that will impact para–cycling performance. The comments from the panel implied that many questioned the impact of impaired ankle strength and impaired ankle PROM on cycling performance. Further research is needed to investigate the impact of the least lower body impairments currently eligible for para–cycling. The MIC of the upper body to be eligible for para–cycling is inability to form and maintain a cylindrical grip with one hand. Study IV showed that 76% believed that the MIC of the upper body does not accurately represent the level of impairment that will impact para–cycling performance. The comments showed that many questioned whether the MIC of the upper body is currently too inclusive of impairments that might not have a large disadvantage in para–cycling. To ensure that the current upper body MIC impacts performance, either by affecting bicycle control or by affecting power output, further research is warranted to investigate the effect of different upper body impairment types on para–cycling performance.

Study IV also revealed that the panel believed that the current classification system does not clearly define the cut–off between the C and T–divisions regarding athletes with CI. Research is needed not only to identify the MIC and class profiles of athletes with impaired coordination, but also to investigate whether there is a clear cut–off in impairment level to determine whether an athlete has the ability to ride a bicycle or requires a trike.

5.6.2 The upper body in para–cycling
Impaired trunk control is most common in athletes with CI but can also be present in athletes with musculoskeletal impairments, such as ALS (amyotrophic lateral sclerosis), a health condition that causes increasing difficulty to keep the torso upright. The effect of impairments in the upper body (trunk and arms) on para–cycling performance is uncertain. The upper body contributes 5% to the total power output in cycling (Elmer et al., 2011), and it has been shown that the upper body contributes to alternating between seated and standing cycling (Bouillod et al., 2018), and to produce high power outputs (Turpin et al., 2017). Furthermore, the arms are used to pull on the handlebars to produce force on the pedals in the downstroke during standing cycling (Stone & Hull, 1993). One study showed that upper body strength and endurance was related to cycling capacity in untrained subjects (Segerström et al., 2011), further highlighting the importance of investigating the impact of impairments in the upper body.

In Study IV, 74% of the Delphi panel believed that athletes with impairments only in the upper body should compete separately from athletes with impairments in the lower body. The majority of the panel therefore implied that upper body impairments have a different impact on para–cycling performance compared with lower body impairments. However, additional comments from the panel showed that function in the upper body (specifically the arms and hands) is of importance when it comes to bicycle control (steering, braking, and shifting gears). The relative impact of limitations to bicycle control in relation to impairments that limit power production needs to be investigated in order to determine the impact of upper body impairments in para–cycling performance. By investigating the impact of upper body impairments, classification methods to assess upper body impairments in order to determine MIC and for appropriate class allocation based on impairment level can be determined.

5.6.3 Non–impaired reference group
To ensure the impacts of different impairments on para–cycling performance, and to evaluate assessment methods used in classification, data in a non–impaired reference group is needed. Data should preferably be collected in cyclists with an equivalent level of weekly training hours as the para–cyclists participating in the data collection of this thesis. In that way, information on the performance of a correspondingly trained group of non–impaired cyclists will be obtained to compare the results of para–cyclists with.
6 Conclusion

The new knowledge that can be drawn from this thesis have been summarized and described below:

- C4 and C5 (least impaired bicycling classes) did not significantly differ in race speed in standardized track time trial results, which implies that the class cut-offs need further investigation.
- The modified MMT (hip, knee, and ankle extension, and hip, knee, and ankle flexion) was associated with isometric and dynamic leg extension and flexion strength, respectively. Therefore, the MMT has potential to be used in classification to assess muscle strength.
- Isometric and dynamic leg muscle strength in athletes with musculoskeletal impairments was associated with cycling performance (sprint power), which highlights the relevance to assess leg muscle strength in classification.
- Leg coordination measured with a tapping test and isometric leg muscle strength were lower in athletes with coordination impairments compared to athletes without. This implies that leg coordination and isometric muscle strength assessments are relevant for classification in athletes with CI.
- Leg coordination measured with a tapping test and a cycling cadence test, and isometric and dynamic leg muscle strength in athletes with CI were associated with cycling performance (sprint power), which highlights the relevance of assessing leg coordination and leg muscle strength in classification in athletes with CI.
- The cadence test distinguished T1 athletes (most impaired tricycle class) from the other classes (less impaired tricycle and bicycle classes), which implies that the cadence test has potential to be used in classification to assess leg coordination.
- The results of the leg coordination tests, isometric and dynamic muscle strength tests, and cycling sprint power test in T2, C1/C2, and C3/C4 did not differ. This implies that these athletes could compete on similar terms and that a reevaluation of the cut-offs between classes might be needed.
- There was consensus in the Delphi panel that the methods to assess leg muscle strength in classification need to be investigated and developed. For example, a 0–2 point scale instead of the current 0–5 point scale to assess muscle strength in classification should be used. Additionally, the numbers to grade the relative importance of different muscle groups in the legs need to be evidence-based.
- There was further consensus in the Delphi panel that the Minimum Impairment Criteria (MIC) of the lower and upper body need to be redefined. The panel believed that the MIC of the lower body should be rewritten to better include different types of leg impairments, and that the MIC of the upper body should be reevaluated to ensure that only upper body impairments with an impact on cycling performance are eligible for para-cycling.
- There was consensus in the Delphi panel that athletes riding a bicycle with one leg should compete separately from athletes riding a bicycle with both legs. The panel believed that these two groups cannot fairly compete against each other because of differences in performance abilities.
- There was consensus in the Delphi panel that athletes with musculoskeletal impairments should compete separately from athletes with coordination impairments, as two different impairment types cannot be accurately compared and thus, fair competition cannot be ensured.


Den här avhandlingen har identifierat prestationsegenskaper hos para-cyklister med muskuloskeletala funktionsnedsättningar och med koordinationsnedsättning, samt föreslagit tester som har potential att användas inom klassificering för att utvärdera koordination och muskelstyrka. Resultaten av den här avhandlingen indikerar att klassindelningen behöver ses över vad gäller klasserna med lägst funktionsnedsättning, samt klasserna för idrottare med koordinationsnedsättning. Framtida studier behöver även undersöka träningsbarheten i testerna som föreslagits användas vid klassificering inom para-cykling.

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9 References


Appendix 1

DELPHI STUDY – INFORMED CONSENT FORM

The procedures and purpose of the present study follow the code of ethics for research in the social and behavioural sciences involving human participants of the Faculty of Behavioural and Movement Sciences (Vrije Universiteit van Amsterdam) and the Swedish School of Sport and Health Sciences (GIH). The procedures follow the General Data Protection Regulation requirements and meet the principles and code of conduct of the American Psychological Association. The Delphi questionnaire is part of a larger research project approved by the Swedish Ethical Review Committee (approval number: 2018/1004–31/4).

Please tick each statement to confirm agreement.

☐ I have read and have had sufficient time to consider the information provided, including the procedures and purpose of the study.
☐ I have had the opportunity to ask questions and have had satisfactory responses to my questions.
☐ I acknowledge and agree that my personal data and questionnaire responses will be collected by the Swedish School of Sport and Health Sciences via Survey&Report.
☐ I acknowledge and agree that my personal data will be coded and handled confidentially and anonymously by the Swedish School of Sport and Health Sciences.
☐ I acknowledge and agree that my anonymous data will be shared confidentially via secure platforms with the Vrije Universiteit Amsterdam.
☐ I understand that personal information about me that can directly identify me, such as my name, will not be shared beyond the Swedish School of Sport and Health Sciences.
☐ I understand that my personal data and questionnaire responses collected will be kept confidentially and stored for five years at the Swedish School of Sport and Health Sciences and for ten years at the Vrije Universiteit Amsterdam.

☐ I have read and understood the information sheet and the consent form and I freely consent to participate in this study.

Consent to participate:

☐ I voluntarily agree to take part in this study.

Demographics

What is your name: 

What is your email address: 

What is your nationality: 

What is your age: 

☐ < 30
☐ 30–39
☐ 40–49
☐ 50–59
☐ 60–69
☐ > 70

What is your gender: 

☐ Male
☐ Female
☐ Do not want to answer

I understand that the primary goal of the data collected is to reach group consensus on the subject of para–cycling classification as part of the Delphi study.
I understand that the information and results of this study will be used for scientific purposes only and that information I provide can be quoted anonymously and on a group–level in research outputs (for example at conferences or in scientific papers).
I understand that the data collected during this study can be reused to answer other research questions from the same research project.
I understand that my participation in this study is voluntary and that I am completely free to refuse to participate or to withdraw from this study at any time without stating a reason and without any consequences.
I have read and understood the information sheet and the consent form and I freely consent to participate in this study.
I confirm that I will handle the findings discussed in this study and the outcomes from unpublished data confidentially until publically disclosed by the research team.
What is your role in para-cycling/para-sport (e.g. athlete, coach, classifier). If you hold more than one role, please add these as well with the most recent or relevant at the top of the list. If you are an athlete, please add which class you are currently in. If you are a classifier, please add if you are a national or international classifier.

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<th>Role #1</th>
<th>Years of experience</th>
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**DELPHI QUESTIONNAIRE ROUND 1**

This section focuses on the lower limbs and the impairments that affect the function of the lower limbs in C-class athletes. The second and third section will focus on musculoskeletal impairments in the H-class. The fourth and last section will focus on motor coordination impairments in the T-class as well as in the C-class.

**Round 1 – Strength assessments**

- Impaired muscle power: Covers health conditions that reduce voluntary muscle contractions.
- Examples of underlying health conditions that can lead to impaired muscle strength are spinal cord injury (tetraplegia, paraplegia, complete or incomplete), spina bifida, muscular dystrophy, hereditary and peripheral neuropathies, and post-polio syndrome.
- Minimum Impairment Criteria (MIC) for impaired muscle power on the lower limbs is inability to heel raise tested in single leg stance (inability in one leg is enough for eligibility). MIC for impaired muscle power in the upper limbs is full loss of grip in one hand, or inability to form and maintain a cylindrical grasp (Muscle grade 0).
- In classification, muscle power is assessed using the Manual Muscle Test (MMT) (according to Daniels and Worthingham scale, 2007) and is adjusted to cover the sport-specific range of movements necessary for cycling. The MMT scale can be studied in Table 1, however, in this study the main focus will be on hip extension and flexion, knee extension and flexion, and ankle dorsiflexion and plantar extension. These movements can be seen in Figure 1. The complete MMT test used in para-cycling classification can be studied in detail in Table 1.
- Column 1 and 2 shows the original MMT scale.
- Column 3 shows the adjustments made for para-cycling classification.
- Column 4 shows the converted score used in para-cycling classification.
- The converted score is thereafter multiplied with a “Factor of Importance”, i.e. the more important the muscle group is for the activity of cycling, the higher factor of importance it is multiplied with. The idea is to give more weight to impairments in muscle groups important for cycling, however, there is no evidence behind the adjustments that have been made to the original MMT scale.
- Suggested literature: Fonda & Sarabon, 2010, Biomechanics of cycling.

**Question 1.1**

A value (“Factor of Importance”) has been assigned to each muscle to highlight their importance in cycling; the higher the value, the more important that muscle is expected to be (Table 1). Do you agree with the assigned values as seen in Table 1? Please answer the three statements below.

<table>
<thead>
<tr>
<th></th>
<th>Knee extension is more important than hip extension.</th>
<th></th>
<th>Knee flexion is more important than hip flexion.</th>
<th></th>
<th>Ankle plantar extension is more important than dorsiflexion.</th>
</tr>
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<tbody>
<tr>
<td>A</td>
<td>Yes</td>
<td>B</td>
<td>Yes</td>
<td>C</td>
<td>Yes</td>
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<td>No</td>
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<td>No</td>
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<td>No</td>
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<tr>
<td></td>
<td>Not able to answer</td>
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<td>Not able to answer</td>
<td></td>
<td>Not able to answer</td>
</tr>
</tbody>
</table>

Please elaborate on why you answered Yes or No on each muscle group (A-C) above:

Please add any additional comments you may have regarding the Factor of Importance in the other muscle groups, as well as comments you may have regarding the use of the MMT scale in para-cycling classification:
As part of the classification research, data were collected in 2018 and 2019 at international para–cycling competitions. The aim of collecting the data was to evaluate the currently used methods (MMT; Table 1) of assessing muscle strength in classification. MMT is a subjective (conducted by several different classifiers) measurement of impairment that is ordinal–scaled (4 points is not twice as much as 2 points), while the strength test is a sport–specific and objective performance measure that is ratio–scaled (4 Watts is twice as much as 2 Watts). In classification, it is important to understand the relationship between ratio–scaled and objective measurements to ensure fair classification.

Maximal muscle strength was tested on the bike: each para–cyclist started with the pedal in the highest position (0°) and pushed the pedal down as hard as they could to the lowest position (180°) (Figure 2).

The graphs below show data from MMT tests of para–cyclists, and how the test results compare to each athlete’s maximal muscle strength as measured in the bike test.

MMT results for Hip Extension (Figure 3, Graph A), Knee Extension (Figure 3, Graph B), and Ankle Plantar Extension (Figure 3, Graph C) are seen on the horizontal axis. The scores are assigned by international para–cycling classifiers according to the procedure in Column 3, Table 1 (“Adjusted for para–cycling classification”). This means that the scores have not yet gone through the process of Column 4 and consequently, the “Factor of Importance” has not been used. This means that 10 is the maximal score when adding the two legs together for each movement (5 is the maximal score per movement in one leg).

In the graphs, Maximal muscle strength is seen on the vertical axis. In each graph, one dot represents one athlete’s MMT test result (horizontal axis) and maximal strength test result (vertical axis).
Graph A shows that the majority of para-cyclists scored 8–10 points in the MMT test for Hip Extension (one athlete scored 6 points).

Graph B shows that the majority of para-cyclists scored 8–10 points in the MMT test for Knee Extension (two athletes scored 6 and 7 points).

The results of Graph A and B suggest that para-cyclists that score 8 and 9 in Hip or Knee Extension, still produces similar results in the maximal strength test as para-cyclists scoring 10 points in Hip or Knee Extension.

Graph C shows that in Ankle Plantar Extension, the MMT results are ranging from 0 to 10 points.

The results of Graph A and B suggest that smaller muscle strength impairments (when the cyclists score 8 or 10) in hip and knee extension strength do not seem to affect their maximal strength in the bike test.

The result of Graph C suggests that the majority of para-cyclists maximal strength was approximately 2–4 Watt/kg, regardless if they scored 0, 5 or 10 in the MMT test for Ankle Plantar Extension, which suggests that ankle plantar extension strength do not have a large impact on the maximal muscle strength that can be achieved in the bike test.

Question 1.2

Based on the graphs in Figure 3, do you agree that the MMT points emphasizes muscle functions that do not seem to have an effect in cycling performance?

A The effect of hip extension strength on para-cycling performance should be re-evaluated.

- Yes
- No
- Not able to answer

B The effect of knee extension strength on para-cycling performance should be re-evaluated.

- Yes
- No
- Not able to answer

C The effect of ankle plantar extension strength on para-cycling performance should be re-evaluated.

- Yes
- No
- Not able to answer

Please elaborate on why you answered Yes or No on each muscle group (A–C) above:

Please add any comments you may have regarding the importance of different muscle groups, including muscle groups that might not have been mentioned:

Question 1.3

Currently, athletes with impaired muscle power, impaired passive range of movement (PROM), limb deficiency or leg length difference are eligible for all five C–classes (C1–C5) according to severity of the impairment. “Active movement” means that the athlete moves his/her limbs with muscle power across the movement range, while “Passive movement” means that the classifier moves the athlete’s relaxed limbs through the ranges, i.e. the athlete does not do any muscle work. Below follows information on PROM, limb deficiency and leg length difference.

Impaired passive range of movement (PROM): Covers health conditions that cause a restriction or a lack of passive movement in one or several joints. The movement ranges that are assessed in classification can be studied in Table 2.

PROM is measured manually with a goniometer measuring joint angles. The athlete gets scored on a 0–3 points scale, where 0 is no movement in the functional range, 1 point is restricted movement within the functional range, 2 points is minimally restricted movement within the functional range, and 3 points is full movement within the functional range.
Examples of underlying health conditions that can lead to PROM are contracture(s) and/or ankyloses resulting from chronic joint immobilization, either congenital or due to trauma or medical reasons.

MIC for impaired PROM in the upper limbs is full loss of grip in one hand, inability to form and maintain a cylindrical, i.e., no functional hand movement due to impaired PROM. MIC for impaired PROM in the lower limbs is inability to heel raise tested in single leg stance (inability in one leg is enough for eligibility) due to impaired PROM.

Limb deficiency: Covers health conditions that cause a total or partial absence of bones, muscles or joints as a consequence of trauma, illness or congenital limb deficiency.

Examples of underlying health conditions that can lead to the eligible impairment are traumatic amputation, amputation due to bone cancer or dysmelia.

The MIC for limb deficiency in the lower limbs is amputation of the foot through Lisfranc/tarsometatarsal (TMT) joints or comparable dysmelia (Figure 4). MIC for limb deficiency in the upper limbs is amputation of all fingers and thumb through the metacarpophalangeal (MCP) joints, or dysmelia with no functional grip, i.e., muscle strength 0 (Figure 4).

Figure 4. MIC for the hand: amputation through the MCP joints. MIC for the foot: amputation through Lisfranc/TMT joints.

Leg length difference: Covers health conditions that cause a difference in the leg length of their legs as a result of limb growth, or as a result of trauma.

Examples of underlying health conditions that can lead to the eligible impairment are dysmelia and congenital or traumatic disturbance of limb growth.

MIC for leg length difference is difference in length between right and left legs equal to or more than 7 cm.

Question 1.3
Do you think that there are reasons to reconsider the amount of C–classes if you only focus on athletes with musculoskeletal impairments in the lower limbs that are eligible for the C–class? That is, para–cyclists with impaired muscle strength, impaired passive range of motion, limb deficiency or leg length difference.

Example: C4 and C5 should be combined into one class. Example: Athletes riding with only one leg should have their own class. Remember there are no right or wrong answers.

☐Yes
☐No
☐Not able to answer
Please elaborate on why you answered Yes or No:
In classification, ataxic movements must be demonstrable in tests of coordination and balance. The scale used to assess ataxia is the Scale for the Assessment and Rating of Ataxia (link to literature).

Minimal impairment criteria: Occasional and mild or subtle signs of ataxia.

The definition of "occasional and mild or subtle signs of ataxia" for use in para–cycling classification is lacking.

Athetosis is continual slow involuntary movements, and includes:
  - Chorea – a random-appearing sequence of one or more discrete involuntary movements
  - Dyskinesia
  - Dystonic movements
  - Tremors, tics, etc.

In classification, athetosis must be evident by abnormal posturing and inability to control unwanted movements at rest and in activity. The scale used to measure athetosis is the Dyskinesia Impairment Scale, modified for para–cycling (link to literature).

Minimal impairment criteria: Occasional signs of dyskinesia with mild or subtle intensity or amplitude of movement, either unilateral (one body half affected) or bilateral (both body halves affected).

The definition of “occasional dyskinesia signs with mild or subtle intensity or amplitude of movement” for use in para–cycling classification is lacking.

30 para–cyclists in the T–class have participated in tests of performance, coordination and strength (Liljedahl et al., not published):

Average power output (Watt/kg) during a 20 seconds maximal sprint test on a cycling ergometer has been assessed. The aim of the test was to measure cycling performance in a standardized way.

A cadence test on the bike has been conducted to assess leg coordination in para–cyclists. The highest cadence the para–cyclist could reach during 6 seconds without resistance in the pedals was registered. The test was performed from a flying start.

Furthermore, a tapping test to assess leg coordination in para–cyclists has also been conducted. Right and left leg were tested together in the following order: right leg forward, left leg forward, right leg backward, left leg backward, right leg forward, and so on. The participants were instructed to tap as fast as possible with maintained accuracy during 20 seconds. The total of correct hits (foot and target connection) was counted.

The graphs below showed that in para–cyclists with motor coordination impairments, maximal cadence has a distinct relationship to average power output in the 20 seconds sprint test (Figure 1, Graph A). This means that the faster you can pedal the higher average power you can produce. The tapping test is also showing a relationship to average power output (Figure 1, Graph B), that the faster you can tap the higher average power you can achieve, but the result is not as clear as the result of the cadence test.

Additionally, a study on road race performance in the T–class showed that there is a statistically significant difference between T1 and T2, both in the men’s and women’s classes (Figure 2) (Borg et al., 2020).

In classification, spasticity is tested with rapid passive movements. A sign of spasticity is a “catch” (increase in muscle tone) during the movement. The scales used to assess hypertonia is the Australian Spasticity Assessment Scale (Table 1) and the Unified Dystonia Rating Scale.

Minimal impairment criteria: Spasticity grade 1 (Table 1) in the affected arm or leg, plus neurological signs such as positive Hoffman/Babinski; noticeably brisk reflexes or difference in reflexes in the left versus right side of the body.

A tapping test on a flying start.

The definition of “occasional and mild or subtle signs of ataxia” for use in para–cycling classification is lacking.

The motor coordination impairment types that make an athlete eligible for para–cycling are hypertonia, ataxia and athetosis. Examples of underlying health conditions that can lead to the following impairment types are for example cerebral palsy, traumatic brain injury and stroke.

Hypertonia includes:
  - Spasticity – reduced ability to passively lengthen the muscle
  - Rigidity – resistance to passive movements at low speed
  - Dystonia – sustained muscle contractions that causes twisting and repetitive movements or abnormal posture

In classification, spasticity is tested with rapid passive movements. A sign of spasticity is a “catch” (increase in muscle tone) during the movement.

The graphs below showed that in para–cyclists in the T–class have participated in tests of performance, coordination and strength (Liljedahl et al., not published):

Average power output (Watt/kg) during a 20 seconds maximal sprint test on a cycling ergometer has been assessed. The aim of the test was to measure cycling performance in a standardized way.

A cadence test on the bike has been conducted to assess leg coordination in para–cyclists. The highest cadence the para–cyclist could reach during 6 seconds without resistance in the pedals was registered. The test was performed from a flying start.

Furthermore, a tapping test to assess leg coordination in para–cyclists has also been conducted. Right and left leg were tested together in the following order: right leg forward, left leg forward, right leg backward, left leg backward, right leg forward, and so on. The participants were instructed to tap as fast as possible with maintained accuracy during 20 seconds. The total of correct hits (foot and target connection) was counted.

The graphs below showed that in para–cyclists with motor coordination impairments, maximal cadence has a distinct relationship to average power output in the 20 seconds sprint test (Figure 1, Graph A). This means that the faster you can pedal the higher average power you can produce. The tapping test is also showing a relationship to average power output (Figure 1, Graph B), that the faster you can tap the higher average power you can achieve, but the result is not as clear as the result of the cadence test.

Additionally, a study on road race performance in the T–class showed that there is a statistically significant difference between T1 and T2, both in the men’s and women’s classes (Figure 2) (Borg et al., 2020).

In classification, spasticity is tested with rapid passive movements. A sign of spasticity is a “catch” (increase in muscle tone) during the movement.

The definition of “occasional and mild or subtle signs of ataxia” for use in para–cycling classification is lacking.

Ataxia is uncoordinated movements due to cerebellar ataxia, which is caused by damage to the central nervous system.

Question 1.4 – 1.8

The motor coordination impairment types that make an athlete eligible for para–cycling are hypertonia, ataxia and athetosis. Examples of underlying health conditions that can lead to the following impairment types are for example cerebral palsy, traumatic brain injury and stroke.

Hypertonia includes:
  - Spasticity – reduced ability to passively lengthen the muscle
  - Rigidity – resistance to passive movements at low speed
  - Dystonia – sustained muscle contractions that causes twisting and repetitive movements or abnormal posture

In classification, spasticity is tested with rapid passive movements. A sign of spasticity is a “catch” (increase in muscle tone) during the movement.

The graphs below showed that in para–cyclists in the T–class have participated in tests of performance, coordination and strength (Liljedahl et al., not published):

Average power output (Watt/kg) during a 20 seconds maximal sprint test on a cycling ergometer has been assessed. The aim of the test was to measure cycling performance in a standardized way.

A cadence test on the bike has been conducted to assess leg coordination in para–cyclists. The highest cadence the para–cyclist could reach during 6 seconds without resistance in the pedals was registered. The test was performed from a flying start.

Furthermore, a tapping test to assess leg coordination in para–cyclists has also been conducted. Right and left leg were tested together in the following order: right leg forward, left leg forward, right leg backward, left leg backward, right leg forward, and so on. The participants were instructed to tap as fast as possible with maintained accuracy during 20 seconds. The total of correct hits (foot and target connection) was counted.

The graphs below showed that in para–cyclists with motor coordination impairments, maximal cadence has a distinct relationship to average power output in the 20 seconds sprint test (Figure 1, Graph A). This means that the faster you can pedal the higher average power you can produce. The tapping test is also showing a relationship to average power output (Figure 1, Graph B), that the faster you can tap the higher average power you can achieve, but the result is not as clear as the result of the cadence test.

Additionally, a study on road race performance in the T–class showed that there is a statistically significant difference between T1 and T2, both in the men’s and women’s classes (Figure 2) (Borg et al., 2020).
Figure 1. The relationships between maximal cadence (horizontal axis) and average sprint power output (vertical axis) (Graph A), and number of taps in the coordination test (horizontal axis) in relation to average sprint power output (vertical axis) (Graph B). The data is from 30 T-class cyclists.

Graph (A) and (B) displays data from international UCI tricycling competitions between 2011 and 2019, for men (A) and women (B). Each dot represents one athlete’s race speed result and the middle black line in each column represents the mean speed. The results show that there is a statistically significant difference in race speed between T1 and T2 in both men’s and women’s classes. The statistics showed that the difference between T1 and T2 is large. However, a difference in results does not equal a valid classification process, but the results can also be caused by para–cyclists being divided into sports classes based on their race performance history.


Figure 2. Mean road race performance of para–cycling athletes competing in the men’s (A) and women’s (B) T–classes at UCI events between 2011 and 2019. Grey circles indicate individual race results. * indicates that there is a statistical different to the adjacent class in the same sex.

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**Question 1.4**

Do you agree that the T– and C–class are two separate disciplines and should therefore, by definition, have two separate classification systems?

This could mean that certain athletes are eligible for both T and C and, if so, could choose whether they want to compete in T or C. Please motivate your answer.

Example: Athlete A and B both show frequent and moderate to severe signs of ataxia. With current classification system, they could theoretically be eligible for both T2 and C2. Athlete A is unable to ride a bicycle and is therefore allocated to T2, while athlete B can ride a bicycle and is allocated to C2. If T and C were two separate disciplines, athlete B could also choose to compete in the T2 class, as athlete B has the same severity of impairments as athlete A.

- Yes
- No
- Not able to answer

Please elaborate on why you answered Yes or No:

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**Question 1.5**

Do you agree that the T and C disciplines are a continuum, i.e. when riding a bicycle is possible, the athlete should no longer be eligible for the T–class?

By definition, the T– and C–class would use the same classification system, with lower activity limitation shown in C1 athletes than T2 athletes. Please motivate your answer.

Example: Athlete A and B both show “constant signs of athetosis/dystonia with large amplitude of movement or extreme intensity of posturing”. With current classification system they are eligible for both T1 and C1. Both athletes need assistance to get on and off a bicycle but can ride it as long as speed is maintained. Athlete A feels insecure while riding the bicycle and only tries a few times before giving up and decides to stick to the tricycle. Athlete B also feels insecure but is persistent and keeps practicing for months until riding the bicycle feels safe (assistance to get on and off the bike is still needed). At classification, athlete A is allocated to T1 because riding the bicycle still feels impossible. Athlete B is allocated to C1 because all the hours of practice has made athlete B skilled at riding the bicycle.

- Yes
- No
- Not able to answer

Please elaborate on why you answered Yes or No:
Question 1.6

Do you think that there are reasons to reconsider the amount of C–classes? Focus only on the athletes with hypertonia, ataxia or athetosis that are eligible for the C–class.

Currently, athletes with hypertonia, ataxia or athetosis are eligible for all five C–classes (C1–C5) according to severity of the impairment. Please motivate your answer.

Example: C1 athletes should be moved to the T2 class and C2–C5 should be combined into one C–class for athletes with mentioned impairments. Example: C1–C5 should all be combined to one big class for athletes with mentioned impairments.

☐ Yes
☐ No
☐ Not able to answer
Please elaborate on why you answered Yes or No:

Question 1.7

Do you think that there are reasons to reconsider the amount of T–classes if you only focus on athletes with hypertonia, ataxia or athetosis that are eligible for the T–class?

Currently, athletes with hypertonia, ataxia or athetosis are eligible for both T–classes (T1–T2) according to severity of impairment. Please motivate your answer.

Example: T2 athletes should be moved to C1 and T1 should be the only T–class for athletes with mentioned impairments. Example: There should be four T–classes (T1–T4) for athletes with mentioned impairments.

☐ Yes
☐ No
☐ Not able to answer
Please elaborate on why you answered Yes or No:

Question 1.8

Based on the previous two sections regarding the T and C–class, do you agree that para–cyclists with motor coordination impairments should compete in separate classes from athletes with musculoskeletal impairments (and by definition, use separate classification systems)?

Currently, athletes with hypertonia, ataxia and athetosis compete against athletes with musculoskeletal impairments (impaired muscle strength, amputation, etc.). By combining different impairment types, it is assumed that a certain level of motor coordination impairment causes similar activity limitation as a certain level of muscle strength impairment/amputation/etc. By separating the impairment types, it is possible that there will not be enough athletes in some classes to generate a satisfying class size. Please motivate your answer.

Example: Class C1–C5 remains open for athletes with musculoskeletal impairments, and T1–T2 for athletes with hypertonia, ataxia or athetosis. Two new C–classes open exclusively for athletes with motor coordination impairments than can ride a two–wheeled bike.

☐ Yes
☐ No
☐ Not able to answer
Please elaborate on why you answered Yes or No:

DELPHI QUESTIONNAIRE ROUND 2

INSTRUCTIONS

• Each section starts with a summary of the Results from Round 1. Please take the time to read this information carefully. One of the aims of the Delphi study is for all panel members to thoroughly consider other perspectives of each topic before once again taking a stand on the questions.

• After the results of the previous round have been presented, Round 2 starts in which you will get additional information to respond to the questions coming up. The aim of each section will be described here.

• Questions for Round 2 are based on the results of Round 1. For each statement, please check the boxes on whether you agree (Completely agree or Somewhat agree) or disagree (Somewhat disagree or Completely disagree).

• For each statement, you have the option to respond Not able to answer. You will also have the option to explain your answer in the text field for each question. Your comments are very valuable to us, so we encourage you to take the time to explain your answers.

Results from Round 1

The panel was not in agreement regarding the importance of hip, knee, and ankle muscle function in cycling performance. 57% believed that knee extension is more important than hip extension, and 56% believed that hip flexion is more important than knee flexion. 74% believed that ankle plantar extension is more important than ankle dorsiflexion.

Several panel members made comments describing the muscles of the hips and knee as more important than the muscles of the ankles.
Most of the panel agreed that the Manual Muscle Test (MMT) point score system needs to be revised regarding the hip (74%), the knee (74%), and the ankle (82%) muscle tests.

Several respondents brought up the use of prostheses in athletes with lower leg amputation, as well as orthoses and braces for athletes with impaired lower leg function. The issues were typically which combinations of impairments have a large impact on cycling performance and which impairments have a small impact.

Issues brought up by the panel in the comment sections during Round 1 included:

- The impact of strength impairments in hip abduction and hip adduction.
- The impact of ankle muscle function.
- The issue that the currently used MMT scores hip muscle function four times (hip extension, flexion, abduction and adduction) and the ankle four times (plantar extension, dorsiflexion, supination and pronation), while the knee is scored twice only (extension and flexion).
- The lack of evidence regarding the Factor of Importance which is used to rate the importance of each muscle group.

Other difficulties in calculating the importance of different muscles in cycling were brought up by the panel:

- Changes in the racecourse topography will impact muscle groups differently (uphill, downhill, flats, corners).
- Changes in position on the bike will impact muscle groups differently (standing, sprinting, aero position).
- The impact of fatigue on different impairment types.

Comments from the research team: Racecourse characteristics are not part of this study, as these factors will always be of benefit or disadvantage to each individual athlete, just like it is in able-bodied sports: If a para–cyclist has an upper body impairment that decreases their performance in hills due to the inability to stand out of the saddle to, it can be compared to a heavy cyclist that is disadvantaged by hills or a small cyclist that is disadvantaged on flats. The impact of fatigue is not part of this study as the aim of classification in para–sports is to assess activity limitation while fatigue is related to training status and therefore is not taken into consideration in classification.

Round 2

The results of Round 1 showed that the panel was not in agreement regarding which muscles are more important in cycling performance. In this round, we will clarify this further with more background information and reformulated questions. The aim of this section is to follow up the panel’s impression of currently used classification methods.
Research in non–impaired cyclists

In general, the hip and knee muscles contribute with 40% each to the total power output on the bike, with hip extension being the most powerful action (Elmer et al, 2011). It has also been shown that the knee flexor muscles become more important relative to the knee extensor muscles during high-intensity cycling. This information indicates that the recruitment pattern of the leg muscles changes depending on the race type (sprint vs. endurance) and depending on the characteristics of the racecourse (hills vs. flats).

Hip extensor muscles in cycling

Research in non–impaired cyclists have shown that the hip extensor muscle, Gluteus Maximus, is active at the same time as the knee extensor muscles, suggesting Gluteus Maximus contributes to produce power during the pedal downstroke. The muscles Semimembranosus, Semitendinosus and Biceps Femoris are activated in the late part of the downstroke and contribute to the power output. These muscles are part of the hip extensor muscle group, but they also act as knee flexors as they reach over both the hip and the knee joints. (da Silva et al, 2016; Bini et al, 2016; Dorel et al, 2008; Jorge & Hull, 1986)

Knee extensor muscles in cycling

Research in non–impaired cyclists have shown that three important knee extensor muscles for power production in cycling during the downstroke are Vastus Medialis, Vastus Lateralis and Rectus Femoris. Rectus Femoris is also activated around the highest point of the pedal revolution (at 0°/360° of one pedal revolution), suggesting it also contributes to controlling the direction of force when moving the pedal from the upstroke motion to the downstroke motion. (da Silva et al, 2016; Bini et al, 2016; Dorel et al, 2008; Jorge & Hull, 1986)

Lower leg muscles in cycling

It has been shown that the lower leg muscles contribute around 15% of the total power (Elmer et al, 2011). Gastrocnemius and Soleus performs ankle plantar extension. The lower leg muscles that supinate and pronate the foot are mainly the same muscles that extend and flex the ankle: Tibialis Anterior performs dorsiflexion and supination, Tibialis Posterior performs plantar extension and supination, Peroneus Longus performs plantar extension and pronation. Research in non–impaired cyclists have shown that the muscles Gastrocnemius, Soleus, Tibialis Anterior, Tibialis Posterior and Peroneus Longus are activated around the lowest point of the pedal revolution (at 180° of a pedal revolution). It has therefore been suggested that these muscles are mainly contributing to controlling the direction of force when the pedal is moved from the downstroke to the upstroke motion.

Other muscles of the thigh

The muscles described above have been extensively researched and their contribution to the pedal cycle has been confirmed several times (for example, see references in the text above). There is a lack of research in other leg muscles (e.g., abductor and adductor muscles of the thigh) due to the difficulty in using surface electromyography to measure activation of muscles that are located deep in the leg. Therefore, it has been difficult to draw conclusions whether these muscles and muscle groups significantly contribute to power production in cycling. (Bini et al, 2008; Dorel et al, 2008; Chapman et al, 2006)

Lower leg prostheses

Research in athletes with or without lower leg prostheses have shown that there was no statistically significant difference in race speed between C4–athletes with lower leg prostheses and the other C4–athletes (according to data from international track championships and Paralympics) (Dyer, 2018). Other research has shown that athletes with a lower leg prosthesis could compen-
sate for the amputation and utilize a similar technique and performance as non-impaired cyclists (Childers and Gregor, 2011). The results of Childers and Gregor (2011) showed similar race speeds when the athletes used either a stiff or flexible prosthesis. The current rules in the Athlete Evaluation Session are stated below:

(UCI Cycling Regulations, Part 16 Para–cycling, Version on 01.01.2021, 16.4.014)

- “The Athlete must attend the Evaluation Session in sports attire and must bring all equipment used in competition, including the bicycle, tricycle or handcycle, helmet, orthopaedic brace(s), prosthesis(es), and any other equipment.
  - Any modification of the bicycle, tricycle or handcycle (e.g. support) must be submitted to the UCI for approval in accordance with the established procedure and article 16.14.002;
  - The Athlete is evaluated together with his/her orthopaedic brace/prosthesis and may entail a change of Sport Class or even division.
  - All orthopaedic braces/prostheses must be submitted to the UCI for its approval in accordance with the established procedure;
- The Athlete must disclose the use of any medication and/or medical device/implant to the Classification Panel.”

The upper body in cycling
It has been shown that the upper body (trunk and arm muscles) contributes around 5% of the total power (Elmer et al, 2011). For example, when sprinting, climbing, and cycling in a standing position, the arms pulling on the handlebars is a beneficial characteristic to increase power (Bouillod & Grappe, 2018; Turpin et al, 2017).

Questions Round 2: Manual Muscle Testing (MMT) and the Minimum Impairment Criteria (MIC) of the lower body

Q1.1 4 points in the MMT test is full movement against resistance, while 5 points is full movement against heavy resistance. 4 and 5 points both show that the athlete has full function in the tested movement, but different strength.

I believe that the difference between 4 and 5 points is redundant and could therefore be combined into one single score, i.e., the new highest score will be defined as full movement against any resistance.

- Completely agree
- Somewhat agree
- Somewhat disagree
- Completely disagree
- Not able to answer

Please add any additional comments you may have:

Q1.2 I believe that the Factor of Importance (see Table 1) should be removed from the MMT evaluation in classification since there is no evidence behind the development of these numbers.

- Completely agree
- Somewhat agree
- Somewhat disagree
- Completely disagree
- Not able to answer

Please add any additional comments you may have:

Q1.3 Instrumental tests for assessing muscle strength in classification could be developed to use ratio–scaled and objective measurements. As an example, the tests could be isometric strength tests measured with force transducers, or dynamic strength tests performed on a cycle ergometer (see images below). Tests like these require equipment which complicates the logistics, costs, and practical procedures of classification.

I believe that the MMT test should be continuously used in classification, after the modifications of question 1.1 and 1.2 have been adopted.

- Completely agree
- Somewhat agree
- Somewhat disagree
- Completely disagree
- Not able to answer

Please add any additional comments you may have:

Q1.4 The MIC for impaired muscle power, impaired PROM, and limb deficiency in the lower body is inability to do a one–legged heel–raise.

The MIC does not clearly define how to treat athletes that have the ability to do a one–legged heel–raise, but instead have muscle strength impairments in the knee or hip muscles.

Research indicates that the muscles of the ankle contribute approximately 15% to the total power produced in cycling. Research indicates that the muscles of the ankle contribute approximately 15% to the total power produced in cycling. The muscles tested in one–legged heel–raise are the muscle group responsible for extending the ankle, i.e., the calf muscles.
I do not believe that this MIC accurately represents the minimum level of impairment in the lower body that will decrease cycling performance.

☐ Completely agree
☐ Somewhat agree
☐ Somewhat disagree
☐ Completely disagree
☐ Not able to answer

Please add any additional comments you may have:

Q1.4.a (Respond to this question if you responded Completely agree or Somewhat agree on Q1-4)

Please indicate which MIC for impaired muscle power, impaired PROM, and limb deficiency in the lower body that you believe should be the limit in order to be eligible for para-cycling?

Note: It is assumed that impairments of a corresponding nature are also included in the suggested MIC.

Note: Walking on the heels is a test of the dorsiflexor muscles of the lower leg (the muscle group on the frontside of the lower leg).

☐ The inability to do a one-legged heel-raise and the inability to walk on the heels in one leg.
☐ The inability to do a one-legged heel-raise and the inability to walk on the heels in both legs.
☐ The inability to perform knee flexion against gravity in one or both legs.
☐ The inability to perform knee extension against gravity in one or both legs.
☐ Other, please explain your answer.
☐ Not able to answer

Please add any additional comments you may have:

Questions Round 2: Lower body function in cycling

Q1.5 Research indicates that the muscles of the hip and knee contribute approximately 80% to the total power produced in cycling.

I believe that the muscle groups performing hip and knee extension and flexion should be rated principle muscle groups and be given high importance when assessing muscle strength in classification.

☐ Completely agree
☐ Somewhat agree
☐ Somewhat disagree
☐ Completely disagree
☐ Not able to answer

Please add any additional comments you may have:

Q1.6 Research indicates that the muscles of the ankle contribute approximately 80% to the total power produced in cycling.

I believe that the muscle groups performing ankle extension and flexion should be rated supporting muscle groups and be given low importance when assessing muscle strength in classification.

☐ Completely agree
☐ Somewhat agree
☐ Somewhat disagree
☐ Completely disagree
☐ Not able to answer

Please add any additional comments you may have:

Q1.7 I believe that athletes with above knee amputation (i.e., transfemoral amputation) that are pedaling the bike using only one leg should compete in a class separate from athletes with other impairment types.

☐ Completely agree
☐ Somewhat agree
☐ Somewhat disagree
☐ Completely disagree
☐ Not able to answer

Please add any additional comments you may have:

Q1.8 I believe that athletes with impaired lower leg strength or PROM should be allowed to wear orthoses/braces that have been approved in classification during competition, as currently is the rule.

☐ Completely agree
☐ Somewhat agree
☐ Somewhat disagree
☐ Completely disagree
☐ Not able to answer

Please add any additional comments you may have:

Q1.8.a (Respond to this question if you responded Somewhat disagree or Completely disagree on Q1.8)

I believe that athletes with impaired lower leg strength or PROM should never be allowed to wear orthoses/braces in competition.
Questions Round 2: Upper body function in cycling

Q1.9 The MIC for impaired muscle power, impaired PROM, and limb deficiency in the upper body is inability to form and maintain a cylindrical grip.

The MIC does not assess grip strength, the ability to release the grip, hand and finger coordination, or the muscle strength of the upper arms and shoulders. Research indicates that the muscles of the upper body (arms and trunk) contribute approximately 5% to the total power produced in cycling. The muscles tested in a gripping task are the muscle group responsible for flexing the wrist, i.e., the muscles of the forearm.

I do not believe that this MIC accurately represents the minimum level of impairment in the upper body that will decrease cycling performance.

Please add any additional comments you may have:

Q1.9.a (Respond to this question if you responded Completely agree or Somewhat agree on Q1.9)

Please indicate which MIC for impaired muscle power, impaired PROM, and limb deficiency in the upper body that you believe should be the limit in order to be eligible for para–cycling?

Note: It is assumed that the suggested MIC also include impairments that are corresponding to the suggested MIC.

Q1.10 I believe that athletes with only upper body impairments of any severity should compete in a class separate from athletes with other impairment types.

Please add any additional comments you may have:

Q1.10.a (Respond to this question if you responded Somewhat disagree or Completely disagree on Q1.10)

I believe that it depends on the severity of the upper body impairment whether these athletes should compete in a separate class. Please explain your answer.

Please add any additional comments you may have:

Results from Round 1

The results of whether the C– and T–divisions are a continuum (i.e., C1 is the natural next step after T2) or whether they are two separate divisions (i.e., C1 is not a higher class than T2) showed that the questions were formulated to allow for different interpretations. Many responses agreed both that the C and T–divisions are separate (66%) and a continuum (68%). The panel was in consensus (81%) that a re–evaluation of the number of C–classes for athletes with musculoskeletal impairments is needed. A majority (60%) of the panel did not believe that re–evaluation of the number of C–classes for athletes with coordination impairments would be needed, and 53% did not believe that the number of T–classes would need re–evaluation.
The comments revealed the main issue to be whether athletes should be able to choose if they want to compete in C or T, and whether the classification rules should be the sole factor that determines if an athlete should compete in C or T. According to several comments, this issue is mainly derived from whether T-athletes can ride a two-wheeled bicycle or not.

Approximately two thirds of the panel argued that it should not be a choice to compete in C or T, leaving it to the classification system to clearly define which class the athlete should be in. Furthermore, since it should not be a choice, athletes who can ride a bicycle should always compete in C:

- Athletes that can train and ride on a bicycle should compete in C. It would not be fair to athletes who ride trikes to compete against athletes who ride bicycles in practice but ride trikes in competition.
- Athletes should not be able to choose between C and T because not every athlete can make this choice due to their impairment.
- Athletes who can ride a bicycle have an advantage in balancing and manoeuvring a bicycle compared to athletes who cannot ride a bicycle, which will give them an unfair advantage when they compete on trikes.
- T should be for athletes whose impairments prevent them from riding a bicycle.
- Athletes should not be able to choose division as they might simply choose the division that will result in the highest chances of winning.
- Allocation to C or T should not depend on how much effort the individual athlete has given to practice riding a bicycle.

Approximately one third of the panel argued that it should be a choice to compete in C or T, assuming the athlete is eligible for the class that they choose:

- Athletes should be able to choose their equipment themselves.
- Athletes should be able to choose between C and T depending on what they are more comfortable with.
- There is a difference between being able to ride a bicycle and being able to ride a bicycle efficiently. Therefore, athletes should be allowed to choose T even if they have proved that they can ride a bicycle.
- There is a difference between being able to ride a bicycle and being able to ride a bicycle safely. Therefore, athletes should not be forced to compete in C when their own and others’ safety cannot be guaranteed.

Additionally, a few comments expressed concerns about cheating and misrepresentation:

- Athletes need to practice riding a bicycle. They should not choose a trike because they believe to have larger chances of winning in the T-division. It is an ethical issue.
- To the public, para-cycling might appear unfair when athletes who are known to ride bicycles compete in the T-division.

Round 2

Responses from both sides highlighted the importance of the classification rules to state the definitions of the C and T-divisions more clearly, including a definition of the cut-off between the two divisions. The aim of this section is to clarify if the panel can come closer to an agreement regarding the definitions of the C and T-divisions.

A summary of the panel’s arguments as to why C and T should be two separate divisions is presented, and after that a summary of the arguments as to why C and T should not be two separate divisions is presented. We ask you to carefully read and ponder the two following paragraphs, and thereafter respond to the questions.

Arguments as to why C and T are two separate divisions:

No class is inferior to another. If C and T are laid out like a continuum, it implies that T-athletes should always strive to become C-athletes, which might not be the goal for everyone. Consequently, the T-division should be reserved for athletes who have a condition rendering riding a bicycle impossible. Considering that the aim of classification is to assess the athletes’ activity limitation in cycling, classification should not be about the equipment (i.e., the bicycle/trike). If C and T are separate divisions, it also means that athletes can change division for any reason (assuming the athlete is eligible). This would give the opportunity for T-athletes to also compete on a bicycle in track races (competition on the track are not available for trikes). It was highlighted by the panel that even if an athlete can choose C or T, they have to pick either or; athletes should not be allowed to race in the C-division one day and in the T-division the next day.

Arguments as to why C and T are not two separate divisions:

All athletes should be riding a bicycle in C if they are capable of it. T should only be for athletes prevented from riding a bicycle. Because of this, athletes who can ride or train on a bicycle should not be allowed to compete in T. Athletes who can ride or train on a bicycle must compete in C. Therefore, choosing between C and T should not be an option. If athletes can choose between C and T (assuming they are eligible for both divisions), that would not be fair from an ethical point of view as not all athletes have the option to choose due to their activity limitation.

Questions Round 2

Q2.1 Consider a test battery of static and dynamic balance tests that has been developed to distinguish between the athletes’ presumed abilities to handle a bicycle. The tests would assess postural control (standing tests) and trunk control (seated tests), and the athletes’ test scores would determine which class (in the C- and T-division) they will be allocated to.

Do you agree with the following statement?

Statement: When an athlete’s test score shows that they are eligible for the T-division, it will not matter whether or not they can ride a bicycle during their private cycling practice since the classification score has shown that the athlete is not eligible for the C-division.

- Completely agree
- Somewhat agree
- Somewhat disagree
- Completely disagree
- Not able to answer

Please add any additional comments you may have:
Results from Round 1

The panel was not in agreement on whether athletes with coordination impairments (hypo-
tonia, ataxia, or athetosis) should be competing separately from athletes with musculoskeletal
impairments (impaired muscle strength, impaired PROM, limb deficiency, or leg length differ-
ence).

Participants that answered Yes (50%) provided the following reasons to split the two impairment
types:
• It is too challenging to match coordination impairments to musculoskeletal impairments
and it will be difficult to create an evidence–based classification system that combines
the two impairment types.
• It is more important to ensure that competition is fair, than to have large classes.

Participants that answered No (50%) provided the following reasons to not split the two impair-
ment types:
• The current classification system provides classes that are fair enough and the two im-
pairment types can be roughly compared in regards of activity limitation.
• It is more important to keep down the number of classes to increase the competitive as-
pect of para–cycling.

Several panel members believe that there is too large of a difference between the two impair-
ment types, and that it is not fair for them to compete in the same class when the impairment
types are not comparable. It was suggested that two new C-classes for athletes with coordina-
tion impairments are introduced, while the number of C-classes for athletes with musculoskele-
tal impairments could be decreased.

Several panel members’ standpoint was that the classification system is fair enough and that
adjusting the classes will not improve anything at the time being. Instead, it was suggested that
athletes should be evaluated in classification more regularly to ensure fair competition. Fur-
thermore, as it is the activity limitation and not the impairment type that is evaluated in classifi-
cation: athletes should not be separated based on impairment type.

Round 2

In this round, the aim is to clarify which approach the panel believes to be the most appropriate
to identify what might be the most applicable number of classes.

Based on the comments from Round 1, the panel was divided into two perspectives which were
grounded in a long–term view on how to increase para–cycling participation, based on the
comments from Round 1.

Perspective A:
• Separating coordination and musculoskeletal impairments will provide fair competition
which will increase participation when athletes see that para–cycling is a fair sport.

Perspective B:
• Not separating coordination and musculoskeletal impairments which results in fewer
classes which will increase participation when athletes see that para–cycling is an exciting
and competitive sport.

Questions Round 2

Q3.1 Consider the two perspectives A and B described above. Which of the two perspec-
tives to you agree with more?
If you do not fully agree with any of the two perspectives, choose the perspective you
might be leaning more towards.
If you do not lean towards any of the two perspectives and feel as though you cannot
answer the question, please explain your answer in the comments.

☐ I agree more with perspective A
☐ I agree more with perspective B
☐ Not able to answer

Please add any additional comments you may have:
DELPHI STUDY ROUND 3

INSTRUCTIONS

• This questionnaire is shorter than the previous ones as consensus has been reached on many topics.
• Each section starts with a summary of the Results from Round 2.
• After the results of the previous round have been presented, Round 3 starts in which you will get any additional background in order to respond to Questions – Round 3.
• For each question, you have the option to respond Not able to answer. You will also have the option to explain your answer in the text field for each question. Your comments are very valuable to us so we encourage you to take the time to explain your answers.

Results from Round 2 – Manual Muscle Testing (MMT)

The panel was not in agreement regarding the merging of score 4 and 5 in the Manual Muscle Test (MMT):

• 52% agreed to merge the scores. 48% did not agree to merge the scores.

The Factor of Importance (FOI) is a score designated to each muscle group and is multiplied with the MMT result of that specific muscle group, to stress the importance of certain muscle groups in cycling. The panel was not in agreement regarding the FOI in the MMT:

• 48% of the panel agreed that the FOI should be removed from the MMT, but it was also expressed that the FOI needs to be based on research. 52% of the panel wants to keep the FOI, and this group too expressed that the factors need to be based on research.

• The comments show that a large part of the panel agrees on keeping some kind of importance factor for different leg muscle groups.

95% agreed that the hip and knee muscle groups should be rated principle muscle groups, and 86% agreed that the ankle muscle groups should be rated secondary muscle groups. Consensus was reached in this question.

76% of the panel agreed that the MMT should be used in para–cycling classification, with modifications. Consensus was reached in this question.

Questions Round 3

In Round 1 of the Delphi study, results from data collected in 26 elite C–division para–cyclists were presented. Figure 1 shows six graphs of the MMT results of left and right leg separately: hip extension (Figure 1a, b), knee extension (Figure 1c, d), and ankle plantar extension (Figure 1e, f), scored on a 0–5 point scale. The MMT results are plotted against the maximal dynamic strength test (as seen in Figure 2).

These graphs show that an MMT score of 4 or 5 results in similar outcomes in the dynamic strength test. It can be concluded that scoring 4 or 5 (or even less in ankle plantar extension;
Results from Round 2 – Braces/orthoses and above knee amputation

The panel was in consensus regarding the use of braces/orthoses in para–cycling competitions: 83% agreed that braces/orthoses that have been approved in classification should be allowed to be worn during competition.

Regarding athletes with an above knee amputation (transfemoral amputation), 72% of the panel believed that athletes with above knee amputation, using only one leg to pedal the bike, should compete in a class separate from athletes with other impairment types. Consensus was not fully reached in this question.

Questions Round 3

1.2 Consider the comments above from the results of the previous round.

If the five C–classes were re-arranged in order to prevent an increase in medal events, do you believe that one of the new classes should be open only for athletes cycling with one leg?

- Completely agree
- Somewhat agree
- Somewhat disagree
- Completely disagree
- Not able to answer

Results from Round 2 – Minimum impairment criteria (MIC) in the C–division

- 97% agreed that the MIC of the lower body does not accurately represent the minimum level of impairment that will reduce cycling performance. Consensus was reached in this question.

- 76% agreed that the MIC of the upper body does not accurately represent the minimum level of impairment that will reduce cycling performance. Consensus was reached in this question.

- There was no consensus regarding which exact level and severity of impairment that would be enough to affect cycling performance for either the lower or upper body. Several suggestions were given from the panel (described in each of the tables for lower and upper body MIC).

- 74% agreed that athletes with only upper body impairments should compete in a class separate from athletes with other impairment types. Consensus was not fully reached in this question.

Questions Round 3

To develop the MIC we first need to come closer to a definition of how to measure muscle function in classification. We will focus on the MIC in the lower body, as there is a limitation in data available for the upper body in cycling in both able–bodied athletes but especially in para–cyclists.

Below is a suggestion of how the MMT scores can be rearranged from a 0–5 point scale into a 0–2 point scale (Table 2a and 2b). Using a 0–2 point scale will make classification easier and increase the reliability of classification. The 0–2 point scale is used in para–canoe and has shown reliability to be used in classification in the Paralympic sport of para–canoe (Rosén et al, 2020):

- 3 classifier teams independently allocated 12 athletes to the same classes, and the test batteries (0–2 point scales) showed excellent interrater reliability (interrater reliability = the reliability between the classifiers, i.e., each classifier independently scored each athlete in the same way).

- The 0–2 scale for para–canoe also included sport–specific range of movement (ROM) in the same study, and the new suggestions of how to include ROM in MMT in para–cycling is described below in the table.

- The 0–2 point scale classification system has been approved by the International Paralympic Committee and is used in para–kayak and para–va’a, which means the change from 0–5 to 0–2 has already been done within Paralympic sports.

There are several similarities between para–cycling and para–canoe, e.g., the legs are mainly only used in the sagittal plane (extension and flexion, i.e., no side movements are performed), the legs are used mainly for pushing against the pedal (in para–cycling) or pushing for support (in para–canoe), and both sports are performed seated, i.e., certain trunk control is needed.

Consider Table 2b Suggested MMT scores for impaired strength and PROM. The range of movement in which the muscle strength test should be conducted in has not been defined here. The angles for the hip, knee, and ankle that the MMT is currently conducted in can be viewed in Figure 3.
Do you agree with the definitions below to meet the criteria of 0, 1 and 2 points when both muscle function and range of movement in the legs are considered?

**Note:** In this question, you can check several options that you agree with.

**0 points:** "Active movement against resistance" in less than 80% of the ranges described in Figure 4. I.e., the athlete has impaired PROM of 10° or more in the hip, 12° or more in the knee, or 4° or more in the ankle.

**1 point:** "Active movement against resistance" in minimum 80% of the ranges described in Figure 4. I.e., the athlete has impaired PROM of 1–10° in the hip, 1–12° in the knee, or 1–4° in the ankle.

**2 points:** "Active movement against resistance" in the full ranges described in Figure 4. I.e., the athlete has no impairments in the range of movement.

The range of the hip is satisfactory.

The range of the knee is satisfactory.

The range of the ankle is satisfactory.

I agree in general, but adjustments to the numbers are needed.

I disagree with this system. Please state your reasoning in the comment field below.

Not able to answer
Consider Table 2b Suggested new MMT scores for impaired strength and PROM, and Figure 4 that describes the Principle and Supporting muscle groups.

1.4 Which of the suggestions below do you believe meets the minimum impairment criteria (MIC) in the muscles of the legs?

A. Loss of function in at least 1 principal muscle group in 1 leg.
B. Loss of function in at least 2 principal muscle groups in 1 leg.
C. Loss of function in at least 2 principal muscle groups across both legs.

Loss of function means a score of 1 or less in the tested muscle group.
Results from Round 2 – T-athletes with the ability to ride a two-wheeled bike

The previous results from Round 1 showed that the main issue of the T- and C-divisions are whether T-athletes able to ride a two-wheeled bicycle should or should not be eligible in the T-division. After re-formulating the question and suggesting a developed classification system that would differentiate between T- and C-athletes in classification, this topic is no closer to consensus after Round 2.

48% of the panel agrees that it does not matter what bike you can ride in training as long as you compete in the class you have been allocated to, while 52% of the panel disagrees by saying that riding a two-wheeled bike during training should exclude that athlete from competing in the T-division.

Questions Round 3

2.1 Please choose one alternative (A or B) per question: If you are not able to answer these questions, please move on to the next page without checking any of the boxes.

Question 1 A Two-wheeled bikes and three-wheeled trikes are different to ride, and therefore, riding a two-wheeled bike in training will not be of advantage when competing in the T-division. □ I agree with A □ I agree with B

B Having the coordination and balance to ride a two-wheeled bike in training will be of advantage when competing in the T-division.

Question 2 A It is better for an athlete to not be eligible for the T-division because they can ride a two-wheeled bike in training. □ I agree with A □ I agree with B

B It is better for an athlete to be eligible for the T-division in spite of being able to ride a two-wheeled bike in training.

Question 3 A A clear cut-off based on ability to ride a two-wheeled bike should state whether an athlete is eligible for the C- or T-division. □ I agree with A □ I agree with B

B A clear cut-off based on impairment severity should state whether an athlete is eligible for the C- or T-division.

Results from Round 2 – Perspective A or B

72% agreed with perspective A: “Separating coordination and musculoskeletal impairments will provide fair competition which will increase participation when athletes see that para-cycling is a fair sport.”

28% agreed with perspective B: “Not separating coordination and musculoskeletal impairments will result in fewer sport classes which will increase participation when athletes see that para-cycling is an exciting and competitive sport.”

Questions Round 3

2.2 Consider a scenario in which the number of medal events stay the same as currently is (i.e., 5 C-classes and 2 T-classes, men/women), then, do you agree that athletes with coordination impairments and athletes with musculoskeletal impairments should compete in separate classes?

□ Completely agree □ Somewhat agree □ Somewhat disagree □ Completely agree □ Not able to answer