International Tennis Federation Classification Working Group:

2020-2021 Review of the Minimal Impairment Criteria and Recommendations

Corresponding author:
Prof B.M. Pluim
E-mail b.pluim@knltb.nl
16 September 2021

Table of Contents

1. Introduction

The International Tennis Federation (ITF) aims to promote a healthy, inclusive and sustainable society. Tennis is an ideal sport to improve and maintain physical activity levels of the population, with all the associated health benefits, as a large majority of the people who play tennis also play well into their later lives.

There are 87 million tennis players around the world and the ITF is there to support each one of them. The ITF aims to increase participation in tennis for people of all ages, genders, playing standards and physical abilities.

Wheelchair tennis is a form of tennis that was developed with the broad aim of providing competitive tennis opportunities for players who have impairments that adversely affect the prospect of a player's competitive success.

To ensure fair competition in wheelchair tennis, a classification system is necessary to define who is eligible to compete in ITF Wheelchair Tennis Tournaments. Players are grouped into sport classes, based on the extent of their impairment.

The ITF process for assessing eligibility for wheelchair tennis is as follows:

1. Determine whether the prospective player has an eligible impairment type;
2. evaluate whether the player has a health condition that can lead to an eligible impairment type ("underlying health condition");
3. and, if the player has an eligible impairment type, determine whether the eligible impairment type meets the minimum impairment criteria.

The aim of this document is to describe the ITF process for reviewing and proposing updates for the Minimum Impairment Criteria (MIC) for impaired muscle power, impaired passive range of movement, limb deficiency and leg length difference for the lower extremities for wheelchair tennis.

Alongside the proposed enhancements to the MIC, recommendations are provided to improve the process for determining eligibility for wheelchair tennis based on the expertise and insight gathered from Classification Working Group and Expert Group members, medical and tennis experts, and feedback from stakeholder consultation webinars.

2. ITF Wheelchair Tennis Classification Working Group and Expert Group

The ITF governs classification for wheelchair tennis within the guidelines and framework of the International Paralympic Committee (IPC) Classification Code. To ensure the classification system is fair and robust, the ITF periodically reviews its classification system to ensure the system is evidence-based, applies to tennis, and is reliable and objective.

In 2020, the ITF tasked a group of experts, the Wheelchair Tennis Classification Working Group, led by ITF Classification Research Consultant Professor Babette Pluim, to review the current classification rules with an initial focus on the MIC for the open class of wheelchair tennis.

The general duties of the Classification Working Group are as follows:

- supporting the delivery of findings based on thorough research and meaningful contributions from medical experts and industry stakeholders;
- supporting the wheelchair tennis community's understanding of such findings;
- recommending changes to the existing classification framework that are fit for purpose, fair and relevant to wheelchair tennis; and
- providing on-going consultation to the ITF on additional areas of research and classification review.

The Wheelchair Tennis Classification Working Group consists of the following individuals, who have coordinated with a wider team of international experts:

- Prof Babette Pluim (Chair)
- Mr Cain Berry
- Mr Iain Gowans
- Dr Machar Reid
- Prof Nick Webborn
- Mr Sam Williamson

A further group of experts (the Expert Group), comprising members with sports medicine, sports science and sports ethics experience, was tasked with reviewing existing research evidence (collated under the supervision of the Classification Working Group), in the context of their knowledge and practical experience in sports medicine and science, and understanding of the physical demands of tennis, and using consensus methods make recommendations for:

i. updated wheelchair tennis minimum impairment criteria (MIC); and
ii. testing protocols to assess MIC for wheelchair tennis players.

The Expert Group consists of the following individuals:

- Dr Clare Ardern (Chair)
- Mr Cain Berry (Co-chair)
- Dr Silvia Camporesi
- Dr Kristina Fagher
- Prof Christa Janse van Rensburg
- Dr Marjolein van der Krogt
- Prof Frans Nollet
- Prof Babette Pluim
- Prof Nick Webborn
- Mr Sam Williamson

In addition to the individuals named above, the following wider group of researchers and experts ("Contributors") provided support to the Classification Working Group to complete a thorough literature review of existing and relevant research in tennis and wheelchair tennis and/or provide input to help refine and/or resolve any outstanding issues following the work of the Expert Group:

- Mr Alex Cockram
- Dr Neil Heron, MD
- Dr Rien Heijboer, MD
- Mr Aldo Hoekstra, MSc
- Ms Marleen Jansen, MSc
- Prof. Karim Khan, AO
- Ms Kirsty Elliott, BSc
- Ms Nikki Kolman, MSc
- Dr Matthew Lester, PhD
- Mr Jeffrey van Limpt, PT
- Dr Reinoud Meyer, MD
- Dr Fabio de Oliveira, PT, PhD
- Dr Sean O'Connor, PT, PhD,
- Ms Linda Schoonmade, MSc
- Dr Erik Slim, MD PhD
- Dr Sjoerd Stufkens, MD PhD
- Dr Jane Thornton, MD, PhD
- Dr Sandra Titulaer, MD
- Prof. Evert Verhagen, MSc, PhD
- Dr Wart van Zoest, MD
- Professor Sean Tweedy, PhD

See section 15 for the full list of experts with their affiliations.

3. Classification Working Group Task, Workplan and Timeline

The task of the Classification Working Group was to:

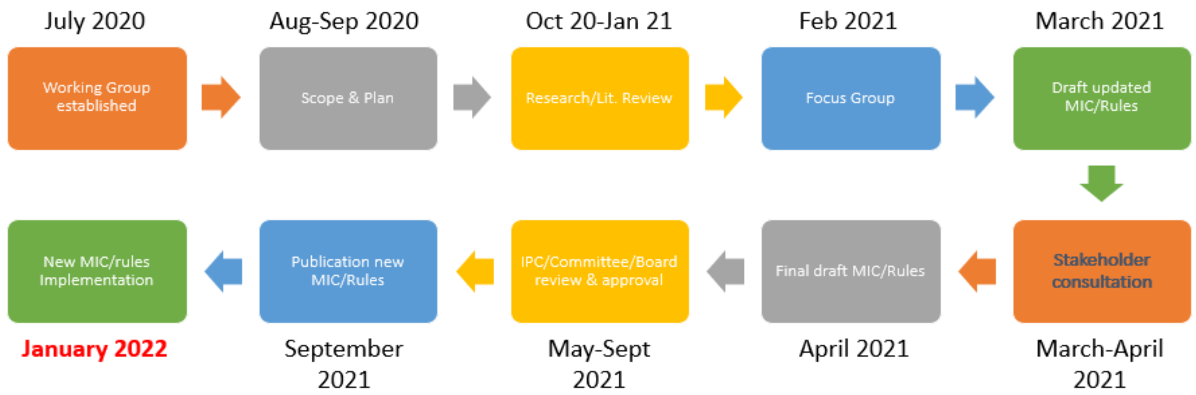
1) **Review** the Classification Rules for Wheelchair Tennis with respect to the MIC used to determine player eligibility.
2) **Refine** the Classification Rules, considering a broad base of content (literature review and expert consultation) and consulting and engaging the tennis community (stakeholder engagement)
3) **Recommend** updated Classification Rules for Wheelchair Tennis.

Classification Working Group Guiding Principles:

- The ITF is committed to Wheelchair Tennis being inclusive, with the MIC being based upon the demands of the sport of tennis.
- The demands of tennis must be based on science, research and medical expertise, related to movement and court coverage, as well as stroke making.
- The MIC should be defined based on scientific research, which assesses the impact of impairments on the sport's activities.

Workplan and Timeline:

July 2020	: Classification Working Group established
Aug/Sept 2020	: Outlining scope and plan
Oct 2020/Jan 2021	: Literature review
Feb/April 2021	: Expert Group meetings
March 2021	: Draft updated MIC and classification rules
March/April 2021	: Stakeholder consultation
April/May 2021	: Final draft MIC and classification rules
May-Sept 2021	: IPC/ITF Wheelchair Committee/ ITF Board review & approval
September 2021	: Publication of new MIC and classification rules
January 2022	: Implementation of new MIC and classification rules



4. The Ethical Basis for Classification

The fair equality of opportunity principle (FEOP) underlies the construction of classes in sport (Loland, 2021; Loland & Hoppeler, 2012; Loland & McNamee, 2012). It has been defined as follows:

> "Inequalities between sport competitors with significant and systematic impact on performance that the competitors cannot impact and control in any reasonable way ought to be eliminated or compensated for".

It is a normative, ethical principle. According to this principle, the impact of inequalities over which individuals have little or no control should be regulated, so that athletes with similar attributes, talents and ambitions receive equal opportunities and equivalent prospects for competitive success.

When significant inequalities that athletes cannot control are removed or compensated for, players can be measured and ranked according to performance and skills that are the outcome of their own efforts and talents.

Three criteria have to be met, where the inequality: 1) exerts a significant impact on performance, 2) exerts a systematic impact in most if not all competitions, and 3) is outside of the competitor impact and control. Typical classification schemes in sport are based on biological sex, age, body weight, and ability/disability.

Inequalities in strength, endurance, and technical and tactical skills are accepted and admired as part of the genetic lottery. However, an external advantage in strength or endurance from performance-enhancing substances or methods (doping) is not accepted in sport and regulated through the World Anti-Doping Agency (WADA).

In Paralympic sport, equality of opportunity requires that within each class, fairness is achieved by considering the impact of the impairment on the athletes' performance:

> "Classification aims to minimise the impact of the impairment on the athletes' performance so that sporting excellence determines which athlete or team is ultimately victorious. Ensuring that athletes are classified prior to competition is crucial to safeguarding the integrity and credibility of the competition".

The first step in classification for Para sport is to define whether the athlete has an eligible impairment type (e.g., impaired muscle power, limb deficiency). Sports classes are then defined depending on the particular impairment's significance and systematic impact (the so-called activity limitation). Players with different impairment types and similar (ideally identical) activity limitations can be grouped into the same sport class.

In wheelchair tennis, there are two main classes for athletes with an impairment: Open division, and Quad division. Participants in the Open division have an impairment resulting in a substantial loss of function in one or both lower extremities. Participants in the Quad division have an impairment resulting in a substantial loss of function in their upper extremities and/or trunk, in addition to the loss of function in their lower extremities.

To be eligible for participation in either the Open or the Quad division, the impairment needs to meet a certain minimum: the so-called minimum impairment criteria.

5. ITF Process for Assessing Eligibility for Wheelchair Tennis

To determine who is eligible to play wheelchair tennis, the ITF uses the following sequential process (see flowchart below):

1. Evaluate whether the prospective player has an eligible impairment type;

2. determine whether the player has a health condition that can lead to at least one eligible impairment type ("Underlying Health Condition");

3. and, if the player has an eligible impairment type, determine whether the eligible impairment type meets the minimum impairment criteria.

The seven impairment types that are eligible for wheelchair tennis are:

- Impaired muscle power
- Impaired passive joint range of movement
- Limb deficiency
- Leg length difference
- Hypertonia
- Ataxia
- Athetosis

In cases involving Limb Deficiency or Leg Length Difference, having an Underlying Health Condition is not required.

In this document, the minimum impairment criteria for impaired muscle power, impaired passive joint range of movement, limb deficiency and leg length difference for the lower extremities are reviewed.

The process for allocating players to a sport class is not addressed in this review.

FLOWCHART – Eligibility to participate in the Open Class of ITF Wheelchair Tennis Events

1. Does the Player have an Eligible Impairment?

Eligible impairments: impaired muscle power, impaired range of motion, limb deficiency, leg length difference, hypertonia, ataxia, athetosis

Non-eligible impairments: pain, hearing impairment, low muscle tone, hypermobility of joints, joint instability (unstable shoulder joint, recurrent dislocation of a joint), impaired muscle endurance, impaired motor reflex function, impaired respiratory function, impaired metabolic function, tics and mannerisms, stereotypes and motor perseveration

Medical Registration Form is assessed by the ITF or an Eligibility Assessment Panel

No → Player is Not Eligible

Yes ↓

Impaired muscle power, impaired range of motion, hypertonia, ataxia, athetosis

Yes ↓

Limb deficiency, leg length difference, **go straight to nr 4**

Yes ↓

2. Is there a Health Condition?
A pathology, acute or chronic disease, disorder, injury or trauma

Medical Registration Form is assessed by the ITF or an Eligibility Assessment Panel

No → Player is Not Eligible

Yes ↓

3. Is the Health Condition an Underlying Health Condition?

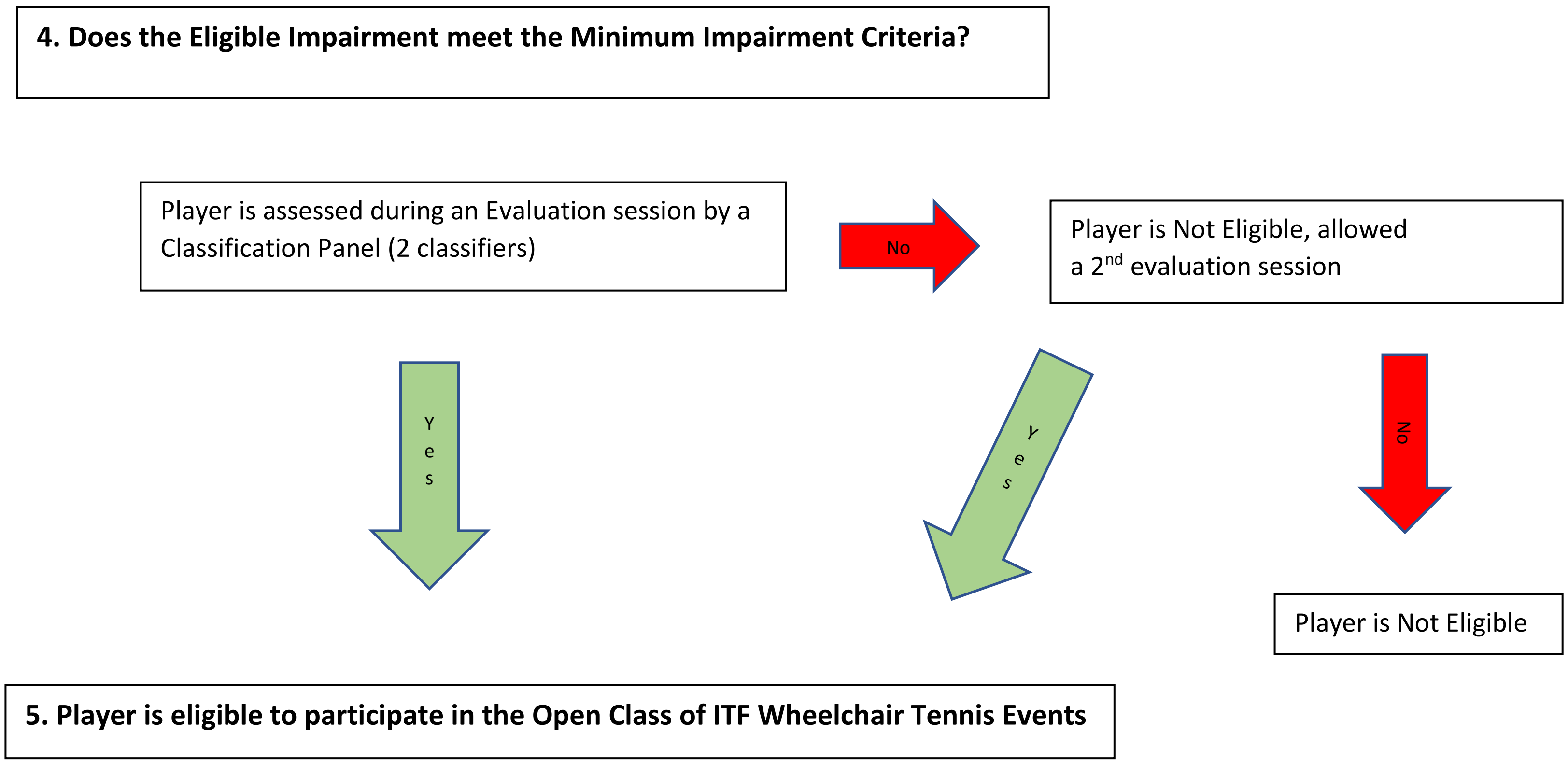
Underlying Health Condition: a health condition that may lead to an eligible impairment

Not Underlying Health Conditions: health conditions that do NOT lead to an Eligible Impairment. These are conditions that are primarily caused by pain, primarily caused by fatigue, or primarily caused by joint hypermobility or hypotonia.

Medical Registration Form is assessed by the ITF or an Eligibility Assessment Panel

No → Player is Not Eligible

Yes ↓


4. Does the Eligible Impairment meet the Minimum Impairment Criteria?
Player is assessed during an Evaluation session by a Classification Panel (2 classifiers)
No
Player is Not Eligible, allowed a 2nd evaluation session
Yes
Yes
No
Player is Not Eligible
5. Player is eligible to participate in the Open Class of ITF Wheelchair Tennis Events

6. General Standard

The Classification Working Group addressed the minimum impairment of four of the seven eligible impairments that apply to wheelchair tennis: impaired muscle power, impaired passive joint range of movement, limb deficiency, and leg length difference. The minimum impairment criteria that are currently in place for athetosis, ataxia and hypertonia were not reviewed at this stage, but they will be reviewed in the future, together with the entry criteria for the Quad division. Only the minimum impairment criteria for lower limb impairments were addressed.

An important stimulus for the review undertaken by the Classification Working Group is that the previous MIC were based on impairments that only caused a limitation in straight line running. However, more than 70% of movements in tennis are side to side, with less than 20% of movements in a forward direction, and an average of four changes of direction per rally (Pereira et al, 2017; Fernandez-Fernandez et al, 2007; Hornery et al, 2007; Kovalchik and Reid, 2007). These movement demands require careful consideration when assessing an individual's ability to play tennis.

The principle that was followed in developing the new MIC for these impairment types is that ITF-sanctioned wheelchair tennis competitions should be reserved for athletes who have impairments that cause sufficient activity limitation in competitive tennis.

The General Standard for what constitutes sufficient activity limitation in competitive tennis is:

> *A player may compete in ITF sanctioned Wheelchair Tennis Competitions if they have an eligible lower limb impairment type that will affect on-court mobility in able-bodied tennis in a way that is demonstrable, and which will adversely impact the prospects of competitive success for that player.*

7. Physical Demands of Tennis

Classification for wheelchair tennis should be based on the latest scientific research and evidence and be as sport-specific as possible (i.e., designed specifically for tennis). Impairments need to be considered in relation to the skill-specific requirements and physical demands of tennis. The previous MIC were based on straight-line running, but the updated criteria need to be based on the movements and directions needed for tennis.

Literature review

We conducted a systematic review on the physical demands of tennis, led by movement scientist Marleen Jansen. Match duration, average and peak running speed, distance covered and movement direction during play, rally pace, rally duration, effective playing time, shots per rally, number of strokes and stroke rate, number of changes of direction and number of accelerations/decelerations were reviewed. Where possible, we separated the numbers for males and females, for playing level (regional, national, and international) and for different playing surfaces (hard court, clay and grass).

The full paper will be submitted for publication in a scientific journal. We provide the headlines that are relevant for the determination of the MIC below.

Main findings

- More than 70% of movements in tennis are side to side; less than 20% of movements are in a forward direction and less than 8% are in a backward direction.
- A player covers 2-2.3. m per forward movement, and 2 m per lateral movement. Court depth (baseline to net) is 11.9 m, and court width is 8.23m (singles)/11 m (doubles).
- In men's and women's tennis, the mean number of change of directions per rally is 4.4 vs 3.9, respectively (Table 7.1). There are up to 1000 changes of direction in a best-of-3-set match.
- Mean distance run per match is 2-3 km for men (best of 5), and 1-2 km for women (best of 3).
- The distance covered per minute and per set is not significantly different between men and women (Table 7.1).
- Peak running velocities of men and women are around 18 and 15 km/h, respectively.
- Rapid accelerations and decelerations variously feature in the preparation for and recovery from groundstrokes and serving.

Table 7.1. Distance covered, changes of direction and peak running speed (mean (95% confidence interval))

	Distance/set (m)	Distance/minute (m)	COD/rally (n)	Peak running speed (km/h)
Men	607 (443-832)	48 (45.3-51.3)	4.4 (3.7-5.2)	18
Women	573 (372-882)	45 (41.5-49.7)	3.9 (2.4-6.2)	16,5

COD is Changes of Direction

8. MIC Recommendations

The ITF, IPC and Classification Working Group are committed to MIC that are based on the extent to which the athlete can execute the specific tasks and activities fundamental to tennis. Given the current MIC were developed from Para Athletics criteria, and based on straight line running, it was appropriate to review the MIC to ensure they align as far as possible and practicable to the physical demands of tennis.

Research on the physical demands of tennis highlighted the importance of lateral movement (70% of movements), changes of direction (up to 1000 changes of direction per match), the need for specific footwork, and the demand placed on the lower limbs in stroke-making, in addition to court coverage.

As such, the MIC needed to better reflect these physical characteristics of the sport.

In the following sections the existing minimum impairment criteria for those four eligible impairments for wheelchair tennis are presented, followed by the proposed new minimum impairment criteria.

An overview of the scientific evidence reviewed is presented in Appendices I to VIII.

9. MIC for Impaired Muscle Power

According to the International Standard for Eligible Impairments (September 2016): "Athletes with Impaired Muscle Power have a Health Condition that either reduces or eliminates their ability to voluntarily contract their muscles in order to move or to generate force".

The ability to contract muscles to move or to generate force, or to transmit the force produced by contracting muscles to in turn, produce sport-specific movement, can be influenced by disorders of the neurological and/or musculoskeletal systems.

Neurological disorders

Neurological disorders encompass diseases and trauma of the brain, spinal cord and nerves. Examples include, but are not limited to spinal cord injury, cerebral palsy, post-polio syndrome, multiple sclerosis, spina bifida, and peripheral nerve injury.

Neurological disorders affect the motor drive to the muscles, which impairs (or inhibits) the ability to appropriately contract the muscles and produce sport-specific movement. The disorder can be located at the level of the brain, the spinal cord, or the peripheral nervous system. When there is brain damage or malformation (e.g., cerebral palsy, multiple sclerosis) this may affect muscle control, muscle coordination, muscle tone, reflexes, posture and/or balance. With a spinal cord injury, signals that are sent from the brain through the spinal cord to voluntary muscles in different parts of the body, which normally lead to movement, cannot get through, which may result in paralysis or paresis (in incomplete lesions), spasticity, and muscle atrophy. When peripheral motor nerves are affected by a variety of diseases (e.g., Charcot Marie Tooth disease, (diabetic) polyneuropathy) or damaged (e.g., traumatic nerve lesion, radiculopathy), the conduction of signals along the nerve are disturbed, affecting the ability to regulate the muscles that are under conscious control. This may result in muscle weakness, cramps and twitching. Also, the signal transmission from the nerve to the muscle may be affected, such as in myasthenia gravies, which impairs muscle function.

Musculoskeletal disorders

Musculoskeletal disorders encompass diseases or damage of the muscles, joints, ligaments, tendons, bones and related structures. Examples include myopathy, muscular dystrophy, muscle necrosis after crush injury/compartment syndrome, rheumatoid arthritis, Perthes disease, and osteogenesis imperfecta.

Musculoskeletal disorders can affect the muscle contraction or the joint biomechanics. Altered joint biomechanics may result in a different lever arm and axis of rotation and/or muscle length-tension relationship and/or reduced joint stability. This may (i) limit the person's capacity to transmit the force generated by the contracting muscle to move the skeleton, or (ii) directly limit the capacity of the muscle(s) to generate force (in the case of poor length-tension relationship). For example, a foot with fixed/limited plantar flexion generates less force than a foot with normal plantar and dorsiflexion range of motion. This is due to a reduced lever arm at the ankle joint and poor length-tension relationship of the calf muscle. A coxa vara deformity of the hip (a reduced angle between the head and the neck of femur) after trauma, or as a sequela of Perthes disease, may result in weakness and ineffective action of the gluteus medius and gluteus minimus muscles. This weakness is characterised by the classical Trendelenburg gait sign.

Therefore, it is evident that both neurological conditions and musculoskeletal conditions can lead to a reduction in an individual's ability to generate force from a given muscle contraction.

Primary Criteria

As outlined, the MIC for wheelchair tennis must be specific to the physical demands of tennis. The muscle groups included in the current MIC for impaired muscle power are felt to be appropriate and therefore, have remained the same for the new MIC. However, the new MIC have a changed grading of these muscle groups to reflect the need in tennis for multi-directional, reactive, and explosive movement. An individual who meets the new MIC would have significant limitations in their ability to perform the movements needed to play tennis.

Currently the MIC for impaired muscle power are stated in terms of loss of muscle points, for example: *"Hip flexion loss of 3 muscle grade points (muscle grade of two)".* After discussion with the expert group, it was decided that a more transparent, and easier to understand method would be to state the highest allowable muscle grade strength.

Guidelines for the method of assessment are provided in Appendix 1, Part 2 of the ITF Wheelchair Tennis Classification Rules.

The new primary MIC for impaired muscle power are outlined in Table 9.1 below. For ease of comparison, the current MIC have been converted to state the highest allowable muscle grade strength. Athletes must meet one of the seven primary criteria to be eligible for wheelchair tennis.

See Appendix I for an overview of the process followed and the scientific evidence reviewed to propose the new, evidence-based minimum impairment criteria for impaired muscle power.

Table 9.1. Current and new primary criteria for impaired muscle power

Joint	**Movement**	**Current Primary Criteria (less than or equal to)** Athletes must meet at least one of the following	**New Primary Criteria (less than or equal to)** Athletes must meet at least one of the following
Hip	Flexion	2	3
	Extension	2	3
	Abduction	2	3
	Adduction	1	2
	Internal Rotation	N/A	3
	External Rotation	N/A	3
Knee	Flexion	N/A	2
	Extension	2	3
Ankle	Plantar flexion	2	3
	Dorsiflexion/Eversion/Inversion	2 in at least two of the three movements	3 in at least two of the three movements

Secondary Criteria

On reviewing the secondary criteria, it was the opinion of the expert group that additional muscle groups should be included to reflect the multi-directional movement demands of tennis. In particular, it was felt that the addition of more criteria relating to the muscles needed for lateral movement, which is vital in tennis, better reflects the demands of the sport. The secondary criteria have changed to reflect the need in tennis for multi-directional, reactive, and explosive movement. An individual who meets the new MIC would have significant limitations in their ability to perform the movements needed to play tennis.

The new secondary MIC for impaired muscle power are outlined in Table 9.2 below.

The secondary criteria are applied if a player has impaired muscle power but does not meet any of the primary criteria. Athletes must meet at least three of the secondary criteria to be eligible for wheelchair tennis.

Table 9.2 Current and new secondary criteria for impaired muscle power

Joint	**Movement**	**Current Secondary Criteria (less than or equal to)** Athletes must have a loss of at least 6 points, across at least 3 muscle groups	**New Secondary Criteria (less than or equal to)** Athletes must meet at least three of the following
Hip	Flexion	Included	4
	Extension	Included	4
	Abduction	Included	4
	Adduction	N/A	3
	Internal Rotation	N/A	4
	External Rotation	N/A	4
Knee	Flexion	N/A	3
	Extension	Included	4
Ankle	Plantar flexion	Included	4
	Dorsiflexion/Eversion/Inversion	N/A	4 in at least two of the three movements

In borderline cases, dynamometry or isokinetic testing should be considered in addition to the physical examination.

10. MIC for Impaired Passive Range of Movement

Currently the MIC for impaired passive range of movement are stated in terms of a deficit in range, for example: "*Hip deficit of > 60°*". After discussion with the expert group, it was decided that a more transparent, and easier to understand method would be to state the highest allowable range of movement.

As outlined, the MIC for wheelchair tennis must be specific to the physical demands of tennis. Given the multi-directional nature of the movement required for tennis, especially lateral movement, it is appropriate to include joint movements required to move in all directions as part of the MIC for wheelchair tennis. Therefore, for both the primary and secondary criteria for impaired passive range of movement, additional criteria have been added (see Tables 10.1 and 10.2).

Similarly, the MIC have changed to better reflect the movement demands of tennis. Athletes who meet the primary and secondary criteria for impaired passive range of movement will still have a significant limitation in their ability to perform the movements need to play tennis.

See appendices V (Review of impaired passive range of motion) and VI (Lower body joint angles per tennis stroke) for an overview of the process followed and the scientific evidence reviewed to propose the new, evidence-based minimum impairment criteria for impaired passive range of movement.

The new primary MIC for impaired passive range of motion are outlined in Table 10.1 below. Athletes must meet at least one of the primary criteria to be eligible for wheelchair tennis.

Guidelines for the method of assessment are provided in Appendix 1, Part 2 of the ITF Wheelchair Tennis Classification Rules.

Table 10.1 Current and new primary criteria for passive range of movement

Joint	**Movement**	**Current Primary Criteria (less than or equal to)** Athletes must meet at least one of the following	**New Primary Criteria (less than or equal to)** Athletes must meet at least one of the following
Hip	Flexion	60°	80°
	Extension	-20°	-10°
	Abduction	N/A	15°
	Adduction	N/A	0
	Internal Rotation	N/A	5°
	External Rotation	N/A	20°
Knee	Flexion	60°	90°
	Extension	-35°	-20°
Ankle	Plantar flexion Dorsiflexion	10° total range between 25° PF and 10° DF	10° PF 0° DF

DF is dorsiflexion; PF is plantar flexion

The new secondary criteria for impaired passive range of motion are outlined in Table 10.1 below.

The secondary criteria are applied if a player has impaired range of motion but does not meet any of the primary criteria. Athletes must meet at least two of the secondary criteria to be eligible for wheelchair tennis.

Table 10.2 Current and new secondary criteria for passive range of movement

Joint	Movement	**Current Secondary Criteria (less than or equal to)** Athletes must meet at least two of the following	**New Secondary Criteria (less than or equal to)** Athletes must meet at least two of the following
Hip	Flexion	75°	100°
	Extension	-5°	0°
	Abduction	N/A	25°
	Adduction	N/A	15°
	Internal Rotation	N/A	15°
	External Rotation	N/A	30°
Knee	Flexion	80°	110°
	Extension	-25°	-10°
Ankle	Plantar flexion	20° total range between	20° PF
	Dorsiflexion	25° PF and 10° DF	10° DF

DF is dorsiflexion; PF is plantar flexion

11. MIC for Limb Deficiency

The current minimum impairment criteria state that there should be a 'complete unilateral amputation of half of the foot length' (see below), but the wording not provide any anatomical level. There is no consideration for any amputation along the length of the foot (as opposed to a transverse amputation).

Research has shown that the loss of the smaller toes (apart from the big toe), either partial or complete, generally leads to little disability, although gait and balance may be affected. However, metatarsal head pressure can become increased, and the shape of the foot may change.

Metatarsal ray resection may lead to foot deformity and loss of walking speed, especially when the 1st or 5th rays are affected. Losing the 1st metatarsal results in lower extremity impairment of 20-24%, and loss of any other metatarsal results in lower extremity impairment of 12-13 %.

A trans-metatarsal amputation (amputation of the metatarsal heads) results in a significant loss of power generation across the ankle joints, and will visibly affect mobility on the tennis court. A trans-metatarsal amputation has a substantial negative effect on performance with impairment levels of 40-44%.

The expert group discussed the effect on gait and tennis performance that an amputation of all five toes would have and the range was 22-25%. However, this disability is seldom seen because it is usually replaced by a trans-metatarsal amputation. It is also uncommon to have just one metatarsal head removed, because the whole ray is normally amputated. Amputation of the 1st or 5th ray has a substantial negative effect on the foot and gait when compared to the removal of the 2nd, 3rd or 4th rays.

It was therefore proposed to include both a trans-metatarsal (transverse) amputation and a ray (longitudinal) amputation of the foot in the minimum impairment criteria. Congenital impairments are often harder to define, and when there is uncertainty, it would be useful to add gait analysis and/or pedobarography.

Current minimum impairment criteria for limb deficiency

"Complete unilateral amputation of half of the foot length (i.e., measured on the non-amputated foot from the tip of the great toe to the posterior aspect of the calcaneus) or equivalent minimum congenital limb deficiency".

Proposed new minimum impairment criteria for limb deficiency

"Unilateral amputation at the level of the metatarsal heads, unilateral single ray amputation, or equivalent minimum congenital limb deficiency. When there is uncertainty whether the player meets the minimum impairment criteria, sport-specific testing, gait analysis and/or pedobarography should be considered in addition to the physical examination."

12. MIC for Leg Length Difference

Leg length difference was discussed by the expert group and it was felt that a cut off of 7 cm was too high. Shoe lifts are appropriate for discrepancies up to 3 cm but further raising of the sole and heel may result in ankle instability, which may require a stabilizing boot or ankle-foot-orthosis. Widening of the heel, to reduce instability, will merely decrease lateral movement and affect tennis performance. It was therefore agreed that 4-5 cm leg length difference might be a more appropriate as a minimum impairment criterion.

However, despite the general consensus that 7 cm was too high, the expert group could not find enough scientific evidence to support or challenge this arbitrary figure. Most of the literature on leg length discrepancy and gait focused on leg length differences of up to 2.5 cm

Since the International Classification of Functioning, Disability, and Health (ICF) classifies a leg length difference of 7 cm as a 'disability', it was finally decided to leave the level unchanged, until more information becomes available.

Leg length differences can be measured using a tape measure, and/or standing blocks, but imaging modalities are much more accurate (CT scanogram, orthoroentgenogram, teleroentgenogram). However, these involve radiation exposure and imaging may be considered unnecessary unless the discrepancy is close to the 7 cm cut off figure.

Current minimum impairment criterion for leg length difference

"The difference in length between right and left legs should be at least 7 cm. To measure, the player should lie supine with legs relaxed and fully extended. With the pelvis in neutral position, measure from the anterior superior spine to medial malleolus on each leg and compare."

Proposed new minimum impairment criterion for limb deficiency

"The difference in length between right and left legs should be at least 7 cm. To measure, the player should lie supine with legs relaxed and fully extended. With the pelvis in neutral position, measure from the anterior superior iliac spine to the tip of the medial malleolus on each leg and compare. In borderline cases, players are allowed to present radiological assessments (medical imaging) to confirm the exact leg length difference."

13. Sport-specific Testing

During the development of the project, and the creation of the proposed MIC, members of the CWG and the focus group experts felt the addition of sport-specific testing would provide greater rigour and accuracy of IMP criteria assessment. Sport-specific tests have the potential to help assessing minimum impairment criteria based on the player's function on the tennis court. These tests can be used to assess whether an athlete is eligible to play wheelchair tennis, but also to diminish ethical concerns about intentional misrepresentation.

However, following constructive meetings and discussion with Sean Tweedy and the IPC, it was agreed that the most appropriate next step was to run sport-specific tests alongside the classification process to accurately understand the relationship between the findings during the physical examination to determine the level of impairment and proposed sport-specific tests, to inform the evolution of the sport's classification in future.

Therefore, in order to further validate the new criteria for IMP, in line with best practice guidance from the IPC, the ITF will conduct a trial period of data collection using some sport-specific tests. The tests chosen are validated tests, using the muscle groups important for the movement demands of tennis, and assessed in classification. Similarly, circumferential measurements to assess muscle mass will be collected for the same purposes. The collection of this data will allow validation of the MIC in relation to functional and movement capacity of athletes presenting with IMP.

It is vital to note that for this trial phase, the results of these tests/measurements WILL NOT determine an athlete's Sport Class or Sport Class Status. This information is being collected for review purposes only and once collected will be stored anonymously.

The sport-specific testing battery used in this trial includes the following three ambulation- related activity limitation tests:

1. 2-minute walk test (Appendix VII)
2. Five Times Sit-to-stand test (Appendix VIII)
3. Edgren side-step test (IX)

Appendices VII to IX provide detailed descriptions of these three sport-specific tests.

14. General Recommendations

Alongside the proposed enhancements to the MIC, recommendations have been collated from the Classification Working Group and Expert Group members, medical and tennis experts, and feedback from the stakeholder consultation webinars (see List of Experts).

1. Minimum Impairment Criteria

a. MIC to be updated based on the physical demands of tennis – see above section with proposed new MIC.

2. Data collection

a. In order to further validate the new criteria for Impaired Muscle Power, in line with best practice guidance from the IPC, it is recommended to have a trial period of data collection using several sport-specific tests and circumferential measurements. The collection of this data will allow validation of the MIC in relation to functional and movement capacity of athletes presenting with impaired muscle power.

b. It is recommended to store all classification and testing data in a secure, centralized database, in compliance with the General Data Protection Regulations.

c. All testing protocols should be standardized and described in detail, to ensure consistency across place and time.

d. It should be monitored what the sporting wheelchair allows the player to achieve to ensure fairness and appropriateness of classification assessment and Sport Class allocation.

3. Classification Rules

a. Classification Rules to be updated to ensure they are fit for purpose, and aligned to IPC Model Guidelines, including updated MIC. Further review is necessary of the Classification Rules to support Classification delivery and management. This links to recommendations in this document regarding Governance and procedural areas, which need further clarification and revision. Review of the Classification Rules should be completed by October 1st 2021, allowing time for legal approval and approval of the ITF Board by November 7th. The updated Classification Rules should be communicated to all stakeholders in November 2021 and introduced by January 1st 2022.

b. Clarity should be provided regarding the application of the Classification Rules in terms of how these apply to all competing players. The Classification Rules apply to ITF-recognised international competitions. They do not apply to non-international events, but National Federations should ensure players competing nationally understand the requirement for international competition.

c. Further work is necessary regarding the Sport Class Status New to ensure consistency of classification. This work should be completed by October 1st 2021.

d. Further work is needed to determine how and when to classify junior players, in line with the Sport Class Status New. This work should be completed by October 1st 2021.

e. Use of Powered chairs as part of a player's adaptive equipment needs to be clarified in reference to ITF tournaments and the Paralympics. This should be clarified and included in the rules by October 1st 2021.

f. The ITF should collaborate with the IPC during the Code Review project on a general basis, but also with regards to health conditions. The ITF should appoint a minimum of three medical experts with expertise in sports medicine, wheelchair tennis and sport science, who will collaborate with the IPC.

g. Legal experts are needed to review and finalise Classification Rule documentation by October 1st. The legal experts need to have experience with medical files in areas such as orthopaedics, rehabilitation and neurology.

4. Rules Education and Communication

a. A clear and detailed stakeholder communication plan needs to be created to ensure current players, potential new players, coaches, physiotherapists and other support staff and National Federation staff understand the rationale for the updated rules and the processes and responsibilities in place.

b. To support the above stakeholder communication plan, resources should be in place to best ensure meaningful education for players and other stakeholders, including targeted web content and videos.

5. Transitional Management

a. To ensure a successful transition to the updated rules, careful and considered planning must be in place to ensure successful implementation of the new rules. Such work should be commenced as soon as possible, and the implementation plan should be completed by 1st October 2021.

b. Current players potentially impacted by the new rules need to be identified and confirmed as requiring a reassessment by a Classification Panel against the new MIC. Such players should be offered Classification Opportunities between 1st October and 30th November 2021, to confirm player classification status per 1st January 2022. This needs to be checked from a legal perspective (application of future rules).

c. Classification opportunities need to be determined for those players identified in 4b. The location, venue and classifiers need to be established, alongside a communication plan to confirm each player classification opportunity and the necessary steps to deliver an outcome.

6. Classifier training and selection

a. Targeted mandatory training is necessary for all Classifiers regarding the changes. The content of the training should be determined by a wheelchair tennis expert group.

b. Consideration should also be given to confirm:

i. The full classifier training program needed for future recruits;

ii. Refresher training for existing classifiers;

iii. Quality assurance measures for all classifiers;

iv. Who are best placed as future classifiers and how are they best recruited. The minimum requirements for classifiers are that they are certified health professionals (e.g., physicians or physiotherapists), with a minimum of five years' work experience.

c. Linked to the above, the ITF must specify and publish Classifier Competencies in a manner that is transparent and accessible, and establish a process of Classifier Certification by which Classifier Competencies are assessed. This needs to be checked and actioned if needed.

d. The ITF needs to confirm how and when the classifier training will be delivered and by whom – for both face-to-face and online training. An example of this can be found here https://www.paralympic.org/news/classifier-education-course-set-spring-2021.

7. Longer-term planning and priorities

a. Finalise a Classification Roadmap and disseminate it to the Wheelchair Tennis community and relevant stakeholders. The Classification Roadmap should clarify the long-term plan of classification, what key milestones and activity will be undertaken, at what time and how it will be delivered.

b. Identify and promote pathways through which the players and other key stakeholder groups can take an active role in supporting the delivery of the Classification Roadmap, such as players taking part in necessary classification-based research (see 7c).

c. Plan and implement a bespoke research project to rigorously study the physical demands of Wheelchair Tennis as they relate to level of impairment and function. Such a project will help (i) identify how players achieve the physical demands of the sport, and (ii) support decision making on Sport Classes and Criteria for player evaluation into those Sport Classes. The aim of the sport classes is to ensure more fair and meaningful competition across the Wheelchair Tennis population. Given the scale of such a project, this should start by January 2022. It may also be beneficial to establish a Classification Science and Research group to help steer the direction of future research.

8. Governance

a. Key individual roles, committees, sub-committees, and panels of the ITF Wheelchair Tennis Department should be clarified. This will enhance the classification governance needed to deliver the aims of the ITF and IPC, and the experiences of players and National Federations. Specifically, the following should be reviewed and confirmed by 1st October:

i. The role of the Wheelchair Tennis Committee, including the responsibilities related to Classification;

ii. The role of the ITF Sport Science and Medicine Committee relating to Classification matters;

iii. The role and responsibilities of the Head of Classification, aligned to best practice across IPC systems, including qualifications and experience;

iv. The communication and collaboration expectations of the Wheelchair Tennis Committee, the ITF Sport Science and Medicine Committee, and the Head of Classification, formally and informally;

v. The ongoing communication and collaboration expectations between the ITF and the IPC, formally and informally;

vi. The roles and responsibilities of Classifiers, including qualifications and experience.

b. Regarding data protection, the ITF should ensure that medical documents can be submitted in a safe manner that is GDPR compliant and will be safely stored, including encryption of emails, other communication channels and storage systems. The model IPC rules state:

37 Classification Data Security

37.1 [Para Sport] must:

37.1.1 protect Classification Data by applying appropriate security safeguards, including physical, organisational, technical, and other measures to prevent the loss, theft or unauthorised access, destruction, use, modification, or disclosure of Classification Data; and

37.1.2 take reasonable steps to ensure that any other party provided with Classification Data uses that Classification Data in a manner consistent with these Classification Rules.

The current process may not be sufficient and will need to be confirmed.

c. The ongoing classification planning and developments must be carried out in an interdisciplinary manner to ensure best outcomes. This will include the Tour operations and competition calendar for classification opportunities, player / staff engagement and education opportunities, and critically, the Wheelchair Tennis chair rules regarding equipment design and innovation.

d. Players exiting the sport due to changes in classification will be an unfortunate reality of Paralympic sport. Sufficient consideration should be given to supporting players who exit.

15. List of Experts

Dr Clare Ardern, PhD
Senior Researcher, Musculoskeletal & Sports Injury Epidemiology Center, Sophiahemmet University, Stockholm, Sweden
Adjunct Lecturer, Sport and Exercise Medicine Research Centre, School of Allied Health, Human Services and Sport, La Trobe University, Melbourne, Australia

Mr Cain Berry
Performance Support Lead, LTA
A decade of experience in elite Wheelchair Tennis
BA Business Studies
7+ years at UK Sport

Dr Silvia Camporesi, PhD
Associate Professor in Bioethics, Department of Global Health & Social Medicine, King's College London, UK
Member of the World Anti-Doping Agency Ethics Advisory Group

Mr Alex Cockram
Physical Performance Manager – Wheelchair Performance Programme – LTA
Level 3 Tennis Coach
UKSCA Accredited
BSc (Hons) Sports Science
Former Professional Tennis Player

Ms Kirsty Elliott, MSc
Sport, Exercise Medicine and Lifestyle Institute, Faculty of Health Sciences, University of Pretoria (Employer)
Division of Biokinetics and Sports Science, Department of Physiology, University of Pretoria (Guest Lecturer)
MA, Human Movement Science, Sport Science, University of Pretoria (2015)

Dr Kristina Fagher, PhD
Post-doctoral researcher, Rehabilitation Medicine Research Group, Lund University, Sweden
PhD in Para athletes health
Sports Physiotherapist, Swedish Paralympic Committee
Member of the Medical Committees´ Swedish Paralympic Committee and The International Blind Sport Association.

Mr Iain Gowans, MSc
Classification Manager for the National Paralympic Committee for Great Britain
Member of the IPC Athlete Classification Code Drafting Team (Eligible Impairments Subgroup)
Member of World Para Swimming's Classification Review Project Management Group
Classification Manager at the London 2012 Paralympic Games
Bachelors' Degree in the Sport in the Community at the University of Strathclyde
Masters' Degree in Equality Studies at University College Dublin
Paralympian (Swimmer) Atlanta 1996 Paralympic Games

Dr Neil Heron, MD PhD
NIHR Clinical Lecturer, School of Medicine, Keele University, Staffordshire, England.
Clinical Lecturer, Centre for Public Health, Queen's University Belfast, Northern Ireland.
Consultant in Sport, Exercise and Musculoskeletal Medicine / General Practitioner.

Dr Rien Heijboer, MD
Orthopaedic surgeon, Erasmus Medical Centre, Rotterdam, the Netherlands

Mr Aldo Hoekstra, MSc
Embedded Scientist, Royal Dutch Lawn Tennis Association, Amstelveen, the Netherlands

Prof Christa Janse van Rensburg, MD PhD
Head of Department, Section Sports Medicine, Faculty of Health Sciences, University of Pretoria, South Africa
Sports Physician, Sport and Exercise Medicine Lifestyle Institute, Faculty of Health Sciences, University of Pretoria, South Africa
Specialist Rheumatologist, Eugene Marais Hospital, Pretoria South Africa
Former international netball player

Ms Marleen Jansen, MSc
Sport Scientist
Royal Dutch Lawn Tennis Association, Amstelveen, the Netherlands
Centre for Human Movement Sciences, University Medical Centre Groningen, University of Groningen, Groningen, the Netherlands

Prof Karim Khan, AO
Professor, Department of Family Practice and School of Kinesiology, University of British Columbia, Vancouver, Canada
Scientific Director, Canadian Institute of Health Research—Institute of Musculoskeletal Health and Arthritis, Vancouver, Canada.

Ms Nikki Kolman, MSc
Specialist Elite Sports, Knowledge Center for Sport and Physical Activity, Ede, the Netherlands
PhD candidate (Talent Identification and Development in Tennis), Center for Human Movement Sciences, University Medical Center Groningen, University of Groningen, Groningen, the Netherlands

Dr Marjolein van der Krogt, MD PhD
Head of Clinical Movement Analysis Laboratory
Amsterdam UMC, Department of Rehabilitation Medicine, Amsterdam Movement Sciences, Amsterdam, Netherlands

Mr Matthew Lester
Performance Science Team, Tennis Australia, Melbourne, Australia
PhD candidate, University of Western Australia, Perth, Australia

Mr Jeffrey van Limpt, PT
Physiotherapist, Hogeschool van Amsterdam, Amsterdam, The Netherlands

Dr Reinoud Meijer, MD
Rehabilitation Physician, Hospital de Gelderse Vallei, Ede, the Netherlands
Klimmendaal, Rehabilitation Specialists, Arnhem, the Netherlands

Prof Frans Nollet, MD PhD
Professor of Rehabilitation Medicine, Vice-chair department of Rehabilitation Medicine, Amsterdam University Medical Center, University of Amsterdam, Amsterdam, The Netherlands
Former director Amsterdam Movement Sciences Research Institute.
Former physician Royal Dutch Skating Union (1987-1996), Olympic Team doctor Winter Olympics Hamar, Norway 1994.

Dr Fabio de Oliveira, PT PhD
Postdoctoral fellow, Center for Interdisciplinary Research in Rehabilitation and Social Integration (CIRRIS), Université Laval, Quebec City, Canada
Research Unit in Sport and Physical Activity (CIDAF), Faculty of Sport Sciences and Physical Education, University of Coimbra, Portugal
Private Physiotherapist on the ATP Tour

Dr Sean O'Connor, PhD
Physiotherapist / Researcher, Centre for Public Health, Queen's University Belfast, UK

Prof Babette Pluim, MD PhD
Consultant in Sports & Exercise Medicine
Chief Medical Officer, Royal Dutch Lawn Tennis Association, Amstelveen, The Netherlands
Extra-Ordinary Professor, Section Sports medicine, Faculty of Health Sciences, University of Pretoria, Pretoria, South Africa
AMC/VUmc IOC Research Center, Academic Center for Evidence-based Sports Medicine (ACES), Amsterdam Collaboration for Health and Safety in Sports (ACHSS), Amsterdam, The Netherlands

Dr Machar Reid, PhD
Dr Machar Reid, Head of Innovation at Tennis Australia, Melbourne, Australia
Adjunct Professor, Victoria University, Melbourne, Australia
Associate Professor, University of Western Australia, Perth, Australia

Ms Linda Schoonmade, MSc
Medical Library, Vrije Universiteit Amsterdam, De Boelelaan 1117, P.O. Box 7057, 1007 MB Amsterdam, The Netherlands

Dr Erik Slim, MD PhD
Department of Rehabilitation Medicine, Rivierenland Hospital, Tiel, The Netherlands

Dr Sjoerd Stufkens, MD PhD
Orthopaedic Surgeon, Foot and Ankle specialist
Amsterdam Movement Sciences, department of Orthopaedic Surgery
Academic Center for Evidence based Sportsmedicine (ACES)

Amsterdam Collaboration for Health and Safety in Sports (ACHSS)
AMC/VUmc IOC Research Center, Amsterdam, The Netherlands

Dr Jane Thornton, MD PhD
Assistant Professor, Department of Family Medicine and Epidemiology & Biostatistics, Schulich School of Medicine & Dentistry, Western University, Canada
Assistant Professor, School of Kinesiology, Faculty of Health Sciences, Western University, Canada
Sport Medicine Physician
Olympian and World Champion in rowing

Dr Sandra Titulaer, MD
Rehabilitation Physician, Rijndam Revalidatie and Erasmus Medical Center Sophia, Rottterdam, the Netherlands
International Classifier and Head of Classification World Para Alpine Skiing, World Para Snowboard
Expert team Classification Netherlands Olympic Committee*Netherlands Sports Federation (NOC*NSF), Arnhem, the Netherlands

Associate Professor Sean Tweedy, PhD
School of Human Movement and Nutrition Sciences,
Faculty of Health and Behavioural Sciences, The University of Queensland, Australia

Prof Evert Verhagen, PhD
Amsterdam Collaboration on Health & Safety in Sports, Department of Public and Occupational Health, Amsterdam Movement Science, Amsterdam UMC, Amsterdam, the Netherlands

Prof Nick Webborn, MD PhD
Clinical Professor (Sport & Exercise Medicine), School of Sport and Health Sciences, University of Brighton, UK
Honorary Clinical Professor in the School of Sport, Exercise and Health Sciences, Loughborough University, UK
Former international wheelchair tennis player

Mr Sam Williamson, PT
Physiotherapist, English Institute of Sport, London, UK.

Dr Wart van Zoest, MD
Orthopaedic Surgeon St-Anna Hospital and TopSupport
Consultant Orthopaedic Surgeon TeamNL
Team Physician PSV Eindhoven
Consultant Orthopaedic Surgeon KNLTB, Royal Dutch Lawn Tennis Association

16. Classification Working Group – Conflicts of Interest

Declaration of conflicts of interest

The members of the Classification Working Group declared the following conflicts of interest:

Prof. Babette Pluim

Positions held in tennis:

- Chief Medical Adviser, KNLTB;
- Medical Consultant, ATP Tour;
- Member, ITF Sport Science and Medicine Commission;
- Director, Society for Tennis Medicine and Science (STMS) Center of Excellence;
- Classification Consultant, ITF (through the KNLTB);
- member, ITF Classification Working Group and Expert Group

Current jobs/paid positions:

- Chief Medical Adviser, KNLTB;
- Medical Consultant, ATP Tour

Significant financial or other interests in the following: NA

Other facts that may give rise to actual, apparent or potential conflicts of interest:

- Extra-Ordinary Professor, University of Pretoria, Pretoria, South Africa
- Assistant Professor, Amsterdam University Medical Center & IOC Research Center for Prevention of Injury and Protection of Athlete Health

Mr Cain Berry

Positions held in tennis:

- Performance Support Lead, LTA

Current jobs/paid positions:

- As above – Performance Support Lead, LTA

Significant financial or other interests in the following: None

Other facts that may give rise to actual, apparent or potential conflicts of interest:

Linked to the above position, I work with GB wheelchair tennis players.

Mr Iain Gowans

Positions held in tennis:

- None

Current jobs/paid positions:

- I am employed on a full-time basis by the British Paralympic Association. This role is funded with support from UK Sport.

Significant financial or other interests in the following:

- I have no financial or other interests to declare

Other facts that may give rise to actual, apparent or potential conflicts of interest:

- IPC Athlete Code Review Drafting Team (Eligible Impairments Sub-group)
- World Para Swimming Classification Review Project Management Group

Prof Nick Webborn

Positions held in tennis:

- ITF Classification Working Group

Current jobs/paid positions:

- Clinical Professor (Sport & Exercise Medicine), School of Sport and Health Sciences, University of Brighton;
- Medical Director, Sportswise Ltd, Sussex Centre for Sport and Exercise Medicine.

Significant financial or other interests in the following: None

Other facts that may give rise to actual, apparent or potential conflicts of interest:

- Chair/President, British Paralympic Association
- Member IPC Medical Committee
- Former international wheelchair tennis player

Dr Machar Reid

Positions held in tennis:

- HEAD OF INNOVATION AT TENNIS AUSTRALIA

Current jobs/paid positions:

- HEAD OF INNOVATION AT TENNIS AUSTRALIA

Significant financial or other interests in the following: N/A

Other facts that may give rise to actual, apparent or potential conflicts of interest:

I am paid employee of Tennis Australia so therefore may be considered to have a potential conflict of interest.

Mr Samuel Williamson

Positions held in tennis:

- Physiotherapist working with the LTA Wheelchair Performance Pathway

Current jobs/paid positions:

- Physiotherapist working with the LTA Wheelchair Performance Pathway

Significant financial or other interests in the following: None

Other facts that may give rise to actual, apparent or potential conflicts of interest:

Changes to classification may affect LTA programme players both positively and negatively, directly and indirectly.

Management of conflicts

The actual, apparent and potential institutional conflicts resulted in a process of mitigation of the risks that they might impact the work of the CWG.

This was threefold:

- Acknowledgement of the potential for conflict in the CWG's first meeting, and instituting a process for recording those conflicts;

- Diversification of nationality, opinion and expertise in the membership of the CWG and the Expert Group;

- Diversification of stakeholders that would be consulted (including the Player Council, International Paralympic Committee Classification Committee, players, coaches, National Association personnel, classifiers), and diversification of those to whom the CWG was accountable (notably the Wheelchair Committee and ITF Board).

Appendix I. Review of Impaired muscle power

Below we present the scientific evidence that was reviewed to establish the new evidence-based minimum impairment criteria for impaired muscle power.

Literature review

The Classification Working Group reviewed the literature, focusing on the association between loss of strength of the lower extremities and gait parameters as a proxy for sporting performance. We identified one article of particular relevance for our classification review:

> Krogt MM van der, Delp SL, Schwartz MH. How robust is human gait to muscle weakness? Gait Posture 2012;36:113-9.

We contacted first author Dr van der Krogt for further information and expert consultation.

Two literature reviews were conducted, led by sports physician Neil Heron and post-doc Séan O'Connor:

1. A scoping review of assessment methods suitable for determining lower limb muscle strength deficits.

2. Determining muscle strength in para-athletes: a systematic review on strength assessment methods and strength characteristics

The literature reviews will be submitted for publication in the scientific literature.

Main results:

- Normal gait is not possible with only grade 3 strength in any of the major muscle groups of the lower extremity, or with more than a 40% loss of strength of the lower extremity muscles.

- Weakness of the plantar flexors, hip abductors, and hip flexors affects gait most. Normal gait is not possible with no strength (0%) of the gluteus medius or plantar flexors in any subject or hamstrings or iliopsoas in most subjects.

- Gait appears to be least affected by weakness of the hip and knee extensors.

- The muscle's relative load during gait compared to its maximum capacity, as well as the availability of compensatory muscles, defines whether weakness can be tolerated or not.

Expert group discussion:

- The hip flexors and extensors are key muscle groups that are needed for accelerations and decelerations, high-speed running and shot making that takes place during tennis. The hip abductors, adductors and rotators are important muscle groups, given the high frequency of lateral movements in tennis and the frequent changes of direction. They are also important for forward movement.

- The knee extensors are vital for tennis because they are needed for running, accelerations, deceleration, lateral movement and shot making. It would be virtually impossible to play tennis without bending your knees. The knee flexors play an important role during running and are used eccentrically when stepping into the ball.

- The plantar flexors are essential muscle groups for walking, running, accelerations, decelerations, changes of direction, jumping and shot making. A small loss of strength of these muscle groups will have a significant effect on mobility.

Expert Group recommendations:

1. To express the minimum impairment criteria as available strength rather than as a strength deficit.
2. To continue using manual muscle testing for classification, because of ease of application, low cost, and acceptable inter- and intra-rater reliability up to grade 3 muscle strength. For testing of plantar flexor muscle strength, we recommend continuing to use the sport-specific test (heel raises).
3. To change the primary criteria from grade two muscle strength to grade three muscle strength, and from grade one muscle strength to grade two muscle strength where applicable (hip adductors).
4. To change the secondary criteria from grade three muscle strength to grade four muscle strength, and from grade two muscle strength to grade three muscle strength where applicable (hip adductors).

Appendix II. Review of Impaired Passive Range of Movement

In this appendix the scientific literature reviewed to establish the new evidence-based minimum impairment criteria for impaired passive range of movement is presented.

Literature reviews

Movement scientist Nikki Kolman conducted a rapid review on the lower body joint angles (hip, knee, ankle) per tennis stroke. This rapid review, entitled “Lower body joint angles per tennis stroke” was expanded with support from Dylan Wood and Machar Reid from Tennis Australia and is presented in Appendix III.

The literature for the minimum and maximum joint angles of the hip, knee, and ankle during walking and running was reviewed. The minimum and maximum hip, knee, and ankle joint angles during walking, running and tennis (forehand and serve) are summarised in Table II.1. We included hip abduction, hip adduction, hip internal and hip external rotation range of movement. These movements are currently not included in the minimum impairment criteria.

Table II.1. Joint angles of the hip, knee and ankle during walking, running and tennis play.

	Tennis		**Gait**	**Sprinting**
	Service	Forehand		
Hip				
Flexion	-	68°	30°	90°
Extension	0°	7°	10°	10°
Abduction	-	35°	5°	-
Adduction	-	10°	10°	-
Internal rotation	-	25°	-	-
External rotation	-	24°	-	-
Knee				
Flexion	90°	62°	65°	125°
Extension	0°	0°	0°	0°
Ankle				
Plantar flexion	>25°	25°	20°	25°
Dorsal flexion	20°	25°	10°	25°

Criteria American Medical Association for level of permanent impairment

The criteria of the American Medical Association (AMA) to determine the level of permanent impairment (mild, moderate and severe) for loss of range of motion were reviewed. These are presented separately for loss of range of motion of the hip, knee and ankle (Tables II.2, II.3 and II.4).

Table II.2. Ankle motion impairments.

Severity	Impairment	Plantar flexion	Flexion contracture (equinus deformity)	Dorsiflexion
Mild	7% LEI	11°-20°	-	10°- 0° (neutral)
Moderate	15% LEI	1°-10°	10°-19°	None
Severe	30% LEI	None	>19°	None

LEI = lower extremity impairment

Table II.3. Knee motion impairments

Severity	Impairment	Flexion	Flexion contracture
Mild	10% LEI	80°-109°	5°-9°
Moderate	20% LEI	60°-79°	10°-19°
Severe	35% LEI	< 60°	>19°

Table II.4. Hip motion impairments.

Severity	Impairment	Flexion	Extension (flexion contracture)	Internal rotation	External rotation	Abduction	Adduction	Adduction (abduction contracture)
Mild	5% LEI	80°-100°	-10° to -19°	10°-20°	20°-30°	15°-25°	0°-15°	0° to -5°
Moderate	10% LEI	50°-79°	-19° to -29°	0°-9°	0°-19°	5°-14°	-	-6° to -10°
Severe	20% LEI	<50°	≥-30°	-	-	<5°	-	-11° to -20°

LEI = lower extremity impairment

Main results:

- More than 70% of movements in tennis are side to side, with less than 20% in a forward direction and less than 8% in a backward direction.
- Hip abduction during a standard forehand is up to 35°, and more when reaching for a shot. Hip adduction during a standard forehand is up to 7°.
- Hip flexion range of motion needed during a tennis serve is up to 100° (landing, arabesque)
- Hip flexion during the preparation phase of a forehand ranges from 40° to 56°. The harder the player hits the ball, the more hip flexion is used.
- Hip range of motion during the follow through of a forehand ranges from 7° flexion to 5° extension. The more powerful the shot, the more the hip extends.
- Hip flexion range of motion during sprinting is up to 90°.
- Hip extension during gait and during running is approximately 10°.

Expert group recommendations:

1. To express the minimum impairment criteria as available range of movement instead of as a deficit.

2. To add hip adduction, abduction, internal and external rotation range of movement to both the primary and the secondary criteria, due to their relevance to the movement demands of tennis.
3. To modify the current minimum impairment criteria for range of movement and allow a slightly greater range of movement for the hip and knee, with the ankle remaining the same.

Appendix III. Lower Body Joint Angles per Tennis Stroke

The minimum and maximum joint angles in the lower extremity differ per tennis stroke. Tennis players have different lower extremity joint angles during the forehand than during the service.

In Table III.1 we present an overview of the lower body joint angles, broken down by stroke, including descriptive information about the samples of players that these angles were drawn from. This gives a global indication of the joint angles in tennis. However, these values may differ greatly from one person to another.

In Table III.2 we present reference values for normal range of motion of the hip, knee and ankle by gender and age, taken from Soucie et al (2011).

Hip

Forehand
During the forehand, the hip flexes between 40 and 56 degrees (Seeley et al, 2011). The following applies: the harder the player hits, the more the player flexes the hips. When the player hits the ball with high speed, the hip extends up to 5 degrees during the follow through, whereas at low ball speeds average hip flexion is around 7 degrees.

One-handed Backhand
The one-handed backhand involves an average hip rotation of 30 degrees, with a range of 19 to 36 degrees. Higher degrees of rotation were noted during shots aimed cross court and upon completion of the backswing (Genevois et al, 2015)

Two-handed Backhand
The two-handed backhand involves an average hip rotation of 36 degrees, with a range of 36 to 59 degrees. Again, higher levels of hip rotation were reported on the cross court shot.

It is evident that the one-handed backhand and two-handed backhand involve different strategies to develop horizontal racquet velocity at impact. Indeed, two-handed backhands rely comparatively more on trunk rotation whereas the one-handed backhand does the same with the rotations of the upper limb joints of the hitting arm (Genevois et al, 2015).

Service
When a player lands with their foot on the court after serving, the hip flexion of the front leg averages 69 degrees, whereas the back leg shows a hip flexion of 13 degrees (Reid et al, 2015). With an exaggerated landing position during the service (arabesque), the hip flexion of the front leg is on average 101 degrees (Reid et al, 2015). The back leg shows a mean hip flexion of 9 degrees (Reid et al, 2015).

Sidestepping
When sidestepping, the hip joint displays flexion/extension ranges of between -5 and 50 degrees (negative value represents extension). A longer duration of activity led to there being increased levels of hip extension during side-stepping, but hip adduction and abduction were less affected (Giles et al, 2019). The hip joint rotated in the frontal plane through 18 degrees of abduction to 12 degrees of adduction during the sidestepping trials, while the range of transverse plane hip joint rotation was 40 degrees (22 degrees of external to 18 degrees of internal rotation)(Giles et al, 2019).

Knee

Forehand
With the forehand, the left knee (for right-handed people) is flexed to an average between 48 and 62 degrees (Herbaut et al, 2016; Nesbit et al, 2008; Sandamas et al, 2013; Seeley et al, 2011). Players bend the right knee a little less: to on 37 to 47 degrees (Herbaut et al, 2016; Sandamas et al, 2013). Players bend their knees more when they hit harder (Seeley et al, 2011).

Backhand
With the backhand, the maximum knee flexion is approximately 35 to 40 degrees (Akutagawa et al, 2005). When hitting a double-handed backhand, right-handed players bend the left knee more than with a one-handed backhand (Akutagawa et al, 2005). During the backhand, the mean minimum knee flexion is between 8 and 23 degrees (Akutagawa et al, 2005).

Service
During the service, the maximum knee flexion is on average between 65 and 96 degrees (Connolly et al, 2019; Fenter et al, 2017; Reid et al, 2008; Reid et al, 2015; Sgrò et al, 2013; Stiles et al, 2006). The maximum knee flexion appears to be the same for different age categories and gender (Connolly et al, 2019; Stiles et al, 2006). However, knee flexion depends on the level of play: high-level players bend their knees more than lower-level players (Sgrò et al, 2013).

Sprinting
Whilst there was no specific information regarding lower limb mechanics and tennis movement, other research has addressed the hip and knee kinematics of running among recreational and high-level athletes (Ferber et al, 2003).

Sidestepping
A planned side-step shows knee flexion angles of between 14 degrees at initial contact to 53 degrees at peak push off (Giles et al, 2019). Whilst extension angles vary from -0.8 degrees at initial contact to - 4.0 degrees at peak push off. During an unplanned side-step the range of knee flexion is 15 degrees to 54 degrees during peak push off. Knee extension during unplanned sidestepping ranges from -0.7 degrees to -3.2 degrees during initial contact and peak push off respectively (Giles et al, 2019).

Ankle

Forehand
During the forehand, the maximum dorsiflexion of the ankle is between 3 and 9 degrees (Herbaut et al, 2006; Seeley et al, 2011). During a running forehand, this dorsiflexion angle can increase to 25 degrees (Starbuck et al, 2016). At ball impact, the ankle is generally plantar-flexed to 16-25 degrees (Herbaut et al, 2006; Seeley et al, 2011).

Backhand
To the knowledge of the contributors, there is no information about the joint angle of the ankle during the backhand. One study addresses lower limb mechanics in terms of identifying injury risks

however it does not assess ankle joint range of motion.

Service

During a service, the ankle is dorsiflexed by between 9-14 degrees (Goktepe et al, 2009), and appears more pronounced in males than in females (Goktepe et al, 2010).

180 ° change of direction on the tennis court

During a 180 degree turn on the tennis court, the ankle is dorsiflexed to 18 to 24 degrees (Soucie et al, 2011). The ankle inverts by up to 10-12 degrees (Soucie et al, 2011).

Table III.1. Overview of lower body joint angles per tennis stroke

Reference	Level	Age	Joint movement	Tennis stroke	Joint angle	Joint angle
Akutagawa, 2005	Division 1	20.4 + 1.8	Knee flexion	Backhand (one-handed)	13° (left knee, min)	8° (right knee, min)
				Backhand (two-handed)	34° (left knee, max)	39° (right knee, max)
					23° (left knee, min)	14° (right knee, min)
					38° (left knee, max)	40° (right knee, max
Brown, 2014	College – Professional	21.4 ± 4	Knee Flexion	Sidestep (planned)	14° (initial contact)	53° (peak push off)
				Sidestep (unplanned)	15° (initial contact)	54° (peak push off)
			Knee Extension	Sidestep (planned)	-0.8° (initial contact)	-4° (peak push off)
				Sidestep (unplanned)	-0.7° (initial contact)	-3.2 (peak push off
Connolly, 2019	Elite	12.6 ± 1.2	Knee flexion	Service (flat)	68° (left knee)	75° (right knee)
				Service (kick)	69° (left knee)	75° (right knee)
Fenter, 2016	Division 3	19.6 ± 1.7	Knee flexion	Service (set 1)	77° (start set 1)	74° (end set 1)
				Service (set 2)	77° (start set 2)	75° (end set 2)
				Service (set 3)	74° (start set 3)	70° (end set 3)
Fleisig, 2003	Professional	?	Knee flexion	Service	24° (ball impact)	13° (max. shoulder rotation)
Genevois 2015	College/Professional	? (College)	Hip Rotation	Backhand (one-handed)	19° (min)	
				Backhand (two-handed)	36.1° (min)	
Giles 2019	Professionally Ranked – male	24.7 ± 5.8	Ankle DF - extension	Forehand (CoD) – Post shot – low intensity	1.12° (mean)	
			Knee flexion - extension		45.66° (mean)	
			Hip Flexion - extension		35.88° (mean)	
			Ankle DF-PF	Forehand (CoD) – Drive leg – low intensity	3.71° (mean)	
			Ankle inversion-eversion		27.48° (mean)	
			Knee Flexion – Extension		26.61° (mean)	
			Hip Flexion - extension		13.88° (mean)	
			Hip Adduction – Abduction		-23.04° (mean)	
			Ankle DF - extension	Forehand (CoD) – Post shot – high intensity	18.36° (mean)	
			Knee flexion - extension		99.37° (mean)	
			Hip Flexion - extension		69.77° (mean)	
			Ankle DF-PF	Forehand (CoD) – Drive leg – high intensity	-0.89° (mean)	
			Ankle inversion-eversion		40.77° (mean)	
			Knee Flexion – Extension		29.89° (mean)	

			Hip Flexion - extension Hip Adduction - Abduction		18.26° (mean) -31.35° (mean)	
Giles 2019	Professionally Ranked – female		Ankle DF- extension Knee flexion - extension Hip Flexion - extension	Forehand (CoD) – Post shot - low intensity	-0.04° (mean) 40.83° (mean) 40.08° (mean)	
			Ankle DF – PF Ankle inversion-eversion Knee Flexion – Extension Hip Flexion - extension Hip Adduction – Abduction	Forehand (CoD) – Drive leg – low intensity	5.38° (mean) 33.4° (mean) 28.32° (mean) 15.79° (mean) -21.39° (mean)	
			Ankle DF - extension Knee flexion - extension Hip Flexion - extension	Forehand (CoD) – Post shot – high intensity	11.27° (mean) 95.28° (mean) 60.93° (mean)	
			Ankle DF-PF Ankle inversion-eversion Knee Flexion – Extension Hip Flexion - extension Hip Adduction - Abduction	Forehand (CoD) – Drive leg – high intensity	3.02° (mean) 42.33° (mean) 30.42° (mean) 38.86° (mean) -25° (mean)	
Göktepe, 2009	Experienced	11.8 ± 0.8	Dorsal flexion ankle (+)erve	Dorsal flexion ankle (+)	14° (pre-impact) 13° (ball impact) 9° (post-impact)	35.9° (max) 59° (max)
Herbaut, 2016	Beginners	10.2 ± 1.1	Knee flexion	Forehand (open stance)	18° (ground contact) 42° (ROM)	56° (max)
			Dorsal flexion ankle (+) Plantair flexion ankle (-)		5° (ground contact) -19° (max)	3° (max)
			Ankle flexion		32° (ROM)	
			Inversion ankle (+) Eversion ankle (-)		-1° (ground contact) 16° (ROM)	 12° (max)
Martin, 2020	Advanced	26.3 ± 11.0	Hip flexion	Forehand (defensive open stance)	68° (max)	
			Hip abduction		34° (max)	

			Hip external rotation		24° (max)	
Nesbit, 2008	College	20 ± 1.4	Knee flexion	Forehand closed	56° (left knee, max)	37° (right knee, max)
Reid, 2008	High-performance	?	Knee flexion	Serve	70° (foot-up, max)	86° (foot-back, max)
					54° (foot-up, front knee)	59° (foot-up, back knee)
			Knee extension (ROM)		65° (foot-back, front knee)	45° (foot-back, back knee)
Reid, 2015	Elite	17.3 ± 1.2	Hip flexion	Serve (normal)	69° (front leg, max)	13° (back leg, landing)
				Serve (arabesque)	101° (front leg, max)	9° (back leg, landing)
			Knee flexion	Serve (normal)	65° (front knee)	95° (back knee)
				Serve (arabesque)	62° (front knee)	96° (back knee)
Sandamas, 2013	University	33 ± 11.5	Knee flexion	Forehand (open)	62° (left knee, max)	47° (right knee, max)
				Forehand (closed)	54° (left knee, max)	43° (right knee, max)
Seeley, 2011	College		Hip flexion (+) / Hip extension (-)	Forehand - fast	-5° (ball impact)	56° (max)
				Forehand - medium	0° (ball impact)	49° (max)
				Forehand – slow	7° (ball impact)	40° (max)
			Knee flexion (+)	Forehand - fast	25° (ball impact)	61° (max)
				Forehand - medium	21° (ball impact)	56° (max)
				Forehand - slow	24° (ball impact)	48° (max)
			Dorsal flexion ankle (+) / plantair flexion anklel (-)	Forehand - fast	-25° (ball impact)	9° (max)
				Forehand - medium	-21° (ball impact)	7° (max)
				Forehand - slow	-16° (ball impact)	4° (max)
Sgrò, 2013	Advanced	26.8 ± 1.4	Knee flexion	Serve (flat)	82° - 83° (left knee)	81° - 83° (right knee)
Starbuck, 2016	LTA 3.6	28.0 ± 5.1	Knee flexion	180° COD on tennis court	33° (clay, impact)	21° (hard court, impact)
		26.0 ± 1.3			47° (clay, max)	40° (hard court, max)
			Dorsal flexion ankle (+)		-3° (clay, impact)	0° (hard court, impact)
			Plantar flexion (-)		18° (clay, max)	24° (hard court, max)
			Inversion ankle (-)		-1° (clay, impact)	-1° (hard court, impact)
					-10° (clay, max)	-12° (hard court, max)
Stiles, 2006	Beginner to professional	20.5 ± 1.8	Knee flexion	Running forehand	12° (left knee, min)	58° (left knee, max)
			Dorsal flexion ankle		46° (left knee, ROM)	25° (left ankle, max)
Whiteside, 2013	Elite	10.5 ± 0.5	Knee flexion	Serve	75° (front knee)	87° (back knee)
		14.6 ± 0.7			65° (front knee)	87° (back knee)
		21.3 ± 3.8			69° (front knee)	88° (back knee)

Table III.2. Reference values for joint range of motion in normal subjects by gender and age.
Data are presented as mean (95% confidence interval).

	Age 9–19	
Motion	**Females**	**Males**
Hip extension	20.5 (18.6 – 22.4)	18.2 (16.6 – 19.8)
Hip flexion	134.9 (133.0 – 136.8)	135.2 (133.0 – 137.4)
Knee flexion	142.3 (140.8 – 143.8)	142.2 (140.4 – 144.0)
Knee extension	2.4 (1.5 – 3.3)	1.8 (0.9 – 2.7)
Ankle dorsiflexion	17.3 (15.6 – 19.0)	16.3 (14.9 – 17.7)
Ankle plantar flexion	57.3 (54.8 – 59.8)	52.8 (50.8 – 54.8)
	Age 20–44	
Motion	**Females**	**Males**
Hip extension	18.1 (17.0 – 19.2)	17.4 (16.3 – 18.5)
Hip flexion	133.8 (132.5 – 135.1)	130.4 (129.0 – 131.8)
Knee flexion	141.9 (140.9 – 142.9)	137.7 (136.5 – 138.9)
Knee extension	1.6 (1.1 – 2.1)	1.0 (0.6 – 1.4)
Ankle dorsiflexion	13.8 (12.9 – 14.7)	12.7 (11.6 – 13.8)
Ankle plantar flexion	62.1 (60.6 – 63.6)	54.6 (53.2 – 56.0)
	Age 45–69	
Motion	**Females**	**Males**
Hip extension	16.7 (15.5 – 17.9)	13.5 (12.5 – 14.5)
Hip flexion	130.8 (129.2 – 132.4)	127.2 (125.7 – 128.7)
Knee flexion	137.8 (136.5 – 139.1)	132.9 (131.6 – 134.2)
Knee extension	1.2 (0.7 – 1.7)	0.5 (0.1 – 0.9)
Ankle dorsiflexion	11.6 (10.6 – 12.6)	11.9 (10.9 – 12.9)
Ankle plantar flexion	56.5 (55.0 – 58.0)	49.4 (47.7 – 51.1)

Data taken from Soucie et al (2011.

Appendix IV. Review of Limb Deficiency

To determine the minimum impairment criteria for players with a limb deficiency to be eligible to play competitive wheelchair tennis we performed an extensive review of the literature on the association between partial foot amputation and sporting performance. Since it is self-evident that players with an upper or lower leg amputation would meet the minimum impairment criteria for limb deficiency in wheelchair tennis, we focused our review on partial foot amputation. We searched for scientific information that would help us determine which level of partial foot amputation is associated with a substantial negative effect on tennis performance.

Literature review

Bachelor Thesis

Physiotherapist Jeffrey van Limpt studied the association between partial foot amputation and parameters of gait in his Bachelor thesis: "What is the effect of the level of a partial foot amputation on parameters of gait pattern?" (van Limpt, 2020). Gait was taken as a proxy for sporting performance.

Rapid review

Movement scientist and PhD candidate Nikki Kolman conducted a rapid review, entitled "What is the effect of various levels of partial amputation of the foot on gait pattern?" (Kolman, 2020)

Scoping review

A group of authors, led by researcher Fabio de Oliveira and under the guidance of a librarian, searched the literature using a scoping review methodology. They aimed to provide an overview of the evidence examining the impact of different partial foot amputation levels on gait as a proxy for sporting performance. The scoping review was designed to answer the following research question: "What gait parameters are associated with different levels of partial foot amputation?" They screened 609 articles, and ultimately included xx articles for review. The scoping review was entitled "The association between level of partial foot amputation, various gait parameters and minimum impairment criteria in para sport: a scoping review".

The scoping review protocol and the full paper will be submitted for publication in a scientific journal.

Main results:

- Loss of the smaller toes (apart from the big toes), either partial or complete, generally leads to relatively little disability, although gait and balance may be affected. Losing one of the lesser toes results in a lower extremity impairment from 2 to 4% (criteria American Medical Association), whereas the impairment from losing the greater toe ranges from 5 to 7%. Metatarsal head pressure can become more prominent, and the shape of the foot may change.
- Metatarsal ray resection may lead to foot deformity and loss of walking speed, especially when the first or fifth rays are affected. Losing the first metatarsal ranges in lower extremity impairment of 20-24%, and loss of any other metatarsal results in lower extremity impairment of 12-13 %. Losing all toes is evaluated as an impairment ranging from 22 to 25%.
- A transmetatarsal amputation (amputation of metatarsal heads) results in a significant loss of power generation across the ankle joints, which impairs the biomechanics of gaits and will visibly

affect mobility on the tennis court. A transmetatarsal amputation has a substantial negative effect on performance with and the impairment levels of 40-44%.

Evaluation of permanent impairment

In Table IV.1 we present the criteria of the American Medical Association to determine the level of amputation impairment.

Table IV.1. Amputation impairment.

Amputation

Diagnostic criteria (key factor)	Class 0	Class 1	Class 2	Class 3	Class 4
Impairment ranges Severity	0%	1%-13% Mild	14%-25% Moderate	26%-49% Severe	50%-100% Very severe
Impairment grade (%)		2 to 4 Lesser toes at MTP joint	20 to 24 First metatarsal	45 to 49 Midfoot	62 to 70 Syme (hindfoot)
		5 to 7 Greater toe at IP joint Metatarsal, other than first	22 to 25 All toes at MTP joint	40 to 44 Transmetatarsal	
		12 to 13 Great toe at MTP			

From: Rondinelli RD. AMA guides to the evaluation of permanent impairment (sixth edition). American Medical Association, 2008 (p 563). IP is interphalangeal joint; MTP is metatarsophalangeal joint.

Expert group discussion

The expert group discussed the effect on gait and tennis performance that an amputation of all five toes would have and the range was 22-25%. However, this disability is seldom seen because it usually replaced by a transmetatarsal amputation. It is also uncommon to have just one metatarsal head removed, because the whole ray is normally amputated. Amputation of the 1st or 5th ray has a substantial negative effect on the foot and gait when compared to removal of the 2nd, 3rd or 4th rays. Congenital impairments are harder to define, and in those cases, it would be useful to add gait analysis and/or pedobarography.

It was therefore proposed to include both a trans-metatarsal (transverse) amputation and a ray (longitudinal) amputation of the foot in the minimum impairment criteria. Congenital impairments are often harder to define, and when there is uncertainty, it would be useful to add gait analysis and/or pedobarography.

Appendix V. Review of Leg Length Difference

To determine at what level the minimum impairment criteria for players with a leg length difference should be set, we searched the literature for studies that reported on the association of leg length discrepancy and gait (as a proxy for sporting performance). We looked for scientific information that would help us determine from which level of leg length difference (from 1 to 10 cm) gait is substantially affected. In addition, we searched for literature that reported on the accuracy and reliability of clinical and imaging modalities for quantifying leg length differences.

Literature review

Rapid review
Nikki Kolman completed a rapid review entitled: "From which leg length difference is there an adverse effect on gait pattern?"

Scoping review
To determine the minimum impairment criteria for leg length discrepancy we used a scoping review methodology. We aimed to provide an overview of the evidence examining the association between various levels of leg length discrepancy and gait, with gait as a proxy for sporting performance. Our scoping review was designed to answer the following research question: "What gait parameters are associated with different levels of leg length discrepancy?"

The scoping review was started, but not completed because the search of the literature showed that most of the literature on leg length discrepancy and gait focused on leg length differences of up to 2.5 cm. There was virtually no literature available on the association between gait and/or sporting performance and leg length differences of 3 to 10 cm.

Main results

- Most of the literature on leg length discrepancy and gait focused on leg length differences of up to 2.5 cm
- Children may be considered candidates for surgery if the projected leg-length difference is more than 4 to 5 cm.
- the International Classification of Functioning, Disability, and Health (ICF) classifies a leg length difference of 7 centimeters as a disability.
    - Leg length differences can be measured using a tape measure, and/or standing blocks, but imaging modalities are much more accurate (CT scanogram, orthoroentgenogram, teleroentgenogram). However, these involve radiation exposure and imaging may be considered unnecessary unless the discrepancy is close to the 7 cm cut off figure.
-

Unresolved issue

- There was very little literature available on gait changes and leg length discrepancy in the range of 3 to 10 cm.

Expert group discussion

Leg length difference was discussed by the expert group and it was felt that a cut off of 7 cm was too high. Shoe lifts are appropriate for discrepancies up to 3 cm but further raising of the sole and heel may result in ankle instability, which may require a stabilizing boot or ankle-foot-orthosis. Widening of the heel, to reduce instability, will merely decrease lateral movement and affect tennis performance. It was therefore agreed that 4-5 cm leg length difference might be a more appropriate as a minimum impairment criterion.

However, despite the general consensus that 7 cm was too high, the expert group could not find enough scientific evidence to support or challenge this arbitrary figure. Most of the literature on leg length discrepancy and gait focused on leg length differences of up to 2.5 cm

Since the International Classification of Functioning, Disability, and Health (ICF) classifies a leg length difference of 7 cm as a 'disability', it was finally decided to leave the level unchanged, until more information becomes available.

Appendix VI. Sport-specific Testing

In order to further validate the new criteria for IMP, in line with best practice guidance from the IPC, the ITF will conduct a trial period of data collection using some sport-specific tests for ambulation specific activity limitation. The tests chosen are validated tests, using the muscle groups important for the movement demands of tennis, and assessed in classification. The collection of this data will allow validation of the MIC in relation to functional and movement capacity of athletes presenting with impaired muscle power.

It is vital to note that for this trial phase, the results of these tests WILL NOT determine an athlete's Sport Class or Sport Class Status. This information is being collected for review purposes only and once collected will be stored anonymously. Not all athletes will be asked to complete these tests, however, if requested by the ITF to complete these tests, doing so is seen as a requirement of the classification process and in line with article 2.3 in the ITF Classification Rules. This is to support the evolution of classification in the sport going forwards.

The sport-specific testing battery used in this trial includes the following three ambulation specific activity limitation tests:

4. 2-minute walk test (Appendix II)
5. Five Times Sit-to-stand test (Appendix III)
6. Edgren side-step test (Appendix IV)

Appendices II to IV provide detailed descriptions of these three sport-specific tests.

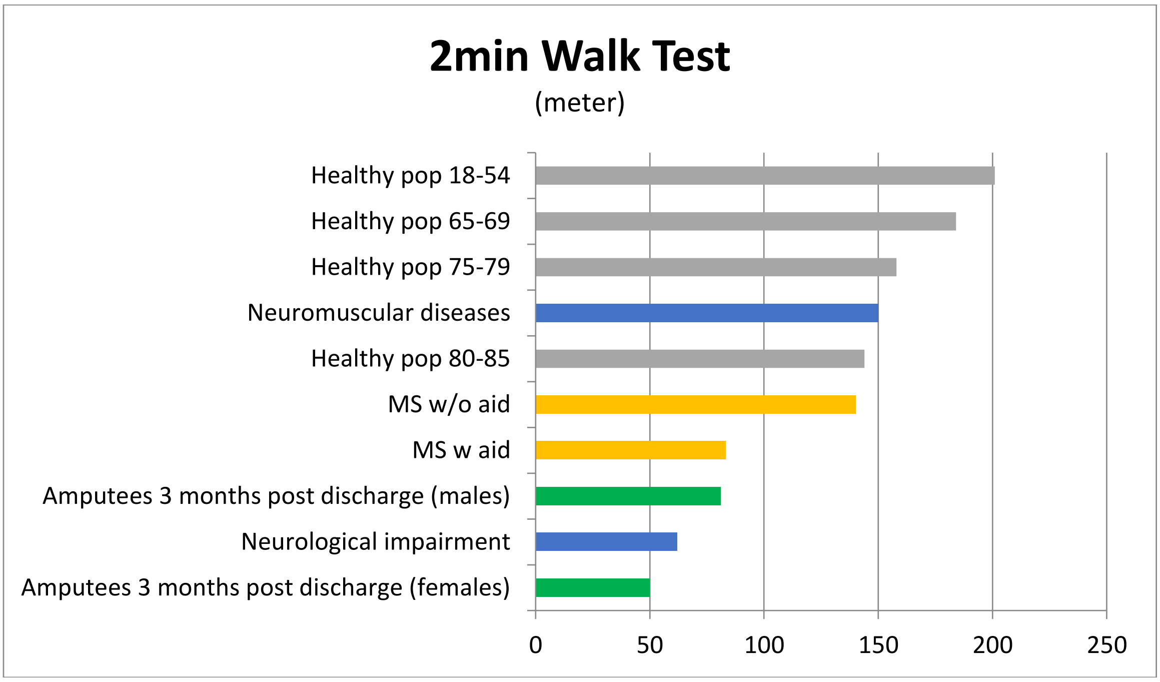
Appendix VII. Two Minute Walk Test

The Two Minute Walk Test (2MWT) is a measure of self-paced walking ability and functional capacity (Butland et al, 1982). It is appropriate for use with individuals who cannot manage the Six Minute Walk test or 12 Minute Walk Test. It is appropriate for use in classification, as if an athlete cannot walk adequately for two minutes due to an underlying health condition, they will not be able to meet the demands of playing tennis.

The 2MWT has been used as an outcome measure in a variety of health conditions including lower limb amputation (Brooks et al, 2001) neuromuscular diseases (Scalzitti et al, 2018; Witherspoon et al, 2019), and in both adult and paediatric populations (Bohannon et al, 2018; Witherspoon et al, 2019). Use in these populations allows a reasonable cut-off score to be established for this purpose (Figure VII.1).

The 2MWT has shown good to excellent inter and intra-rater reliability in able-bodied, and amputee populations (Brooks et al, 2002; Bohannon et al, 2015) and corelates well with 4 and 6-minute walk tests in individuals with a neuromuscular disease (Witherspoon et al, 2019).

Figure VII.1. Reference values for the 2 min Walk Test

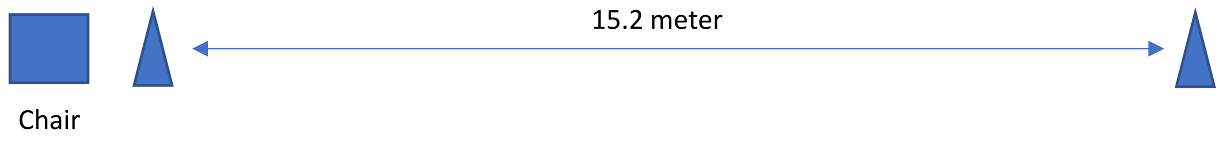


Key:
- (green) Players currently classified eligible for the sport
- (yellow) Players currently within the sport but details of level of function unknown at this time
- (blue) Eligible underlying health condition, but currently unknown playing population within sport
- (grey) Reference populations without eligible underlying health condition

Equipment

Stopwatch
Chair
Cones
Measuring wheel

Set up:



Instructions

This test should be video recorded. One classifier will administer the test and one will record the test. This test should be filmed from a behind the starting cone, so that the athlete is walking away from and then towards the and the whole of the athlete should be visible at all times.

Commands given are based on those of the 6MWT: before the participant starts walking the classifier advises them to "Cover as much ground as possible without running" or "Walk as fast as possible" and to take a rest break if needed. The classifier then gives encouragement after the first minute with standardised responses: "You're doing well" and "One minute left". Start timing when the individual is instructed to “Go” and stop timing at 2 minutes. Physical assistance to walk should not be provided. If the athlete needs assistance to prevent injury, this may be provided. Athletes will be asked to perform once without being timed or recorded to allow familiarisation with the test and ensure comprehension of instruction.
Following the test, the total distance covered should be calculated. This is done by multiplying the number of completed lengths of the course (between the cones) by 15.2 and then adding the distanced covered on the final length. The final length should be measured from the cone at the start of that length, to the athletes finishing position, using a measuring wheel.

Patient instructions

Cover as much ground as possible over 2 minutes without running. Walk continuously, if possible, but do not be concerned if you need to slow down or stop to rest. The goal is to feel at the end of the test that more ground could not have been covered in the 2 minutes.

Appendix VIII. Five Times Sit to Stand Test

The sit-to-stand test was designed by Csuka and McCarty in 1985, originally called timed-stands test. Their test determined the time spent to perform 10 repetitions. Subsequent variations were developed, including the five-repetition sit-to-stand test.

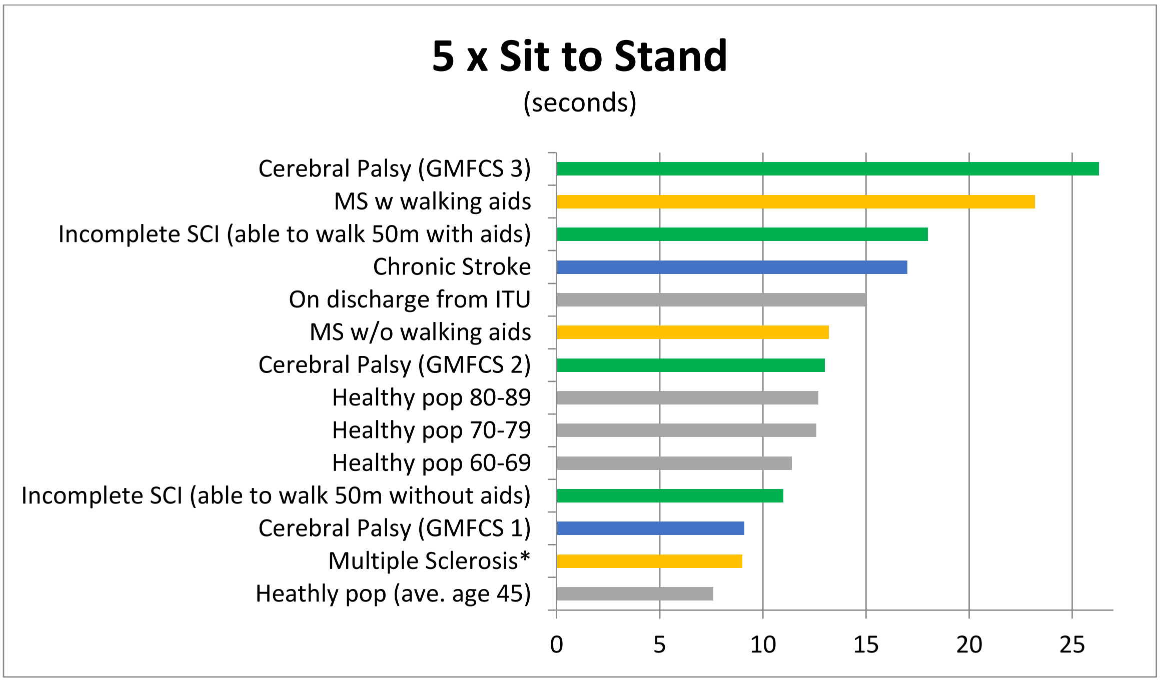
The 5-times sit-to-stand test is used as a global measure of lower limb strength and function (Bohannon et al, 2010) utilising the triple extension pattern required for tennis. This test has been investigated in populations with disabilities and conditions commonly associated with sarcopenia and impaired muscle power (de Melo et al, 2019; Mong et al 2010).

The test has been shown to have excellent inter- and intra-rater reliability, including with assessors across a range of experience using the test (de Melo et al, 2019, Mong et al 2010). The 5 times sit-to-stand test has also demonstrated good clinical feasibility in the elderly and good test-retest reliability in healthy individuals between 14 and 85 years of age (Bohannon, 2011). Reference values for disability and non-disability populations have been established (Bohannon, 2006; Silva et al, 2014), improving the ability to determine a reasonable cut-off time for its use.

Reference Values

Below is a chart outlining 5 x Sit to Stand performance in healthy populations and varying clinical groups which often present with impaired muscle power, based on published literature.

Figure VIII.1. Reference values for the 5 x Sit to Stand



Key:
- Players currently classified eligible for the sport
- Players currently within the sport but details of level of function unknown at this time
- Eligible underlying health condition, but currently unknown playing population within sport
- Reference populations without eligible underlying health condition

Equipment

Stopwatch
Video camera

Set up

The athlete sits on a plinth / chair without arm rests. The athlete's feet should be on the floor and their arms crossed across their chest. The height of the plinth / chair should be adjusted so that the athlete's knee and hip joints are at approximately 90^{o} flexion when seated.

Instructions

This test should be video recorded. One classifier will administer the test and one will record the test. This test should be filmed from a lateral view (from the side of the athlete) and the whole of the athlete should be visible at all times.

On the command of 'Go', the athlete is required to perform a sit to stand movement 5 times as fast as possible. The classifier starts timing on the command of 'Go' and stops timing once the athlete's buttocks contact the chair after the 5^{th} repetition of the sit to stand movement. Athletes will be asked to perform once without being timed or recorded to allow familiarisation with the test and ensure comprehension of instruction.

The time is measured to the nearest decimal point recorded. The athlete passes this test if they have completed the 5 repetitions in less than or exactly X seconds.

*****include images*****

Appendix IX. Edgren Side Step Test

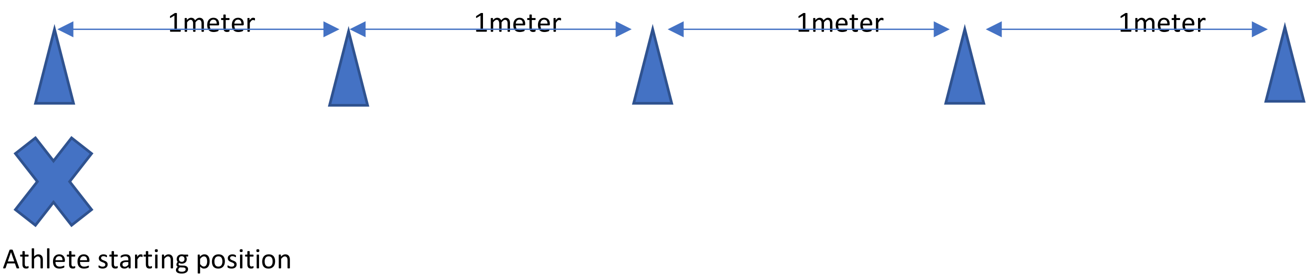
The Edgren side step (Edgren, 1932) is used to assess an athlete's ability to move side to side and change direction (Reiman and Manske, 2009). This test reflects the essential lateral movement requirements in tennis (Pereira et al, 2016).

In addition, this test has been used in a disability population, with average scores established previously (Gailey, 2011), and shows excellent interrater reliability and test-retest reliability (Gailey et al, 2013). This improves the ability for this test to fairly utilised by multiple classifiers at different time points without a change to the outcome.

Equipment

Five cones
Stopwatch
Tape measure
Video camera

Set up



Instructions

This test should be video recorded. One classifier will administer the test and one will record the test. This test should be filmed from an anterior view (from in front of the athlete) and the whole of the athlete and the test set up should be visible at all times.

On the command of 'Go', the athlete sidesteps along the course until their leading foot is in line with, or crosses the final cone. At this point they change direction and sidestep back until their leading foot on or over the line of the outer cone. The athlete repeats this continually for 10 seconds. Athletes will be asked to perform once without being timed or recorded to allow familiarisation with the test and ensure comprehension of instruction.

Classifiers should record the test for the purposes of accurate scoring and review.

The athlete scores 1 point for each cone they pass during the 10 seconds.

Appendix X. References

Chapter 4.

Fricker M. Epistemic injustice. Power and the ethics of knowing. Oxford University Press, 2009. ISBN 9780199570522

Loland S. Classification in sport: A question of fairness. Eur J Sport Sci 2021;1-8. https://doi.org/10.1080/17461391.2021.1923816

Loland S. Caster Semenya, athlete classification, and fair equality of opportunity in sport. J Med Ethics 2020;46: 584-90.

Loland S, Hoppeler H. Justifying anti-doping: The fair opportunity principle and the biology of performance enhancement. Eur J Sport Sci 2012;12:347-353.

Loland S, McNamee M. (2000). Fair play and the ethos of sports: an eclectic philosophical framework. J Philosophy Sport 2000;27:63-80.

Chapter 8. General standard

Fernandez-Fernandez J, Mendez-Villanueva A, Fernandez-Garcia B, Terrados N. Match activity and physiological responses during a junior female singles tennis tournament. Br J Sports Med 2007;41:711-716.

Hornery DJ, Farrow D, Mujika I, Young W. An integrated physiological and performance profile of professional tennis. Br J Sports Med 2007; 41:531-536; discussion 536.

Kovalchik SA, Reid M. Comparing matchplay characteristics and physical demands of junior and professional tennis athletes in the era of big data. J Sports Sci Med 2017;16:489-497.

Pereira TJC, Nakamura FY, de Jesus MT, Vieira CL, Misuta MS, de Barros RM, Moura FA. Analysis of the distances covered and technical actions performed by professional tennis players during official matches. J Sports Sci 2017;35:361-368.

Chapter 9. Physical demands of tennis

Bergeron MF, McLeod KS, Coyle J F. Core body temperature during competition in the heat: national boys' 14s junior tennis championships. Br J Sports Med 2007;41:779-783.

Carboch J, Siman J, Sklenarik M, Blau M. Match characteristics and rally pace of male tennis matches in three Grand Slam tournaments. Phys Act Rev 2019;7:49-56.

Carboch JAN, Blau M, Sklenarik M, Siman J, Placha K. Ball change in tennis: How does it affect match characteristics and rally pace in Grand Slam tournaments? J Hum Sport Exerc 2020;15:153-162.

Carboch JAN, Plachá K. Development of rally pace and other match characteristics in women's matches in the Australian Open 2017. J Phys Educ Sport 2018;18:1079-1083.

Carboch, J. A. N., Placha, K., & Sklenarik, M. Rally pace and match characteristics of male and female tennis matches at the Australian Open 2017. J Hum Sport Exerc 2018;13:743-750.

Cui Y, Gómez M, Gonçalves B, Sampaio, J. Performance profiles of professional female tennis players in grand slams. PloS one 2018;13: e0200591.

Cui Y, Gómez M, Gonçalves B, Liu H, Sampaio J. Effects of experience and relative quality in tennis match performance during four Grand Slams. Int J Perform Anal Sport 2017;17:783-801.

Cui Y, Liu H, Gómez M, Liu H, Gonçalves B. Set-to-set performance variation in tennis Grand Slams: play with consistency and risks. J Hum Kinet 2020;73:153-163.

Cui Y, Zhao Y, Liu H, Gómez M, Wei R, Liu Y. Effect of a seeding system on competitive performance of elite players during major tennis tournaments. Front Psychol 2020;11: 1294.

Fernandez J, Mendez-Villanueva A, Pluim BM. Intensity of tennis match play. Br J Sports Med 2006;40:387-391; discussion 391.

Fernández-Elías V, Courel-Ibáñez J, Pérez-López A, Jodra P, Moreno-Pérez V, Coso JD, López-Samanes, Á. Acute beetroot juice supplementation does not improve match-play activity in professional tennis players. J Am Coll Nutr 2020;1-8.

Fernandez-Fernandez J, Mendez-Villanueva A, Fernandez-Garcia B, Terrados N. Match activity and physiological responses during a junior female singles tennis tournament. Br J Sports Med 2007;41:711-716.

Fernandez-Fernandez J, Sanz-Rivas D, Fernandez-Garcia B, Mendez-Villanueva A. Match activity and physiological load during a clay-court tennis tournament in elite female players. J Sports Sci 2008;26:1589-1595.

Fernandez-Fernandez J, Sanz-Rivas D, Mendez-Villanueva A. A review of the activity profile and physiological demands of tennis match play. Strength Cond J 2009;31:15-26.

Fernandez-Fernandez J, Sanz-Rivas D, Sanchez-Muñoz C, Pluim BM, Tiemessen I, Mendez-Villanueva A. (2009). A comparison of the activity profile and physiological demands between advanced and recreational veteran tennis players. J Strength Cond Res 2009;23:604-610.

Filipcic A, Zecic M, Reid M, Crespo M, Panjan A, Nejc S. Differences in performance indicators of elite tennis players in the period 1991-2010. J Phys Educ Sport 2015;15:671-677.

Fitzpatrick A, Stone JA, Choppin S, Kelley J. Important performance characteristics in elite clay and grass court tennis match-play. Int J Perform Anal Sport 2019;19:942-952.

Galé-Ansodi C, Castellano J, Usabiaga O. More acceleration and less speed to assess physical demands in female young tennis players. Int J Perform Anal Sport 2017;17:872-884.

Galé-Ansodi C, Castellano J, Usabiaga O. Differences between running activity in tennis training and match-play. Int J Perform Anal Sport 2018;18:855-867.

Galé-Ansodi C, Castellano J, Usabiaga O. Physical profile of young tennis players in the tennis match-play using global positioning systems. J Phys Educ Sport 2017;17:826-832.

Galé-Ansodi C, Castellano J, Usabiaga O. Effects of different surfaces in time-motion characteristics in youth elite tennis players. Int J Perform Anal Sport 2016;16:860-870.

Gallo-Salazar C, Del Coso J, Sanz-Rivas D, Fernandez-Fernandez J. Game activity and physiological responses of young tennis players in a competition with two consecutive matches in a day. Int J Sports Physiol Perform 2019;14:887-893.

Gescheit DT, Duffield R, Skein M, Brydon N, Cormack SJ, Reid M. Effects of consecutive days of match play on technical performance in tennis. J Sports Sci 2017;35:1988-1994.

Gomes RV, Capitani CD, Ugrinowitsch C, Zourdos MC, Fernandez-Fernandez J, Mendez-Villanueva A, Aoki MS. Does carbohydrate supplementation enhance tennis match play performance? J Int Soc Sports Nutr 2013;10:46.

Gomes RV, Coutts AJ, Viveiros L, Aoki MS. Physiological demands of match-play in elite tennis: A case study. Eur J Sport Sci 2011;11:105-109.

Hoppe MW, Baumgart C, Bornefeld J, Sperlich B, Freiwald J, Holmberg HC. Running activity profile of adolescent tennis players during match play. Pediatr Exerc Sci 2014;26:281-290.

Hoppe MW, Baumgart C, Freiwald J. (2016). Do running activities of adolescent and adult tennis players differ during play? Int J Sports Physiol Perform 2016;11:793-801.

Hoppe MW, Baumgart C, Stückradt A, Hoffmann N, Engelhardt M, Freiwald J, Grim C. Effects of playing strategies on match activities and physiological responses in well-trained female tennis players derived by an alternative statistical approach. Sports Orthop Traumatol 2019;35:31-39.

Hoppe MW, Hotfiel T, Stückradt A, Grim C, Ueberschär O, Freiwald J, Baumgart C. Effects of passive, active, and mixed playing strategies on external and internal loads in female tennis players. PloS one 2020;15:e0239463.

Hornery DJ, Farrow D, Mujika I, Young W. An integrated physiological and performance profile of professional tennis. Br J Sports Med 2007; 41:531-536; discussion 536.

Hughes MG, Meyers R. (2005). Movement patterns in elite men's singles tennis. Int J Perform Anal Sport 2017;5:110-134.

Johnson CD, McHugh MP, Wood T, Kibler B. Performance demands of professional male tennis players. Br J Sports Med 2006; 40:696-699; discussion 699.

Kilit B, Arslan E. Physiological responses and time-motion characteristics of young tennis players: comparison of serve vs. return games and winners vs. losers matches. Int J Perform Anal Sport 2017;17:684-694.

Kilit B, Arslan E. Playing tennis matches on clay court surfaces are associated with more perceived enjoyment response but less perceived exertion compared to hard courts. Acta Gymnica 2018; 48:147-152.

Kilit B, Şenel Ö, Arslan E, Can S. Physiological responses and match characteristics in professional tennis players during a one-hour simulated tennis match. J Hum Kin 2016;51:83-92.

Kovacs MS. Energy system-specific training for tennis. Strength Cond J 2004;26:10-13.

Kovacs MS. Applied physiology of tennis performance. Br J Sports Med 2006;40:381-385; discussion 386.

Kovacs MS. Tennis physiology: training the competitive athlete. Sports Med 2007;37:189-198.

Kovalchik SA, Reid M. Comparing matchplay characteristics and physical demands of junior and professional tennis athletes in the era of big data. J Sports Sci Med 2017;16:489-497.

Lees A. Science and the major racket sports: a review. J Sports Sci 2003;21:707-732.

Luque GT, Gutiérrez CV. Plasma volume and electrolyte changes after a female single tennis match. Apunts Sports Med 2007;42:169-174.

Maquirriain J, Baglione R, Cardey M. Male professional tennis players maintain constant serve speed and accuracy over long matches on grass courts. Eur J Sport Sci 2-16;16:845-849.

Maraga, N., Duffield, R., Gescheit, D., Perri, T., & Reid, M. (2018). Playing not once, not twice but three times in a day: the effect of fatigue on performance in junior tennis players. Int Perform Analys Sport, 18, 104-114.

Martin C, Thevenet D, Zouhal H, Mornet Y, Delès R, Crestel T, Ben Abderrahman A, Prioux J. Effects of playing surface (hard and clay courts) on heart rate and blood lactate during tennis matches played by high-level players. J Strength Cond Res 2011;25:163-170.

MartÍnez-Gallego R, Crespo M, Ramón-Llin J, Micó S, Guzmán JF. Men's doubles professional tennis on hard courts: Game structure and point ending characteristics. J Hum Sport Exerc 2020;15:633-642.

Martínez-Gallego R, Guzmán JF, Crespo M, Ramón-Llin J, Vučković G. Technical, tactical and movement analysis of men's professional tennis on hard courts. J Sports Med Phys Fitness 2017;59: 50-56.

Martínez-Gallego R, Guzmán JF, James N, Pers J, Ramón-Llin J, Vuckovic G. Movement characteristics of elite tennis players on hard courts with respect to the direction of ground strokes. J Sports Sci Med 2013;12:275-281.

McCarthy PR, Thorpe RD, Williams C. Body fluid loss during competitive tennis match-play. In: Lees A, Maynard I, Hughes M, Reilly T (eds). Science and Racket Sports II, Taylor & Francis 1998, pp. 70-73.

Meffert D, O'Shannessy C, Born P, Grambow R, Vogt T. Tennis at tiebreaks: addressing elite players' performance for tomorrows' coaching. German J Exerc Sports Res 2019;49:339-344.

Mendez-Villanueva A, Fernandez-Fernández J, Bishop D, Fernandez-Garcia B. Ratings of perceived exertion-lactate association during actual singles tennis match play. J Strength Cond Res 2010;24:165-170.

Mendez-Villanueva A, Fernandez-Fernandez J, Bishop D, Fernández-García B, Terrados N. Activity patterns, blood lactate concentrations and ratings of perceived exertion during a professional singles tennis tournament. Br J Sports Med 2007;41:296-300.

Morante SM, Brotherhood JR, Brotherhood J. Match characteristics of professional singles tennis. Med Sci Tennis 2005;10:12-13.

Moreno-Pérez V, López-Samanes Á, Domínguez R, Fernández-Elías VE, González-Frutos P, Fernández-Ruiz V, Pérez-López A, & Fernández-Fernández J. Acute effects of a single tennis match on passive shoulder rotation range of motion, isometric strength and serve speed in professional tennis players. PloS one 2019;14:e0215015.

Murias JM, Lanatta D, Arcuri CR, Laino FA. Metabolic and functional responses playing tennis on different surfaces. J Strength Cond Res 2007;21:112-117.

Murphy AP, Duffield R, Kellett A, Reid M. A comparison of the perceptual and technical demands of tennis training, simulated match play, and competitive tournaments. Int J Sports Physiol Perform 2016;11:40-47.

Myers NL., Sciascia AD, Kibler WB, Uhl TL. Volume-based interval training program for elite tennis players. Sports Health 2016;8:536-540.

O'Donoghue P, Ingram B. A notational analysis of elite tennis strategy. J Sports Sci 2001;19:107-115.

O'Donoghue PD, Liddle SD. A notational analysis of time factors of elite mens and ladies singles tennis on clay and grass surfaces. In: Lees A, Maynard I, Hughes M, Reilly T (eds). Science and Racket Sports II, Taylor & Francis 1998, pp. 241-246.

Peltier SL, Leprêtre PM, Metz L, Ennequin G, Aubineau N, Lescuyer JF, Duclos M, Brink T, Sirvent P. Effects of pre-exercise, endurance, and recovery designer sports drinks on performance during tennis tournament simulation. J Strength Cond Res 2013;27:3076-3083.

Pereira LA, Freitas V, Arruda Moura F, Saldanha Aoki M, Loturco I, Yuzo Nakamura F. The activity profile of young tennis athletes playing on clay and hard courts: preliminary data. J Hum Kinet 2016;50:211-218.

Pereira TJ, Nakamura FY, de Jesus MT, Vieira CL, Misuta MS, de Barros RM, Moura FA. Analysis of the distances covered and technical actions performed by professional tennis players during official matches. J Sports Sci 2017;35:361-368.

Perri T, Norton KI, Bellenger CR, Murphy AP. Training loads in typical junior-elite tennis training and competition: implications for transition periods in a high-performance pathway. Int J Perform Anal Sport 2018;18:327-338.

Ponzano M, Gollin M. Movement analysis and metabolic profile of tennis match play: comparison between hard courts and clay courts. Int J Perform Anal Sport 2017;17:220-231.

Reid M, Morgan S, Whiteside D. Matchplay characteristics of Grand Slam tennis: implications for training and conditioning. J Sports Sci 2016;34:1791-1798.

Roetert EP, Ellenbecker TS, Reid M. Biomechanics of the tennis serve: implications for strength training. Strength Cond J 2009; 31:35-40.

Smekal G, von Duvillard SP, Rihacek C, Pokan R, Hofmann P, Baron R, Tschan H, Bachl N. A physiological profile of tennis match play. Med Sci Sports Exerc 2001;33:999-1005.

Smith MT, Reid M, Kovalchik S, Wood T, Duffield R. Heat stress incidence and matchplay characteristics in Women's Grand Slam Tennis. J Sci Med Sport 2018;21:666-670.

Smith MT, Reid M, Kovalchik S, Woods TO, Duffield R. Heat stress incident prevalence and tennis matchplay performance at the Australian Open. J Sci Med Sport 2018;21:467-472.

Stare M, Žibrat U, Filipčič A. Stroke effectiveness in professional and junior tennis. Kinesiologia Slovenica 2015;21:39-50.

Takahashi H, Wada T, Maeda A, Kodama M, Nishizono H. An analysis of time factors in elite male tennis players using the computerised scorebook for tennis. Int J Perform Anal Sport 2009;9:314-319.

Takahashi H, Wada T, Maeda A, Kodama M, Nishizono H, Kurata H. The relationship between court surface and tactics in tennis using a computerized scorebook. Int J Perform Anal Sport 2006;6:15-25.

Torres-Luque G, Cabello-Manrique D, Hernández-Garcia R, Garatachea N. An analysis of competition in young tennis players. Eur J Sport Sci 2011;11:39-43.

Torres-Luque G, Sánchez-Pay A, Belmonte J B, Ramón MM. Functional aspects of competitive tennis. J Human Sport Exerc 2011;6:528-539.

Whiteside D, Reid M. External match workloads during the first week of Australian Open tennis competition. Int J Sports Physiol Perform 2017;12:756-763.

Whiteside D, Bane M K, Reid M. Differentiating top-ranked male tennis players from lower-ranked players using Hawk-Eye data: An investigation of the 2012–2014 Australian Open tournaments. In: Colloud F, Domalain M, Monnet T (eds). 33rd International Conference on Biomechanics in Sport 2015, pp 1308-1311.

Appendix I. Review of Impaired Muscle Power

Strength and musculoskeletal disorders

Casartelli NC, Maffiuletti NA, Item-Glatthorn JF et al. Hip muscle weakness in patients with symptomatic femoroacetabular impingement. 2011;19:816-21.

Larson AN, Sucato DJ, Herring JA et al. A prospective multicenter study of Legg-Calvé-Perthes disease: functional and radiographic outcomes of nonoperative treatment at a mean follow-up of twenty years. J Bone Joint Surg Am 2012;94:584-92.

Leung J, Smith R, Harvey LA, Moseley AM, Chapparo J. The impact of simulated ankle plantarflexion contracture on the knee joint during stance phase of gait: w within-subject study. Clin Biomech 2014;29:423-8.

Veilleux LN, Trejo P, Rauch F. Muscle abnormalities in osteogenesis imperfecta. J Musculoskelet Neuronal Interact 2017;17:1-7.

Wenger Dennis R. Leg-Calvé-Perthes disease: Functional prognosis in an era of high expectations. J Am Acad Orthop Surg 2010;18:676-686.

Strength and gait

Aguiar LT, Martins JC, Brito SAF, Mendes CLG, Teixeira-Salmela LF, Faria CDCM. Knee extensor muscle strength indicates global lower-limb strength in individuals who have suffered a stroke: a cross-sectional study. Braz J Phys Ther 2019; 23: 221-227.

Aguiar LT, Camargo LBA, Estarlino LD, Teixeira-Salmela LF, de Morais Faria CDC. Strength of the lower limb and trunk muscles is associated with gait speed in individuals with sub-acute stroke: a cross-sectional study. Braz J Phys Ther 2018; 22: 459-466.

Baker RW. Measuring walking: a handbook of clinical gait analysis. Mac Keith Press, 2013

Dorsch S, Ada L, Canning CG, Al-Zharani M, Dean C. The strength of the ankle dorsiflexors has a significant contribution to walking speed in people who can walk independently after stroke: an observational study. Arch Phys Med Rehabil 2012;93:1072-1076.

Hadders-Algra M. The neurological examination of the child with minor neurological dysfunction. Mac Keith Press, 2010.

Krogt MM van der, Delp SL, Schwartz MH. How robust is human gait to muscle weakness? Gait Posture 2012;36:113-9.

Leijendekkers RA, Marra MA, Kolk S, Bob G van, Schreurs BW, Weerdesteyn V, Verdonschot N. Gait symmetry and hip strength in women with developmental dysplasia following hip arthroplasty compared to health subjects: a cross-sectional study. PLoS One 2018; 13: e0193487.

Perry J, Burnfield JM. Gait analysis. Slack Incorporated, Thorofare, 2010 (2nd ed)

Steele KM, Krogt MM van der, Delp SJ. How much muscle strength is required to walk in a crouch gait? J Biomech 2012;45: 2564-9.

Thompson JA, Chaudhari AMW, Schmitt LC, Best TM, Siston RA. Gluteus maximus and soleus compensate for simulated quadriceps atrophy and activation failure during walking. J Biomech 2013;46:2165-2172.

Strength testing

Bohannon RW. Manual muscle testing: does it meet the standards of an adequate screening test. Clin Rehabil 2005;19:662-7.

Beckman E, Connick M, Tweedy S. Assessing muscle strength for the purpose of classification in Paralympic sport: a review and recommendations. J Sci Med Sport 2017;20:391-396.

Beckman EM, Newcombe P, Vanlandewijck Y, Connick MJ, Tweedy SM. Novel strength test battery to permit evidence-based Paralympic classification. Medicine 2014; 93:e31.

Fosang A, Baker R. A method for comparing manual muscle strength measurement with joint moments during walking. Gait Posture 2006;24:406-411.

Manago MM, Hebert JR, Kittelson J, Schenkman M. Contributions of ankle, knee, hip, and trunk muscle function to gait performance in people with multiple sclerosis: a cross-sectional study. Phys Ther 2018;98:595-604.

Marmon AR, Pozzi F, Alnahdi AH, Zeni JA. The validity of plantar flexors strength measures obtained through hand-held dynamometry measurements of force. In J Sports Phys Ther 2013;8:820-827.

Mentiplay BJ, Perraton LG, Bower KJ, Adair B, Pua YH, Williams GP, McGaw R, Clark RA. Assessment of lower limb muscle strength hand power using hand-held and fixed dynamometry: a reliability and validity study. PLoS One 2015 10:e0140822.

Stark T, Walker B, Philips JK, Fejer R, Beck R. Hand-held dynamometry correlation with the gold standard isokinetic dynamometry : a systematic review. Phys Med Rehabil 2011;3:472-479.

Tweedy SM, Williams G, Bourke J. Selecting and modifying methods of manual muscle testing for classification in Paralympic sport. Eur J Adapt Phys Activ 2010;3:7-16.

Appendix II & III. MIC for Impaired Range of Movement & Lower Body Joint Angles per Tennis Stroke

Akutagawa S, Kojima T. Trunk rotation torques through the hip joints during the one-and two-handed backhand tennis strokes. J Sports Sci 2005; 23: 781-793.

Brown S, Brughelli M, Hume P. Knee mechanics during planned and unplanned sidestepping: a systematic review and meta-analysis. Sports Med 2014; 44: 1573–1588.

Connolly M, Middleton K, Reid M. Differences in tennis serve kinematics between elite adolescent male and female players. ISBS Proceedings Archive 2019; 37: 431-434.

Fenter B, Marzilli TS, Wang YT, Dong XN. Effects of a three-set tennis match on knee kinematics and leg muscle activation during the tennis serve. Percept Mot Skills 2017; 124: 214-232.

Ferber R, Davis I, Williams DS. Gender differences in lower extremity mechanics during running. Clinical biomechanics (Bristol, Avon). 2003;18: 350-7.

Fleisig G, Nicholls R, Elliott B, Escamilla R. Tennis: Kinematics used by world class tennis players to produce high-velocity serves. Sports Biomech 2003; 2: 51-64.

Genevois C, Reid M, Rogowski I, Crespo M. Performance factors related to the different tennis backhand groundstrokes: a review. J Sports Sci Med 2015; 14: 194–202.

Giles B, Kovalchik S, Reid M. A machine learning approach for automatic detection and classification of changes of direction from player tracking data in professional tennis. J Sports Sci 2020; 38: 106-113.

Goktepe A, Ak E, Söğüt M, Karabörk H, Korkusuz F. Joint angles during successful and unsuccessful tennis serves kinematics of tennis serve. Jt Dis Rel Surg 2009; 20: 156-60.

Goktepe A, Karabork H, Kocaman E. An examination of the differences in the angles created in the lower and upper extremities during tennis serves by male and female players. International Conference on 3D Body Scanning Technologies, Lugano, Switzerland, 2010.

Herbaut A, Chavet P, Roux M, Guéguen N, Gillet C, Barbier F, Simoneau-Buessinger E. The influence of shoe drop on the kinematics and kinetics of children tennis players. Eur J Sport Sci 2016; 16: 1121-1129.

Kolman N. Wat zijn de minimale en maximale hoeken van de heup-, knie- en enkelgewrichten bij tennis? Topsport Topics, 2020.

Martin C, Sorel A, Touzard P. Can the open stance forehand increase the risk of hip injuries in tennis players? Orthop J Sports Med 2020;8:2325967120966297

Moreno-Pérez V, Ayala F, Fernandez-Fernandez J, Vera-Garcia F J. Descriptive profile of hip range of motion in elite tennis players. Phys Ther Sport 2016;19*:* 43–48.

Nesbit SM, Serrano M, Elzinga M. The role of knee positioning and range-of-motion on the closed-stance forehand tennis swing. J Sports Sci Med 2008; 7: 114-124.

Potter D, Reidinger K, Szymialowicz R, Martin T, Dione D, Feinn R, Wallace D, Garbalosa JC. Sidestep and crossover lower limb kinematics during a prolonged sport-like agility test. Int J Sports Phys Ther 2014; 9: 617–627.

Reid M, Elliott B, Alderson J. Lower-limb coordination and shoulder joint mechanics in the tennis serve. Med Sci Sports Exerc 2008; 40: 308-315.

Reid M, Giblin G. Another day, another tennis coaching intervention, but does this one do what coaches purport? Sports Biomech 2015; 14: 180-189.

Sandamas P. Knee joint loading in the open and square stance tennis forehands (Unpublished master's thesis). University of Jyväskylä, Jyväskylä, Finland, 2013.

Seeley MK, Funk MD, Denning WM, Hager RL, Hopkins JT. Tennis forehand kinematics change as postimpact ball speed is altered. Sports Biomech 2011; 10: 415-426.

Sgrò F, Mango P, Nicolosi S, Lipoma M. Analysis of knee joint motion in tennis flat serve using low-cost technological approach. International Workshop on Computer Science in Sports (IWCSS). 2013; 77: 250-254.

Soucie, JM, Wang C, Forsyth A, Funk S, Denny M, Roach KE, Boone D & Hemophilia Treatment Center Network. Range of motion measurements: reference values and a database for comparison studies. Haemophilia 2011;17: 500–507.

Starbuck C, Damm L, Clarke J, Carré M, Capel-Davis J, Miller S, Stiles V, Dixon S. The influence of tennis court surfaces on player perceptions and biomechanical response. J Sports Sci 2016; 34: 1627-1636.

Stiles VH, Dixon SJ (2006). The influence of different playing surfaces on the biomechanics of a tennis running forehand foot plant. J Appl Biomech 2006; 22: 14-24.

Whiteside D, Elliott B, Lay B, Reid M. The effect of age on discrete kinematics of the elite female tennis serve. J Appl Biomech 2013; 29: 573-582.

Appendix IV. Review of Limb Deficiency

Aprile I, Galli M, Pitocco D, Di Sipio E, Simbolotti C, Germanotta M, Bordieri C, Padua L, Ferrarin M. Does first ray amputation in diabetic patients influence gait and quality of life? J Foot Ankle Surg 2018; 57: 44 – 51.

Burger H, Erzar D, Maver T, Olenšek A, Cikajlo I, Matjačić Z. Biomechanics of walking with silicone prosthesis after midtarsal (Chopart) disarticulation. Clin. Biomech 2009; 24: 510-516.

Burnfield JM, Boyd LA, Rao S, Mulroy SJ, Perry J. The effect of partial foot amputation on sound limb loading force during barefoot walking. Gait Posture 1998:7: 178-179.

Dillon MP, Barker TM. Preservation of residual foot length in partial foot amputation: a biomechanical analysis. Foot Ankle Int 2006; 2: 110 – 116.

Garbalosa JC, Cavanagh PR, Wu G, Ulbrecht JS, Becker MB, Alexander IJ, Campbell JH. Foot function in diabetic patients after partial amputation. Foot Ankle Int 1996; 17: 43-48.

Greene WB, Cary JM. Partial foot amputations in children. A comparison of the several types with the Syme amputation. J Bone Joint Surg 1982; 3: 438 – 443.

Kanade RV, Van Deursen RWM, Harding K, Price P. Walking performance in people with diabetic neuropathy: benefits and threats. Diabetologia 2006; 49: 1747-1754.

Kelly, V.E. Mueller, M.J. Sinacore, D.R. Timing of peak plantar pressure during the stance phase of walking. J Am Podiat Med Assoc 2000; 1: 18 - 23.

Kolman N. Wat is het effect van verschillende niveaus van partiele amputatie van de voet op het looppatroon? Topsport Topics, 2020.

Limpt J van. Wat is het effect van het amputatieniveau van een partiele voetamputatie op de parameters van het looppatroon? Bachelor Thesis, Hogeschool van Amsterdam, Amsterdam, 2020.

Marks RM, Long JT, Exten EL. Gait abnormality following amputation in diabetic patients. Foot Ankle Clinics 2010; 15: 501–507.

Mueller MJ, Salsich GB, Bastian AJ. Differences in the gait characteristics of people with diabetes and transmetatarsal amputation compared with age-matched controls. Gait Posture 1998; 7: 200–206.

Mueller MJ, Salsich GB, Shube MJ. Functional limitations in patients with diabetes and transmetatarsal amputations. Phys Ther 1997; 9: 937 - 943.

De Oliveira FCL, Wiliamson W, Ardern C, et al. The association between level of partial foot amputation, various gait parameters and minimum impairment criteria in para sport: a scoping review protocol. Clin Rehab 2021 (submitted).

Pinzur MS, Gold J, Schwartz D, Gross N. Energy demands for walking in dysvascular amputees as related to the level of amputation. Orthopedics 1992; 15: 1033-1037.

Poppen NK, Mann RA, O'Konski M, Buncke HJ, Jahss MH. Amputation of the great toe. Foot Ankle 1981; 1: 333-337.

Rondinelli RD. AMA guides to the evaluation of permanent impairment (sixth edition). American Medical Association, 2008.

Salsich GB, Mueller MJ. Relationships between measures of function, strength and walking speed in patients with diabetes and transmetatarsal amputation. Clin Rehab 1997; 11: 60 – 67.

Appendix V. Review of Leg Length Difference

Gordon JE, Davis LE. Leg length discrepancy: the natural history (and what do we really know). J Pediatr Orthop 2019; 39: S10-S13.

Khamis S, Carmeli E. Relationship and significance of gait deviations associated with limb length discrepancy: A systematic review. Gait Posture 2017; 57: 115-123.

Khamis S, Carmeli E. The effect of simulated leg length discrepancy on lower limb biomechanics during gait. Gait Posture 2018; 61: 73-80.

Knutson GA. Anatomic and functional leg-length inequality: a review and recommendation for clinical decision-making. Part I, anatomic leg-length inequality: prevalence, magnitude, effects and clinical significance. Chiropr Osteopath 2005; 13: 1-10.

Lampe HIH. Children with lower limb length inequality. The measurement of inequality, the timing of physiodesis and gait analysis. PhD thesis, Erasmus University Rotterdam, Rotterdam, 1997.

Sabharwal S, Kumar A. Methods for assessing leg length discrepancy. Clin Orthop Relat Res 2008;466:2910-2922.

Vogt B, Gosheger G, Wirth T, Horn J, Rödl R. Leg Length Discrepancy—treatment Indications and strategies. Dtsch Arztebl Int 2020; 117: 405-411.

Appendix VII. Two Minute Walk Test.

Butland RJ, Pang J, Gross ER, Woodcock AA, Geddes DM. Two-, six-, and 12-minute walking tests in respiratory disease. Br Med J (Clin Res Ed) 1982;284:1607-8.

Brooks D, Parsons J, Hunter JP, Devlin M, Walker J. The 2-minute walk test as a measure of functional improvement in persons with lower limb amputation. Arch Phys Med Rehab. 2001: 82(10):1478-83

Scalzitti DA, Harwood KJ, Maring JR, Leach SJ, Ruckert EA, Costello E. Validation of the 2-minute walk test with the 6-minute walk test and other functional measures in persons with multiple sclerosis. Int J MS Care 2018; 20: 158–163.

Witherspoon JW, Vasavada R, Logari RH et al. Two-minute versus 6-minute walk distances during 6-minute walk test in neuromuscular diseases: is the 2-minute walk test an effective alternative to a 6-minute walk test? Eur J Ped Neurol 2019;23:165-170.

Upton CJ, Tyrrell JC, Hiller EJ. Two-minute walking distance in cystic fibrosis. Arch Dis Child 1988;63:1444e8.

Selman, JPR, de Camargi AA, Santos J, Lanza FC, Dal Corso S. Reference equation for the 2-minute walk test in adults and the elderly. Respir Care 2014; 59: 525-530.

Bohannon RW, Wang Y, Gershon RC. Two-minute walk test performance by adults 18-85 years: normative values, reliability, and responsiveness. Arch Phys Med Rehab 2015; 96:472-7.

Bohannon RW. Normative reference values for the two minute-walk test derived by meta-analysis. J Phys Ther Sci 2017; 29: 2224–2227.

Bohannon RW, Wang Y, Bubela D, Gershon RC. Normative two-minute walk test distances for boys and girls 3 to 17 years of age. Phys Occup Ther Pediatr 2018; 38:1, 39-45.

Appendix VIII. Five times sit to stand test

Bohannon RW, Bubela DJ, Magasi SR, et al. Sit-to-stand test: performance and determinants across the age-span. Isokinet Exerc Sci 2010;18:235-240.

Bohannon RW. Reference values for the five-repetition sit-to-stand test: a descriptive meta-analysis of data from elders. Percept Mot Skills 2006;103:215-222.

Csuka M, McCarty DJ. Simple method for measurement of lower extremity muscle strength. Am J Med 1985;78:77–81

De Melo TA, Duarte ACM, Bezerra TS, et al. The five times sit-to-stand test: safety and reliability with older intensive care unit patients at discharge. Rev Bras Ter Intensiva 2019;31:27-33.

Mong Y, Teo TW, Ng SS. 5-repetition sit-to-stand test in subjects with chronic stroke: reliability and validity. Arch Physical Med Rehabil 2010;91:407–413.

Bohannon RW, Bubela DJ, Magasi SR, Gershon RC. Relative reliability of three objectives tests of limb muscle strength. Isokinet Exerc Sci. 2011;19:77-81.

Silva PFS, Quintino L, Franco J, Faria CDCM. Measurement properties and feasibility of clinical tests to assess sit-to-stand/stand-to-sit tasks in subjects with neurologic disease: a systematic review. Braz J Phys Ther 2014;18:99-110.

Appendix IX. Edgren Side Step Test

Edgren HD. An experiment in the testing of the ability and progress in basketball. Res Quart 1932;3:159-171.

Reiman MP, Manske RC. Functional testing in human performance. Human Kinetics, 2009. ISBN-10:0-7360-6879-1.

Pereira TJC, Nakamura FY, Jesus MTD, et al. Analysis of the distances covered and technical actions performed by professional tennis players during official matches.
J Sports Sci 2016;1-8.

Gailey RS, Gaunaurd IA, Raya MA, et al. Comparison of three agility tests with male servicemembers: Edgren side step test, T-test, and Illinois agility test. J Rehabil Res Dev 2013;50:951-60.

Gailey RS, Raya M, Gaunaurd IA, Roach KE, Gaunaurd I, Scoville C, Linberg A, Jayne D, Campbell S. The validity and reliability of the Comprehensive High-Level Activity Mobility Predictor (CHAMP) established for military ser-vice members with traumatic lower limb loss. J Orthop Sports Phys Ther. 2011;41:A46–47.