DEPARTAMENTO DE PSICOLOGÍA DE LA SALUD

**Programa de Doctorado en Psicología de la Salud**

# ASSESSMENT OF PERFORMANCE PARAMETERS IN BOCCIA: TOWARDS EVIDENCE-BASED CLASSIFICATION

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AUTORIZA:

Que el trabajo de investigación titulado "Assessment of Performance Parameters in Boccia: Towards Evidence-Based Classification", realizado por Dña. Alba Roldán Romero bajo la dirección del Dr. D. Raúl Reina Vaíllo y el Dr. D. David Barbado Murillo sea depositado en el Departamento y posteriormente defendido como Tesis Doctoral en esta Universidad ante el tribunal correspondiente.

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**Título de la Tesis**

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**Tesis Doctoral presentada por:**

**Dña. Alba Roldán Romero**

Dirigida por el Dr. D. Raúl Reina Vaíllo y el Dr. D. David Barbado Murillo

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Elche, 2017

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*A mis padres, hermana y hermano*

*A family is, without doubt, the greatest wealth that we will ever possess...*

*"Whatever you end up doing, love it"*

*(Alfredo, Cinema Paradiso, 1988)*

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**BBLT:** Box and Ball Test

**BBT:** Box and Block Test

**BC:** prefix for sport classes in Boccia

**BISFed:** Boccia International Sport Federation

**CP:** cerebral palsy

**CVTTB:** Continuous Vertical Tapping Test with Ball

**DAP:** stable sitting while performing anterior-posterior displacements with feedback

**DC:** stable sitting while performing circular displacements with feedback

**$d_g$:** effect with Hedges´ correction

**DHFTT:** Discrete Horizontal Finger Tapping Test.

**DML**: stable sitting while performing medial-lateral displacements with feedback

**DVFTT:** Discrete Vertical Finger Tapping Test

**DVTTB:** Discrete Vertical Tapping Test with Ball

**ICC:** intra-class correlation

**ILC:** intra-limb coordination

**IPC:** International Paralympic Committee

**MD:** manual dexterity

**MRE:** mean radial error

**SAP:** stable sitting while performing anterior-posterior displacements with feedback

**SCD:** stable sitting while performing circular displacements with feedback

**SML:** stable sitting while performing medial-lateral displacements with feedback

**SNF:** stable sitting without feedback

**SNVF:** stable sitting without feedback

**SVF:** stable sitting with feedback

**SWF:** stable sitting with feedback

**TC:** trunk control

**TE:** typical error

**UAP:** unstable sitting while performing anterior-posterior displacements with feedback

**UCD:** unstable sitting while performing circular displacements with feedback

**UML:** unstable sitting while performing medial-lateral displacements with feedback

**UNF:** unstable sitting without feedback

**UWF:** unstable sitting with feedback

# ABSTRACT

Classification systems play a major role in the Paralympic sport and valid systems of classification ensure a fair and equitable competition. Classification must comply with the International Paralympic Committee Athletes Classification Code (IPC, 2015), which specifies that classification must be evidence-based, meaning that it is focused on the relationship between the impairment of the player and key performance determinants. The application of the new Code is mandatory for all Paralympic Sports.

Boccia is a Paralympic sport open for the called “Athletes with High Support Needs”. Although its debut was many years ago (1984) and it is one of the two specific Paralympic sports that has not homologous in the Olympic program, little studies have been conducted about this Para sport. Therefore, it is not surprising that Boccia does not count with a classification system supported in evidence. This Thesis aims to contribute to the development of a more objective classification system that helps to promote sports practice among athletes with severe impairments, promoting the Paralympic values of “determination, equality, inspiration and courage”.

Across this dissertation it is intended to provide information about functional abilities of individuals with moderate-to-severe cerebral palsy, eligible for Boccia. The strengths and weaknesses of current classification methods are presented, discussed and questioned. The three studies provide evidence about how to assess trunk control, hand function and intra-limb coordination, describing how much impaired are athletes with moderate-to-severe CP, and the discriminant capacity of these tests to differentiate between BC1 and BC2 sport classes. These findings provide a basis for further research to evaluate the strength of the measures of the impairment and the key determinants of performance.

# RESUMEN

Los sistemas de clasificación juegan un papel crucial en el deporte paralímpico, ya que un sistema de clasificación válido garantizaría una competición justa y equitativa. La clasificación debe cumplir con el Código de Clasificación de Deportistas del Comité Paralímpico Internacional, especificando que la clasificación debe estar basada en evidencias científicas (IPC, 2015), centrándose en la relación entre el impedimento del jugador y los determinantes clave del rendimiento deportivo. La implementación de dicho Código de Clasificación para con el desarrollo de sistemas de clasificación basados en evidencias es aplicable a todos los paradeportes y, además, es de carácter obligatorio.

La Boccia es un deporte paralímpico que ofrece oportunidades deportivas a los deportistas denominados como "Atletas con Grandes Necesidades", haciendo referencia a aquellos que presentan impedimentos más severos. A pesar de que la Boccia hizo su debut en los Juegos Paralímpicos hace ya 33 años, y es uno de los dos deportes paralímpicos específicos (i.e. no tiene un homólogo en los Juegos Olímpicos), pocos estudios se han llevado a cabo sobre este deporte. De hecho, no es sorprendente que este deporte aún no cuente con un sistema de clasificación objetivo y basado en evidencias científicas. Esta tesis pretende contribuir a la generación de evidencia acerca de la evaluación del control postural, la destreza de la mano y la coordinación intra-segmentaria del brazo de lanzamiento, elementos clave para el rendimiento en este paradeporte. Además, se analizará el grado de limitación presentado por personas con moderada-a-severa parálisis cerebral con respecto a un grupo control, y la capacidad de discriminación de tales test para diferenciar entre deportistas de las clases BC1 y BC2.

# PREAMBLE

This project emerged in 2012 after London Paralympic Games with the leadership of Professor Raúl Reina and a multidisciplinary collaboration among different Laboratories of the Sport Research Center (CID) of the Miguel Hernandez University. Part of this project got a financing collaboration between 2012 and 2013 of the Bancaja Banking Institution (Ref. 11859/11), whose contribution was crucial for the first phase of this project.

The work we present here represents a part of the original project. Difficulties in assessing this population due to their transportation needs and their physical limitations, have required a high number of collaborators who have worked on this project on a voluntary basis.

This dissertation is a novel, ambitious, and above all, necessary project for the target population, trying to explain throughout this work. This thesis, after all, intends to obtain a more in-depth and realistic knowledge of the complex functionality of boccia players with cerebral palsy, regarding trunk control and upper limbs (arm and hands) coordination. The whole project wanted to obtain evidence-based information that could help to optimize the current and functional profiles to compete within this sport. Transference to the para-sport is guaranteed because principal investigator of this project is member of the BISFed Classification Committee and the PhD candidate is international trainee classifier.

Some aspects of this project have been developed thanks international collaborations with the University of Queensland (Australia), through Professor Sean Tweedy, and also with the Boccia International Sport Federation (BISFed), through the Boccia Head of Classification, Elsa Matthee. At National level, we counted with the support of the National Federation of Sport for people with Cerebral Palsy (FEDPC).

# OUTLINE OF THE DOCTORAL THESIS

Classification is a major issue in current Paralympic sport, and Paralympics Games are the pinnacle of the career of Paralympic athletes and motivate others to participate or engage in Paralympic events. This dissertation intends to go a step further for the achievement of an objective classification system in Boccia, in order to achieve fair competition among Athletes with High Support Needs. This aim is in line with the United Nations (UN) Convention on the rights and dignities for persons with disabilities (UN, 1993), as an appropriate classification system may promote equal access and rights to participate in recreational activities and sport (Art. 30 UN, 2006). Furthermore, promoting the values of the Paralympic Movement about *courage, determination, inspiration* and *equality* (IPC, 2015a), being its ultimate aspiration *"to make for a more inclusive society for people with an impairment through para-sport"*.

According with Tweedy and Howe (2011), classification is a critical aspect of Paralympic sport, for two key reasons. Firstly, classification determines who is not eligible to compete in Paralympic sport. As the stature sport increases (increased public awareness or media attention) there is a proportional importance of decisions which determine eligibility for Paralympic sport. Traditionally athletes within each sport/event were classified by type and degree of disability to ensure equitable competition. However, this resulted in a very large number of events, medals and world records – peaking in Seoul in 1988 with 1257 events, 971 world records and 2208 medals for around 3000 athletes (Darcy, 2012; Strohkendl, 2001). Originally, probably because Paralympic sport originated as extension of the rehabilitation process, early systems of classification were medically based. The organizational structure of classification with a medical approach separate the classes by impairments as spinal cord injury, amputations, brain damage, among others, and each sport receive a class according athlete´s impairment and compete with the same class in all the sports. This conception of classification it not feasible today due to the specialization and athletes´ performance of every Paralympic sport.

Secondly, classification is the sole means by which success in Paralympic sport is legitimized. If stakeholders in Paralympic sport (athletes, media, administrators, the media, or the public) suspect that the athletes who succeed in Paralympic sport are simply those who have disabilities that are less severe than their competitors, then the value of success in Paralympic sport become questionable. Moreover, because the classification systems are so complex, most people find it confusing, presenting an obstacle to the Paralympics in gaining more widespread public acceptance (Darcy and Cashman 2008).

Due to the maturation of the Paralympic movement, sport ceased to be a mere extension of rehabilitation and become important in its own right (Tweedy and Howe, 2011). The focus on sport, rather than rehabilitation, drove the development of functional classification systems, where the main factors that determine class are not the diagnosis and medical evaluation, but how much the impairment of a person impacts upon sport performance. Then, the key purpose of the classification process is to minimize the impact of the impairment on the outcome of competition (Tweedy and Vanlandewijck, 2011).

The current IPC´s Athlete Classification Code (IPC, 2015b) highlights that "International Sport Federations must develop sports-specific Classification Systems through multidisciplinary scientific research. Such research must be evidence-based and focus on the relationship between Impairment and key performance determinants". In order to accomplish with this statement, the structure of this dissertation is organized as follows:

- The general introduction **(Chapter I)** aims to provide a general background about cerebral palsy and the related eligible impairments for Boccia. A description of Boccia sport is included, highlighting the performance factors identified for this Para sport.

- **Chapter II** lays out the reasoning behind this study regarding the theoretical model for the development of evidence-based classification systems in Paralympic sport. This reasoning justifies the study in order to develop three studies to address different questions regarding evidence-based classification in Boccia. The aims and the hypothesis of the dissertation are also stablished in this chapter.
- **Chapter III** includes a study that analyzes the relative and absolute intra-session reliability of a trunk control test battery based in posturography, using a force platform and a biofeedback system. This study aims to quantify in which extent trunk control is impaired in adults with moderate-to-severe cerebral palsy in comparison to a control group without disabilities. Besides, trunk control performance (i.e. how much the participant is able to keep his/her center of pressure on the target provided by the biofeedback system) is assessed in static and dynamic conditions.
- **Chapter IV** explores the ability of the BISFed TFS and the posturographic protocol have to discriminate between BC1 and BC2 sport classes. That study also examines the relationship between both methodologies (clinical/field vs laboratory tests) to study their concurrent validity, and its potential to be used for classification purposes.
- **Chapter V** includes a coordination battery of tests combining generic and sport-specific coordination tests to evaluate hand function and intra-limb coordination in boccia players. This Chapter also analyses the concurrent validity among this tests in order to study their potential use for classification purposes, describing how much coordination is impaired in individuals with moderate-to-severe CP in comparison with controls.

- The doctoral thesis will conclude by a General Discussion **(Chapter VI)**, in which main findings of the studies are summarized. Practical Implications, methodological considerations and limitations are also discussed in this chapter, finalizing with some recommendations and future research issues.
- **Chapter VII** includes the same information of the previous point in Spanish language.
- **Chapter VIII** includes the references of the Doctoral Thesis.

# Chapter I


## Conceptual Framework

# 1. Conceptual Framework

## 1.1. People First Language

Language reflects and shapes the way we understand the world. The words we use can influence community attitudes, both in positive and negatively (building or breaking down stereotypes), and it can affect the lives of others (Collier, 2012). *People First Language* is the way of describing disability demonstrating more respectful, accurate language and positive attitudes. This language consists on putting the word *person* or *people* before the word disability, preventing we have to focus only on one aspect of a person (i.e. disability), ignoring their other roles and attributes. This dissertation supports the use of people fist language throughout the entire document.

## 1.2. International Classification of Functioning, Disability and Health

In the last decade, there has been a greater interest to know the levels of participation of people with disabilities in physical activity and sport. This participation has been reported based on the International Classification of Functioning, Disability, and Health -ICF- (World Health Organization, 2001), which is based on a social model, considering disability as the result of the interaction between the person and his / her environment.

The concept of participation is a prominent aspect in the ICF approach, and its terminology and structure has become the core of the current classification system in Paralympic sports. Tweedy and Vanlandewyck (2011) explained that the use of the ICF terminology brings with it certain advantages such as clear, unambiguous and internationally accepted definitions of important concepts. This is very important to achieve better reliability between observers (in this case, between classifiers), especially when these definitions are used around the world, improving communication within the scientific community

The ICF is a comprehensive classification system designed to capture functioning, and not only medical descriptions of limitations (WHO, 2001). In the ICF, domains are grouped according to body function and structures, and a list of domains of activity and participation. Thus, on one hand, the term of *functioning* refers to all body functions, activities and participation; this means, the evaluation of the complex relation or interaction between the health condition and the factors of the context. However, on the other hand, *disability* is similarly an umbrella term for impairments, activity limitations and participation restrictions (Reina, 2014). In this Thesis, we will focus on cerebral palsy as health condition; spasticity, dystonia, athetosis and ataxia as impaired body functions; and limitations for trunk control, arm coordination and hand function.

The type and severity of the disability are intimately related to participation (Imms et al., 2016). Therefore, participation in physical activity (PA) and sport decreases according to impairment severity or limitations in gross motor and cognitive functions (Lauruschkus, Westbom, Hallström, Wagner, & Nordmark, 2013). Environmental factors refer to those barriers that are external to the person and they can limit participation in PA. Some authors as Rimmer, Riley, Wang, Rauworth and Jurkowski (2004), Jaarsma, Dijkstre, Geertzen and Dekker (2014) or Bragaru et al. (2013) have highlighted that the most common environmental barriers that people with disabilities might face are economical, architectural, but also society attitudes or lack of well trained professionals to work with this population. On the other hand, personal factors are understood as those barriers internal to the person, and some of the most common ones are feelings of isolation, poor self-esteem, self-concept or motivation (Bragaru et al., 2013; Gregoul et al., 2015; Rimmer et al., 2004). In short, the ICF puts the notion of ‘health’ and ‘disability’ in a new light and it is applied to classification in Paralympic sports (Reina, 2014).

### 1.3. Definition and Classification of Cerebral Palsy

Although cerebral palsy (CP) is a well-recognized neurodevelopmental condition, it remains as an idea – a concept – rather than a specific disease entity (Rosembaum, 2017). To this day, the most accepted definition is a group of permanent disorders of the development of movement and posture, causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain (Rosenbaum et al., 2007). Most common motor disorders showed by people with CP are in muscle tone (abnormal muscle stiffness or floppiness), muscle weakness, random and uncontrolled body movements, balance and coordination problems (Rethlefsen, Ryan, & Kay, 2010). Furthermore, these motor impairments are often accompanied by disturbances of sensation, perception, cognition, communication and behavior, by epilepsy and by secondary musculoskeletal problems (Rosenbaum et al., 2007). These motor and sensory disorders have high impact on activities of daily living (ADL). For example, more than a half of the children with muscle stiffness in upper limbs, experience difficulties to perform activities that involve grasping, releasing or manipulating objects (Arnould, Bleyenheuft, & Thonnard, 2014). However, we cannot forget that, although clinical and functional symptoms onset in early development, CP it is a lifelong and non-progressive condition that cannot be cured, and some of its effects can appear for the first time, change or become more severe with age (Graham et al., 2016).

| Type | Spastic | Dyskinetic | Ataxic |
|---|---|---|---|
| **Location of the brain damage** | Motor/Cerebral Cortex  | Basal Ganglia  | Cerebellum  |

**Figure 1.** Types of CP and locations of the brain damage according to the Surveillance of Cerebral Palsy in Europe (SCPE).

The brain damage caused during the time of birth manifests itself in many ways, explaining the great heterogeneity within this group. In 1998, many professionals and researchers from different countries created the Surveillance of Cerebral Palsy in Europe (SCPE), which aim was to develop a common database to unify treatments and assessments, developing screening tools and a tree of CP subtypes to classify them. The SCPE advocates for a more universal and simply classification system of CP, focusing on what a child can accomplish in opposition to the limitations imposed by his/her impairment. This classification grouped CP types according to the predominant neurological impairment, considering that all these CP types have in common an abnormal pattern of movement and posture (SCPE, 2000) (Figure 1).

### 1.3.1. Hypertonia

According to the IPC´s International Standard for Eligible Impairments (IPC, 2016a), hypertonia is an increase in muscle tension and a reduced ability of a muscle to stretch caused by damage in the central nervous system. The most common type of hypertonia is spasticity. Individuals with spastic CP usually present pathological tone and reflexes (e.g.: hyper-reflexia or pyramidal signs, such as Babinski response), and increased resistance, which is velocity dependent (Sanger, et al., 2006), producing what is called the *catch*. A spastic *catch* is felt some time after the onset of movement and followed, afterwards, by a sudden relaxation. The resistance to the movement is directly proportional to the speed of this movement. It has been studied that spasticity level can vary according to excitability and strength stimulation state that the individual is forced at any moment (Günel, Türker, Ozal, & Kara, 2014).

### 1.3.2. Dyskinesia

Dyskinetic CP profiles affect 10-20% of people with Cp. These individuals usually present involuntary, uncontrolled, recurring, and occasionally stereotyped movements, provoking abnormal patterns of posture and/or movement (Krigger, 2006). The primitive reflex patterns predominate, and the muscle tone is varying. The IPC´s International Standard for Eligible Impairments (IPC, 2016a) includes Athetosis as eligible impairment for Paralympic Sport, defining it as an impairment that provokes continual slow involuntary movements. The Boccia Classification Rulesbook (BISFed, 2017) differences within this group between two subtypes: dystonia and choreo-athetosis (SCPE, 2000).

- **Dystonic** CP is dominated by abnormal postures (may give the impression of hypokinesia: reduced muscle activity (i.e. stiff movements) and hypertonia (muscle tone fluctuating, but with easy tone increase). Characteristics are involuntary movements, distorted voluntary movements, and abnormal postures due to sustained muscle contractions (slow rotation, extension, and flexion of body parts).

- **Choreo-Athetotic** CP is dominated by hyperkinesia (increased activity, i.e. stormy movement) and hypotonia (muscle tone fluctuating, but mainly decreased).
    - *Chorea* means rapid involuntary, jerky, often fragmented movements.
    - *Athetosis* means slower, constantly changing, writhing, or contorting movements.

These two subgroups can be hard to delineate if individuals present features of both types. For that reason, many clinical manuals group both and refer to them as Dyskinesia (Graham et al., 2016).

### 1.3.3. Ataxia

According to the IPC´s International Standard for Eligible Impairments (IPC, 2016a), athletes with Ataxia have uncoordinated movements that can be seen when an athlete attempts to perform voluntary movements such as walking or picking up objects. Ataxia causes an alteration of muscle control in the four limbs, resulting in loss of orderly muscular coordination, producing movements with abnormal force, rhythm, and accuracy (Cans et al., 2007). Furthermore, athletes with ataxia appear very unsteady and shaky because their sense of balance and depth perception is affected.

Individuals with CP tend to show mixed profiles (i.e. spasticity with ataxia and/or dyskinesia), being one of the reasons of why the CP health condition is very heterogeneous and the effects of CP vary widely from person to person (Sandström, 2009).

## 1.4. Benefits of Physical Activity in People with Cerebral Palsy

People with disabilities tend to shown higher levels of sedentary lifestyle than healthy individuals from early childhood (Keawutan et al., 2017). Impairments related to CP (e.g. dyskinesia, ataxia or spasticity) leads to restriction in physical activity and experience with exercise (Lee, Kim, & Jeong, 2015). Therefore, children with CP usually have poor physical fitness, due to both primary impairments (e.g. muscle biology and strength) and secondary impairments (e.g. contractures or movement limitations). Given the high prevalence of sedentary lifestyles in individuals with CP, and the concomitant risk of chronic conditions in adults with CP, physical activity promotion is vital for health preservation across the lifespan (Verschuren, Peterson, Balemans, & Hurvitz, 2016).

Sedentary lifestyles have serious consequences for public health (WHO, 2001). It has already been shown that that physical activity (PA) is a fundamental way to improve physical, social and mental health in all individuals no matter age, gender or race (Colletto and Rodriguez, 2017; Trost, Owen, Bauman, Sallis, & Brown, 2002; Van der Horst, Paw, Twisk, & Van Mechelen, 2007). Personal and environmental barriers associated with disability restrict access to physical activity venues and services. Personal barriers include pain, lack of energy, self-consciousness about exercising in public, or the perceptions that exercise is too difficult (Phillips, Flemming, & Tsintzas, 2009). Environmental barriers include transportation, lower opportunities, lack of accessible exercise equipment, unqualified staff that cannot modify or adapt individual and group classes, programs and equipment costs, or discriminatory practices (Jaarsma et al., 2014).

Correcting the decline of physical activity in adolescents with CP, removing the barriers for its participation, may carry benefits over into adulthood (Koldoff and Holtzclaw, 2015). In recent years, scientific literature has paid more attention to the benefits of PA in people with CP, and more are the benefits that have been proven (Verschuren et al., 2016). It has been demonstrated that a program based on fitness and progressive resistance training is able to increase cardiovascular capacity in children with CP (Novak et al., 2013). In addition, it has been demonstrated that a combined strength and endurance-training program can also improve their peak power production, improving the ability to walk faster and further distances (Peungsuwan, Parasin, Siritaratiwat, Prasertnu, & Yamauchi, 2017; Moreau and Gannotti, 2015), increasing the overall functional ability and independence. Furthermore, it has also shown that altering fascicle strain through stretching may reduce muscle stiffness in individuals with spastic and mixed profiles (Theis, Korff, & Mohagheghi, 2015). This is very important because when muscles cannot stretch they lose their ability to grow with the surrounding bone structure, reducing children general flexibility (Wiart, Darrah, & Kembhavi, 2008).

In summary, PA has a profound and positive impact on people with CP quality of life. However, due to external and internal factors, these individuals are less active than people without disabilities, and being, therefore, three times more likely to have diseases by inactivity (Boslaugh and Andresen, 2006).

## 1.5. Classification in Para Sports

Paralympic classification provides a structure for competition in para sports. In regular sports, it is enough separating athletes by gender, age or body weight in order to minimize the impact of these attributes on the result of the competition. However, athletes who compete in para-sports present an impairment, leading to a competitive disadvantage, and therefore, classifying by previous attributes is not enough to achieve fair and equal competition among participants.

In its origin, classification in para-sports was based on medical systems, dividing the athletes according to their medical diagnostics and/or level of injury, being the same for any para-sport. Thus, there were classification systems for spinal cord injury, amputations, *les autres* (other physical disabilities), cerebral palsy, or visual impairments. Due to the number of events in many sports at 1988 Seoul Paralympic Games, it was encouraged the development of functional classification systems, where same events or sport classes could integrate athletes with different disabilities, but with similar functions (Reina and Vilanova-Périz, 2017) (Figure 2).

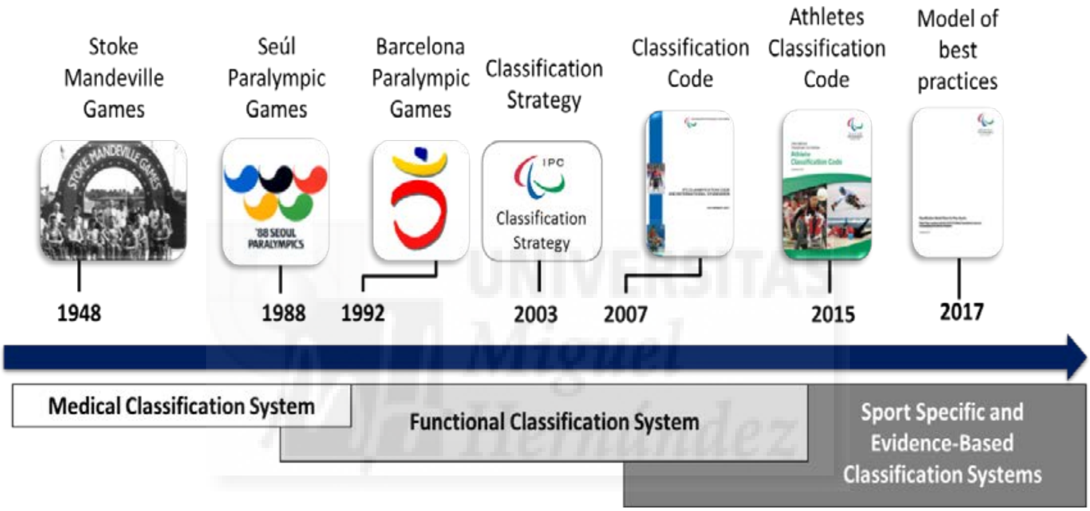



**Figure 2.** Classification System evolution.

The current IPC´s Athlete Classification Code (IPC, 2015b) defines *Classification* as the process to group athletes into Sport Classes according to how much their impairment affects fundamental activities in each specific sport or discipline. So, the purpose of classification is to define who competes in para-sport and to ensure that the impact of eligible impairment in each event is minimised. To achieve this purpose, a classification system must:

- Clearly state that a para-athlete must have an eligible impairment in order to compete in Boccia.

- Set processes and procedures for assessing whether a para-athlete has an eligible impairment. These processes and procedures must conform to the International Standard for Eligible Impairments (see section 1.4).
- Set Minimum Impairment Criteria for each eligible impairment.
- Allocation in a particular Sport Class is based on the extent to which para-athletes are able to execute the specific tasks and activities fundamental to Boccia.

The Boccia International Sport Federation (BISFed) Classification Rulebook, according to the IPC´s International Standard for Athlete Evaluation (IPC, 2016b), indicates that the Athlete Evaluation Process has three steps:

- Physical Assessment: It is the first step, in which a Classification Panel of three classifiers (i.e. medical doctors, physiotherapists, occupational therapists or sport scientists) address two aspects: i) gathering information on the athlete's medical background and training history; ii) conducting a physical assessment of the athlete in accordance with the assessment methods stipulated in the BISFed Classification Rules. The physical assessment may include, but is not limited to, the examination by the Medical members of the Classification Panel (Doctor, Physiotherapist or Occupational therapist).
- Technical Assessment: It is the second step, including, but is not limited to, an evaluation in a non-competitive environment. The Technical member (i.e. sport scientists, former coaches) asks athletes to perform specific tasks and activities related to Boccia (grab or release a ball, throwing a ball, strength control) with which athletes are well familiarized. Classifiers may conduct these tasks or activities under simulated sport conditions, in order to observe how athletes perform them.

- Observation in Competition: The third and last step, in which the Classification Panel observes athlete performance during training practice, during a real game situation or even, during a pool play (i.e. prior to elimination/knockout stages). Observation in Competition will not be completed until the Classification panel has not decided that the athlete's observation is enough.

## 1.6. Evidence Based Classification

Evidence based classification systems (EBCS) are those in which scientific evidence will allow classifiers to identify which methods should be considered for assessing impairments, and assigning a sport class will result in classes that comprise athletes who have impairments that approximately cause the same amount of difficulty in a given sport (Tweedy and Vanlandewijck, 2011; Tweedy, Beckman, & Connick, 2014).

To achieve a classification system based on scientific evidences it is mandatory to standardize the assessment methods used during classification (Tweedy, Williams. & Bourke, 2010). These authors stated that only valid and reliable instruments, based on empirical evidences will achieve the proposed goal of having an objective and fair classification system for para-athletes.

It is important to mention that the competitive structure provided by the classification systems is not only important in high-performance sport, but for promoting participation in health oriented and recreational sports. Additionally, the current IPC Athlete Classification Code emphasizes the importance of using clear and easy-to-use language for para-athletes to understand the purpose of the classification and thus promote their participation in para sports (IPC, 2015b).

Tweedy, Beckman and Connick (2014) proposed a four steps model to ensure that the methods used to assess impairment/s and to assign sport classes is optimal, in order to end up with an evidence-based classification:

1. *Specify Impairment Type Eligible for the Sport.*

The IPC recognizes ten eligible impairments (eight physical, visual and intellectual) in order to compete in Paralympic sports. Therefore, the first step to achieve EBCS is defining which impairment(s) type/s is/are eligible for a particular para-sport. This first step is fundamental for those para-sports that combine different impairments, such as Boccia.

2. *Develop Valid Measures of Impairment(s).*

Any method used for achieving EBCS has to provide construct validity and be reliable, objective, ratio-scaled, specific and resistance to training, in order to assess the impairment of interest.

3. *Develop Standardized and Sport-Specific Measures of Performance.*

This might be the most complex step of the process, in which it is necessary to identifying what activities can determine performance in a specific para-sport, with the intention of developing later standardize measures to evaluate such skills.

4. *Assess the Relative Strength of Association between Valid Measures of Impairment and Measures of Performance.*

The last step is to identify how the eligible impairment(s) influences in more or less extent in the specific para-sport activity, allowing understanding what relationship type they have and its strength.

Figure 3 shows the ICF´s components related to classification in Paralympic sports, highlighting (in red colour typewriting) those specific for Boccia.

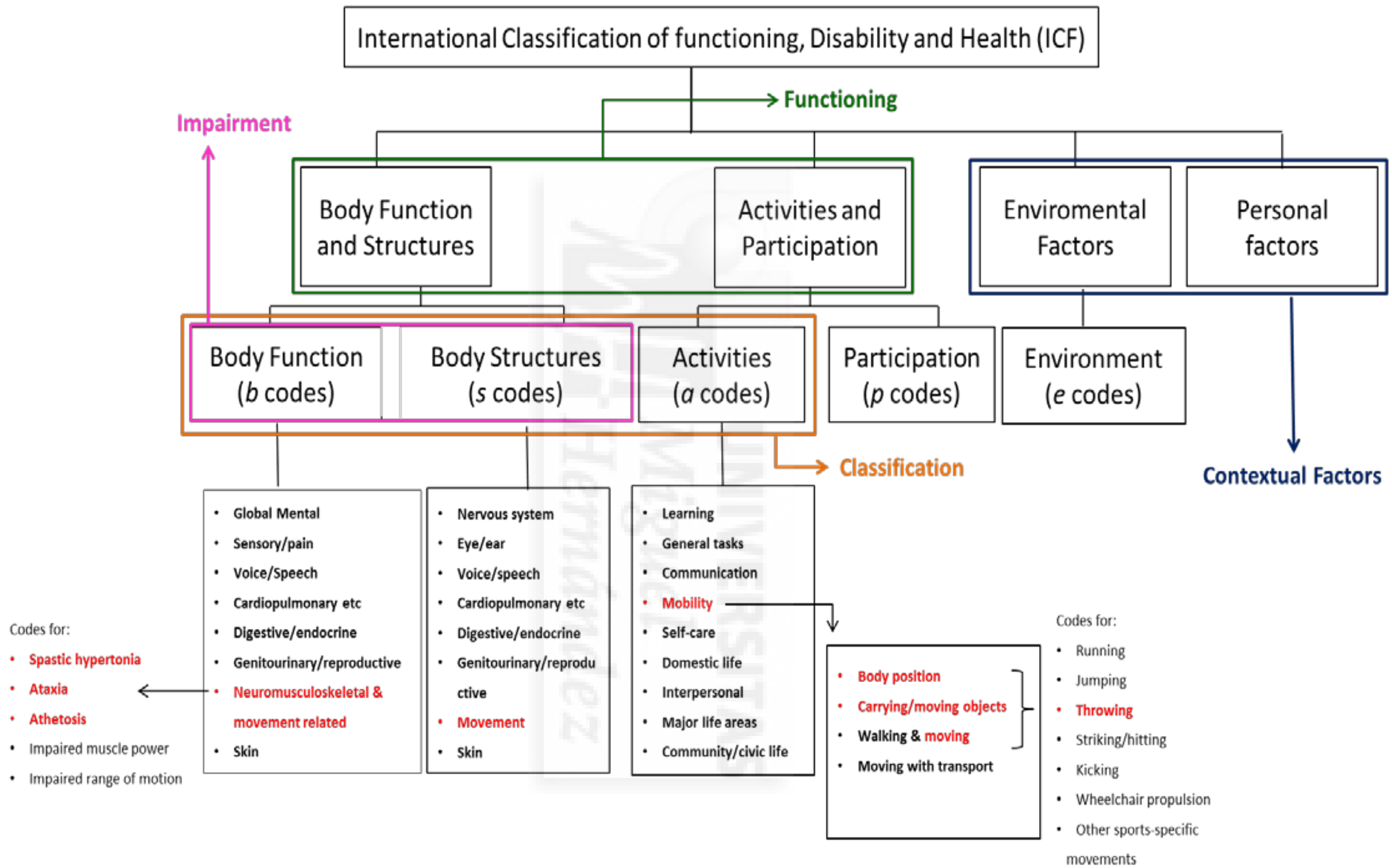



**Figure 3.** Relationships between ICF and Classification in Paralympic Sports (adapted from Tweedy and Vanlandewijck, 2011)

## 1.7. Athletes with High Support Needs

In the Paralympic Movement, Athletes with High Support Needs (AHSN) refers to those athletes who present the most severe impairments levels (physical or visual), and they usually require more intensive and specialized support at competitions (e.g. coaching, special equipment, etc.). This implies that no many para-athletes with severe disabilities end up practicing sport, and even less, achieving sport excellence.

The implementation of the functional classification system (from Barcelona 1992) and the low representation of AHSN in the Paralympic Games caused some modification within the sports classes that fostered the AHSN. As a result, para-athletes with different impairment levels were grouped together, forcing athletes with most severe impairments to compete against other with higher functional levels, providing unfair competitive conditions for these para-athletes (Howe and Jones, 2006). Today, the number of AHSN competing at the Paralympic Games has been reduced little by little, being today the less representative group at the Games (IPC, 2014). The current IPC´s 2015-2018 *Strategic Plan* emphasizes the fact that it is important to increase the number of AHSN: *"… together we need to expand the pool of women athletes and athletes with high support needs"* (IPC, 2015a). However, Paralympic Games keeps moving to become one of the most remarkable sport shows in the world, trying to accomplish the commercial interests of the contemporary sport (i.e.: stronger, higher, faster) (Howe, 2008). In this way, AHSN will remain facing barriers to participation (Perdue and Howe, 2013), receiving poor media coverage and sport research attention, in comparison to athletes with more relative functional ability, implying that many of these para-athletes simply could lose motivation to participate in para-sport and will end up giving up on it (Brittain, 2016).

## 1.8. Scope of the Dissertation: Application to Boccia

### 1.8.1. Boccia as a Paralympic Sport

The game of Boccia dates back to classical Greece, recovered in the 80's by the Nordic countries that adapted it for the people with disabilities (Calverol, 1999). Boccia is a sport of strategy and accuracy very similar to *petanque*, although it differs in the equipment, the dimensions of the field of play and in some rules of the game. Since 2013, it is governed by the Boccia International Sports Federation (BISFed) and is one of only two Paralympic sports (along with Goalball) that have no counterpart in the Olympic program.

The BISFed provides an opportunity for individuals with severe physical impairments affecting all four limbs, including:

- *Neurological impairments* in the Central Nervous System (CNS), which include spastic-hypertonia, dystonia, athetosis or ataxia. The most representative health condition in this group is the CP.
- *Severe locomotor dysfunctions* in all four limbs of non-cerebral origin, such as impaired passive range of motion, impaired muscle power and/or limb deficiencies. The most representative health conditions in this category are spinal cord injuries or muscle dystrophies, among others.

This sport is played on a flat, smooth surface of 12.5 x 6 m (Figure 4), and the aim of the game is to throw colored balls (blue and red) as close as possible to a white target ball, known as the Jack (see in Figure 4). The team with the closest balls to the jack wins the set. Generally, boccia balls are made of leather and are slightly larger than a tennis ball, weighing 275 +/-12 grams and measuring 270 +/- 8 mm in circumference. Boccia balls can present different grades of hardness in order to facilitate its manipulation and throwing according to players' characteristics. The game can be played in individuals, pairs or teams, and the player/pair/team that has won the most sets wins the match. One set is finish when the balls of both players/pairs/teams are played on the court (i.e. 12 balls, 6 of each color).

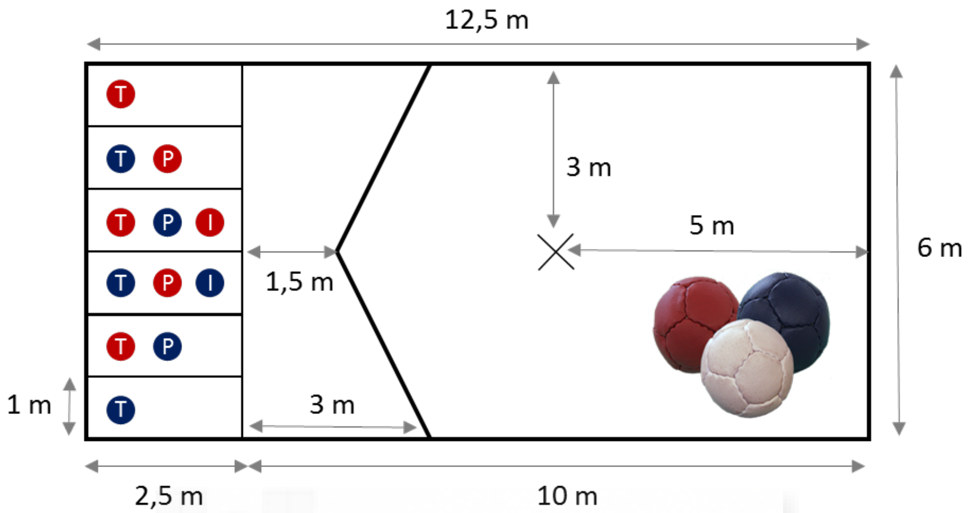



**Figure 4.** Field of play and distribution for individuals (I), pairs (P) and teams (T) competition.

### 1.8.2. Boccia Sport Classes

Boccia players are allocated into five sport classes, depending on their functional ability: BC1, BC2, BC3, BC4 or BC5. As represented in Figure 5, sport classes BC1 and BC2 are exclusively for athletes with spastic hypertonia, dystonia, athetosis or ataxia. These players throw the ball by hand or even kicking it with their foot (i.e. BC1 foot player). The BC3 sport class fosters the players with most severe impairments, whether it is of cerebral origin or not. Their impairment severity does not allow them to throw using their hand nor with their foot, thereby, do players use an external device called ramp, in which the ball rolls down enabling a smooth transition from ramp to floor. The class BC4 is only for athletes with severe locomotor dysfunction of non-Cerebral origin. Finally, class BC5, it is a new class opened in January 2017. This sport class is not yet admitted to compete at the Paralympic Games, only at national and some international competitions. Players grouped in this class might present neurological impairments of cerebral and non-cerebral origin (BISFed, 2017).

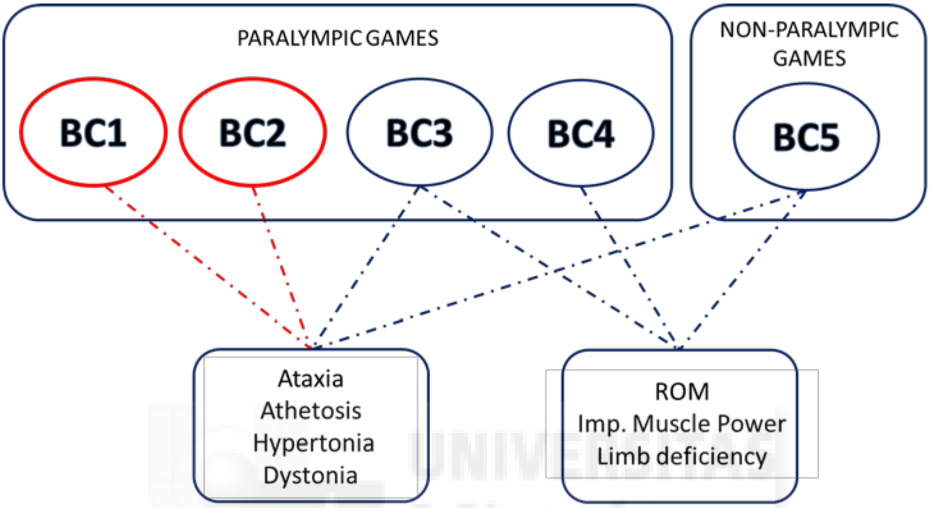



**Figure 5.** Schema of Boccia sport classes and eligible impairments for each sport class.

As highlighted in red in Figure 5, this dissertation focuses primarily on players from the BC1 and BC2 sport classes. The rationale behind this is these players only present neurological impairments of cerebral origin. The physical profiles of athletes within BC1 and BC2 classes are defined by the Boccia Classification Rulesbook (BISFed, 2017, p.29), as follows:

- **BC1** includes players with spastic or athetosis quadriplegia, or with mixed picture, including those with severe ataxia, affecting all four limbs. These players use a powered wheelchair or assistance for everyday mobility, being unlikely to use manual wheelchairs for any length of time. They also present high spasticity (above grade 3), according to the Australian Spasticity Assessment Scale (ASAS) (Calame and Singer, 2015) with or without athetosis. According of which impairment is more prevalent, players will present some functional aspects more or less limited, for example:

- o In a severe spasticity profile, the range of movement and/or limited functional strength in trunk and extremities.
- o In a severe athetosis or dystonia profile, aspects as strength and postural control get more limited.
- o In a severe ataxia profile coordination actions, such as grasp and release are highly affected.

- **BC2** players who also present high affectation in all four limbs, but they show less impairment level than BC1 players do. BC2 players can use manual wheelchairs for everyday mobility and some of them might also walk short-to-moderate distances with assistance. They tend to show less spasticity levels, below ASAS grade 3, with or without athetosis (mixed profile). In addition, some limitations in active functional range of movement due to weakness or spasticity, or lack of control affecting trunk or upper limbs can also be observed.

Based on these profiles, it is not surprising that Boccia has been used as a rehabilitation method, since it enables individuals to work different aspects. Some of these features are: relaxation, manual dexterity (i.e: object manipulations), balance in the wheelchair, trunk control to perform throws to difference distances, and proprioceptive aspects such as: distances, sizes and special orientation of some objects (Rubiera and Mendoza, 2008).

Although BC3 and BC5 sport classes also include athletes with hyperthonia, athetosis, dystonia and ataxia, they have not been included in this Thesis because: i) BC3 players require a ramp to play, being not able to handle a ball and keep an upright sitting position without external aids or supports; and ii) BC5 is a new sport class for Boccia since January 2017, not being possible to recruit participants for this Thesis at the moment of the data collection. BC4 sport class was not also considered due to these eligible impairments does not cause coordination problems.


**Figure 6.** Players from BC1 (A) and BC2 (B) sport classes.

### 1.8.3. Which Parameters underlay Boccia Performance?

Boccia has received disappointingly little research attention. As a result, there is no clear consensus on what elements determine performance in this para-sport. There are several reasons why this may be so, like the difficulty of recruiting a large and homogeneous samples, and the feasibility of evaluation methods to assess this population (Pavão, dos Santos, Woollacott, & Rochaa, 2013).

The available literature in Boccia has suggested several functional factors that may further affect players' performance. On one hand, Reina (2011) indicated five elements: i) trunk control (TC); ii) ability to grasp and release a ball; iii) the range of motion of the upper extremities; iv) movement coordination; and v) muscle strength. On the other hand, Sirera (2011) considered four elements: i) strength; ii) TC coordination; iii) muscle contraction velocity and, iv) balance. Some of those aspects are actually viewed in the current Boccia Classification Rules (BISFed, 2017), taking into consideration during the classification process. Specifically, the Boccia classification rulebook considers: i) the evaluation of the upper extremities (i.e. shoulder, elbow and hand), by focusing on the evaluation of the ROM and the handgrip function; ii) the assessment of the trunk/postural control and balance of the player, including the use of compensatory movements, and iii) the evaluation of the lower limbs (i.e. pelvis, hip, knee and ankle).

Classifiers base their decision-making on some of those components to allocate a player in one sport class. For example, TC is a crucial component to differentiate a player from BC2 or BC5 classes. Class BC5 usually present better postural control and balance than BC2, especially during their throw preparation and, during or after their follow through. Moreover, TC is also seen as differentiating element between class BC1 and BC2, where BC1 players tend to present poorer postural control, especially after throwing, and also poorer ability to perform compensatory strategies. However, BC2 players present higher degree of dissociation between trunk and pelvis, allowing them to use the trunk in an efficient way. On the other hand, ability to grasp is crucial to identify BC3 players. Players with no capacity to grasp a ball, or with poor capacity to throw a ball with direction and purpose, are directly classified as ramp players.

To the best authors' knowledge, there are six scientific studies in the literature mainly focused on Boccia performance, and it is interesting to highlight that five of them have been published in recent years. Therefore, we would like to think that perhaps there is an emerging research interest in this sport. A short summary of the main findings of each study are included below.

Throwing analysis has been studied. The first study that addressed this topic dates from the late 90’s. Calverol (1998) studied the relationship between the throwing technique and performance, by a case study where a BC2 player executed different throwing techniques and his accuracy was assessed. Results showed the preference of low-throws (i.e.: below the waist), but with high variability movements, instead of overarm-throws because more accuracy was obtained. On the other hand, Ávila and Moreno (2000), using electromyography, studied arm extensors activity in boccia players with severe spasticity. They demonstrated that the level of impairment (i.e. grade of spasticity) stablish the throwing technique. For example, players with severe spasticity tend to perform overarm-throws, while players with more athetoid or ataxic features perform low-throws (i.e. greater movement amplitude).

Two studies have paid attention regarding training programme designs. On one hand, Morris and Wittmannová (2010) studied what could be the most efficient training structure in Boccia, in order to maximize sport performance. This study showed that blocked training schedules tended to present higher practical significance improving skills performance over random training schedules. When designing the type of training for a boccia player, it is important to consider his/her fatigue levels. Therefore, two years later, Fong, Yam, Chu, Cheung, and Chan (2012) studied the effect of acute fatigue in Boccia performance. They reported that Boccia players presented high levels of fatigue following a prolonged Boccia game, affecting their performance, presenting lower throwing velocity and worse accuracy (target hitting). Fatigue was especially noticeable in the shoulder (e.g. trapezius muscle). On the other hand, De Martino and Dayana (2013) designed a battery of tests focused on strength and ball direction (i.e. a crucial aspect in the game of Boccia), in order to achieve benefits in the game and in the trunk posture. After an eight week training program, the players did not improve significantly, but a small improvement regarding the velocity of the throw, joint amplitude, and coordination was observed. However, longer interventions are necessary when working with players with more severe impairments.

More recently, others author have explored other parameters related to throwing technique (Huang, Pan, Ouc, Yu, & Tsai, 2014). In particular, that study demonstrated that children with CP tend to show longer movement durations, higher amplitude of shoulder abduction and flexion, but lower in elbow, shorter sway ratio and lower maximal velocity of torso flexion when playing Boccia. In addition, children demonstrated to move their head and shoulder to throw the ball further, and the movement of their torso was reduced at the same time. Interestingly, these authors did not find differences in distance performance between children with and without CP. Reina, Domínguez, Urbán and Roldan (in review) carried out a similar study with the BC1 and BC2 players of the Spanish Paralympic Boccia team. They found that trunk control and the degrees of spasticity in upper limbs were two aspects that influenced Boccia performance. They studied the ability of the Boccia players to play according to three strategic distances of the field: short (1.5 m), medium (5 m) and long (9 m). Results showed that throws were faster and more accurate in short and medium distances, it seems that long distances (more than 6-7 m) are difficult to reach by those athletes due their severe impairments, constraining sport performance.

Another aspect mentioned as a potential key performance was the TC or postural control, which has already been studied in children with CP. So, Tsai, Yu, Huang and Cheng (2014) showed how postural control was significantly affected by seat inclination. An anterior inclination of the seat surface increased postural stability, reducing the movement displacement of the centre of pressure, allowing greater amplitude of elbow movement for throwing; while a posterior inclination of the seat surface made the throw more difficult.

Finally, Reina, Caballero, Roldán, Barbado and Sabido (2015) studied what is going on during the throw at neurological level, studying the electromechanical delay by EMG in a ball release activity with time and non-time constrains. Participants showed muscle coordination problems, especially in task with a time constraint, where athletes presented high muscle co-activations. The EMG seems not to be a sensitive tool to discriminate between sport classes BC1 and BC2 as both present high muscle co-activation problems.

### 1.8.4. Bridging the Gaps for Classification in Boccia

Boccia players with CP usually present physical impairments (muscle tone, strength, control of voluntary movements…), affecting the performance of certain activities such as body position in the wheelchair, carry and manipulate objects, or specific Para sport skills such as throwing.

The literature review has proven strong insights regarding key functional aspects that experts have considered important when play Boccia (Reina, 2011; Sirera, 2011). However, there is little research or discussion in the literature around how to apply these outcomes to sport classification. Most studies simply describe the impairment limitation rather than examining its impact on Boccia performance. Besides, they included small samples of participants, being difficult the generalization of the results. Additionally, there are no many specific tests in the literature for athletes with this kind (and severity) of eligible impairments (i.e. hypertonia, athetosis, dystonia and ataxia); and many of the available tests have been applied in clinical settings, being rarely used for classification purposes.

BISFed includes in its classification rulebook a (qualitative) description of all the sport classes (BISFed, 2017), based on: i) function of upper extremities (shoulder, elbow and hand), ii) hand function and grip; iii) trunk / postural control and balance; and iv) function of lower limbs (pelvis, hip, knee and ankle). Hence, this Thesis analyses trunk control, intra-limb coordination and hand dexterity in participants with moderate-to-severe neurological impairments, eligible for BC1 and BC2 classes in this Para sport. Operational definitions of these parameters are:

- **Trunk Control (TC)** is understood as the ability to control the position and the movement of the trunk (spine and pelvis) in the surrounding space when it undergoes loadings (Butcher et al., 2007; Granata and England, 2006), due to internal or external perturbations (Maaswinkel, Griffioen, Perez, & van Dieën, 2016).
- **Coordination** is the ability to voluntarily execute fluid, accurate and controlled movements rapidly (Connick, 2017).
- **Manual Dexterity (MD)** is defined as the ability to make precise hand and finger movements to grasp and manipulate objects (Kreutzer, DeLuca, & Caplan, 2011).
- **Intra-Limb Coordination (ILC)** is understood as the coupling among two or more joints in the same limb (Matsuo et al., 2005). This study will assess the throwing upper limb function.

Following the four steps model to develop evidence-based classification (Tweedy et al., 2014), described in section 1.6 of this Chapter, this Doctoral Thesis will be focused on steps 2a and 2b of that model, evaluating TC, MD and ILC, involving some specific boccia equipment (Figure 7).

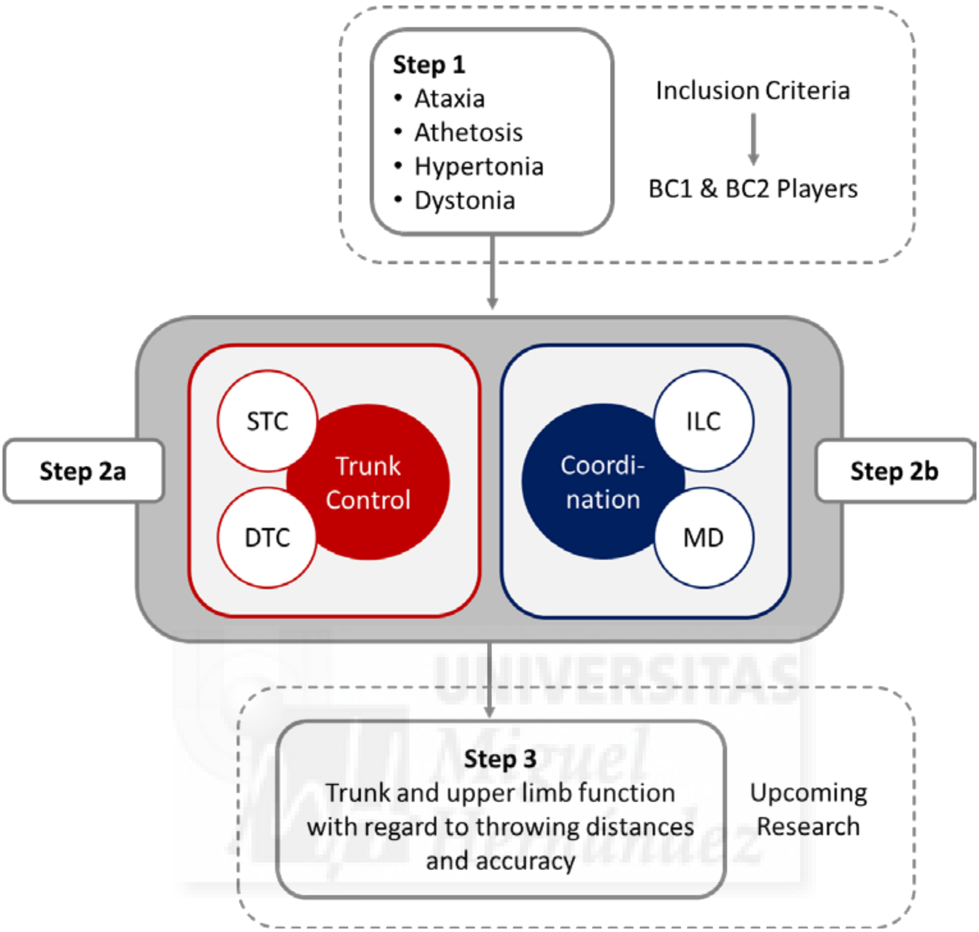



**Figure 7.** Rationale of the Doctoral Thesis.

# Chapter II


# Research Rationale, Aims and Hypothesis

# 2. RESEARCH RATIONALE, AIMS AND HYPOTHESIS

## 2.1. Research Rationale

Previous Chapter explained the literature gaps regarding classification in Boccia, and three studies are included in this Thesis (Chapters III, IV and V). Although each study will include a unique background, in order to stablish the research aims and hypothesis for these studies, the following needs have been identified:

- **Study 1:** Lack of tools or assessment methods to evaluate TC in an objective and quantitative way (i.e. ratio-scale) in CP adults with severe-to-moderate impairments. So, the reliability of those methods has not been reported yet.
- **Study 2:** The discriminant capacity of the current TC assessment method used in Boccia (i.e. decision-making between BC1 and BC2 players) has not been explored. Nor, it has been compared with a laboratory test, in order to check its concurrent validity to assess TC in boccia players.
- **Study 3:** There are many tests to evaluate MD and ILC with clinical purposes, being scarce its application into Para sport. Therefore, there are no sport-specific tools to asses MD and ILC in adults with coordination impairments (i.e. eligible for Boccia).

## 2.2. Aims and Hypothesis

### 2.2.1. Study 1: *How much Trunk Control is affected in Adults with Cerebral Palsy?*

#### 2.2.1.1. Objectives of the Study 1

- Quantifying how impaired is trunk control in adults with moderate-to-severe CP regarding to a control group without CP.

- Analysing the intra-session reliability of a posturographic protocol to assess TC in adults with moderate-to-severe CP
- Studying how testing conditions (static vs dynamic) constrain TC.

#### 2.2.1.2. Hypothesis of the Study 1

- Impaired trunk control is a common feature in children with CP. Due to CP is a life-long condition, adults with CP will also show TC limitations.
- Posturography is a well-known methodology to assess TC. As it has already been implemented in different populations with neurological disorders, it will be also appropriate to assess TC in adults with CP.
- Adults with CP will exhibit higher TC limitation in dynamic than in static conditions.

### 2.2.2. Study 2: *Trunk control in Boccia players with moderate-to-severe cerebral palsy: implications for classification.*

#### 2.2.2.1. Objectives of the Study 2

- Studying is the current boccia TC assessment method is capable to discriminate between sport classes (i.e. BC1 and BC2).
- Comparing the current boccia TC assessment method with a posturographic protocol to analyse its concurrent validity.

#### 2.2.2.2. Hypothesis of the Study 2

- The current assessment method to assess TC in Boccia has been implemented for many years for classification purposes. Thus, this method has the capacity to discriminate between BC1 and BC2 sport classes.
- The current boccia TC assessment method and the posturographic protocol will present good concurrent validity.

### 2.2.3. **Study 3:** *Assessment of Impaired Manual Dexterity and Intra-Limb Coordination in Adults with Moderate-to-Severe Cerebral Palsy*

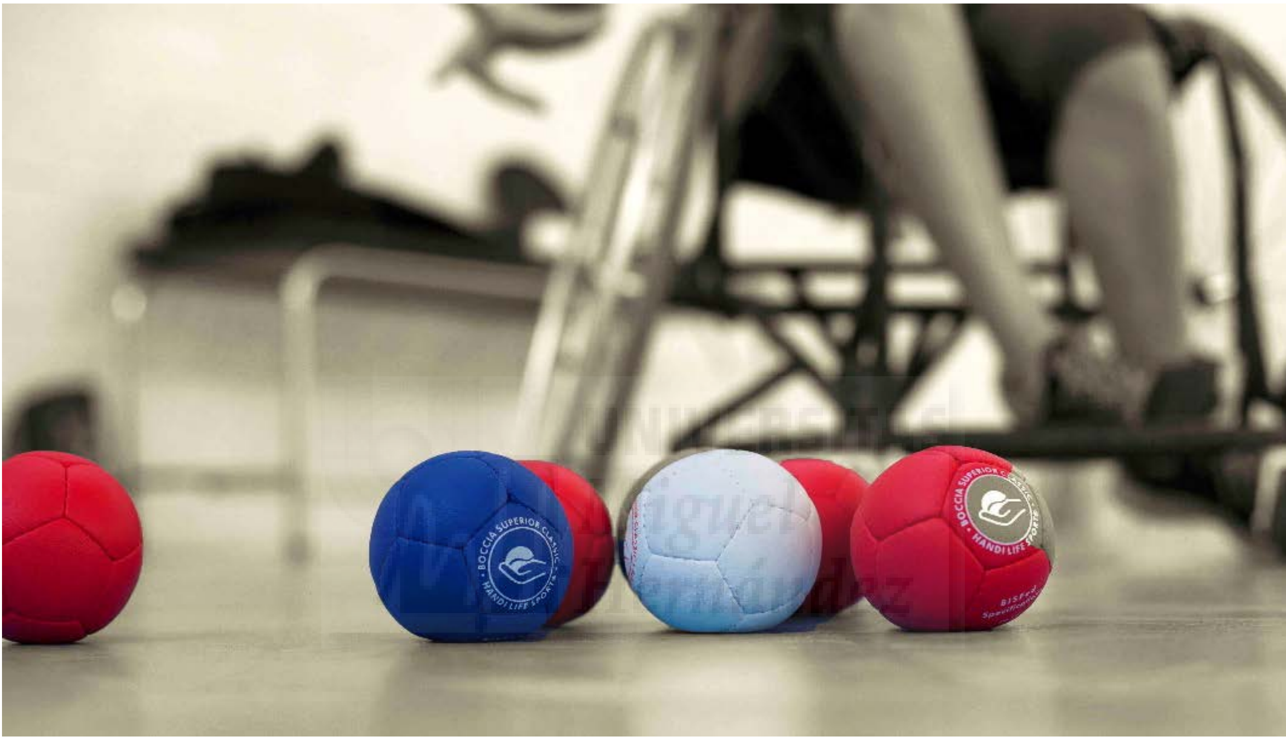
#### 2.2.3.1. Objectives of the Study 3

- Designing three new coordination sport-specific tests to assess impaired coordination in boccia players.
- Comparing the new coordination sport-specific tests with regards to generic coordination tests in order to assess their concurrent validity.
- Quantifying how much impaired is coordination in boccia players regarding to a control group without neurological impairments.

#### 2.2.3.2. Hypothesis of the Study 3

- The new sport-specific tests will show good concurrent validity in comparison to the coordination generic tests.
- Boccia players will show lower coordination performance in comparison to a group of individuals without neurological impairments.

# Chapter III




## Study 1

### How much Trunk Control is affected in Adults with Moderate-to-Severe Cerebral Palsy?

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Submitted at *Research in Developmental Disabilities*

# 3. STUDY 1

## 3.1. Abstract

Trunk control (TC) impairment is a typical feature in individuals with cerebral palsy (CP). However, there is a scarcity of information regarding adults with CP and a lack of reliable methods for assessing static and dynamic TC in this population. This study aims to: i) analyse the reliability of a posturographic protocol to assess TC in adults with CP (n = 47), and ii) assess the level of TC impairment in this population compared to a control group (CG) of adults without CP (n = 19). All the participants were assessed via a protocol of (two) static and (three) dynamic seated trunk tasks, performed on a stable and an unstable surface placed on a force-plate (a total of 10 tasks). Stable conditions were successfully completed by a large percentage of adults with CP (93%-to-72.3%), while percentage of success decreased considerably on the unstable surface (51.1-to-34.0%). Conversely, the CG was able to successfully complete the 10 tasks of the protocol. The posturographic protocol displayed good reliability in adults with CP (0.89 ≤ ICC ≤ 0.95; 15.2% ≤ TE ≤ 20.7%). Adults with CP decreased significantly their TC in 4/5 tasks on the stable seat, particularly in the dynamic conditions in comparison to the CG ($p < 0.01$; $1.71 \leq d_g \leq 1.91$). Therefore, dynamic tasks on a stable surface should be implemented to assess TC impairment in adults with severe-to-moderate CP, finding the unstable surface very challenging.

**Keywords:** posturography, reliability, biofeedback, trunk control impairment.

## 3.2. Introduction

Trunk control is understood as the ability to control the position and the movement of the trunk (spine and pelvis) in the surrounding space when it undergoes loadings (Butcher et al., 2007; Granata and England, 2006), due to internal or external perturbations (Maaswinkel, Griffioen, Perez, & van Dieën, 2016). Optimal TC requires the effective use of a complex sensorimotor system, with interplay between feedback (sensory) and feedforward (motor) control (Peterka, 2002), which is crucial in order to develop basic activities of daily living such as sitting or reaching (van der Heide, Fock, Otten, Stremmelaar, & Hadders-Algra, 2005). Trunk control seems to be affected in individuals with neurological disorders, such as CP (Desloovere and Heyrman, 2015; Westcott, Lowes, & Richardson, 1997).

Cerebral Palsy is defined as a "group of permanent disorders that affect the development of movement and posture, causing activity limitation that is attributed to non-progressive disturbance" (Rosenbaum et al., 2007). The relevance of TC in individuals with CP has been emphasized in the literature showing that an impaired TC might lead into coordination problems in the postural muscles, altering the static and dynamic control and trunk stabilization (Sahinoglu, Coskun, & Bek, 2017; Heyrman et al., 2013). Evidence has also indicates that impaired TC impacts on developmental milestones; such as social engagement with others, understanding of spatial relationships, and the use of the upper-body motor functions to explore objects (Ryalls et al., 2016; Brundavanam, Gadde, Balne, & Purohit, 2015). However, despite its importance and the fact that CP is a life-long condition, literature has particularly focused on children populations, knowing very little about the impact of impaired TC in adulthood (Jahnsen, 2004), and far less about adults with moderate-to-severe CP (Goodworth, Wu, Felmlee, Dunklebarger, & Saavedra, 2017).

Because of the TC impact on childhood motor development, posturography tests (Kyvelidou, Harbourne, Shostrom, & Stergiou, 2010) and visual assessment scales (Saether, Helbostad, Riphagen, & Vik, 2013) have been used in laboratory and clinical settings to assess TC in children with CP. Some scales, such as the Trunk Control Measurement Scale (Marsico, Mitteregger, Balzer, & Hedel, 2017) or the Trunk Impaired Scale (Pham et al, 2016), have been specifically designed to assess TC in adult populations with different neurological conditions, such as stroke or Parkinson. However, none of these scales have yet been validated through an objective method. In correspondence with balance assessment in upright stance (Santos, Delisle, Lariviere, Plamondon, & Imbeau, 2008), TC has been assessed through the analysis of center of pressure (CoP) fluctuations, measured by force platforms (Barbado, Barbado, Elvira, van Dieën, & Vera-Garcia, 2016a; Barbado et al., 2016b; Barbado, Moreside, & Vera-Garcia, 2017; Cholewicki, Polzhofer, & Radebold, 2000). This methodology consists in maintaining a trunk position or trajectory, whilst sitting on stable or unstable surfaces with leg motion restriction. It has been used to both: (a) identify trunk control deficits in individuals with lower back injuries (Willigenburg, Kingma, & van Dieën, 2013), Parkinson's disease (van der Burg, van Wegen, Rietberg, Kwakkel, & van Dieën, 2006) or multiple sclerosis (Verheyden et al., 2006); and (b) to assess the relationship of TC with sport specialization (Barbado et al., 2016a) and sport performance level (Barbado et al., 2016b). Sitting protocols to evaluate TC have been applied on children with CP under static conditions (Kyvelidou et al., 2010; Szopa and Domagalska-Szopa, 2015) or whilst performing functional reach/grasp tasks (Cherng, Lin, Ju, & Ho, 2009). However, to the best of the authors' knowledge, posturography sitting assessment of TC through force platform has not been performed in adults with severe CP, specially using dynamic conditions.

Based on the literature limitations, a battery of static and dynamic balance tasks were performed by adults with (and without) moderate-to-severe CP, while sitting on a stable and an unstable seat placed over a force platform. The aims of this study were to: (1) assess the relative and absolute intra-session reliability of the used measurements in this population, and (2) to quantify TC deficits in adults with moderate-to-severe CP, in order to understand in which type of tasks (static vs dynamic) this population present more limitations in comparison with adults without CP. As a methodological aspect, the relationships between the static and dynamic balance tasks were also analysed, enabling a better understanding of TC deficits in adults with severe-to-moderate CP.

## 3.3. Methods

### 3.3.1. Participants

Forty-seven adults with CP were recruited via purposeful sampling from eight special care centers to participate in this study (age = 36.58 ± 14.14 yrs; weight = 49.47 ± 11.32 kg; trunk height = 52.0 ± 7.95 cm; 27 men and 20 women). They are classified according to the Gross Motor Function Scale (GMFCS) as level II (n = 6, 12.77%), III (n = 15, 31.91%) or IV (n = 26, 55.32%). The level V was not included as they were not able to perform the test due their lack of TC. So, the inclusion criteria for CP individuals were: (1) medical diagnosis of CP; (2) classified as class CP1 (n = 18, 38.30%) (severe spastic or athetoid tetraplegia) or CP2 (n = 29, 61.70%) (moderate to severe spastic athetoid tetraplegia) by CPISRA classification scale (2012); (3) no surgeries or Botulinum toxin-A injections in the six months prior to testing; and (4) able to follow the pertinent test instructions given by the researchers. In addition, a CG of 19 participants (age: 27.89 ± 7.08 yrs; weight: 83.60 ± 11.55 kg; trunk height: 55.74 ± 3.52 cm; 12 men and 7 women) was recruited from a university community. Inclusion criteria for controls were: (1) no pain in the hip or back; (2) no past pathology in these regions; and (3) no neurologic or musculoskeletal problems. Ethics approval was obtained through the local University Ethics Committee (reference# DPS-RVV-001-10).

### 3.3.2. Procedure

To assess the participant's TC, they performed different tasks while sitting on a stable or an unstable seat (Figure 8a,b) using a reliable protocol, previously designed for physically active individuals and judo/canoeing competitive athletes (Barbado et al., 2016a,b). Participants were seated in a stable and an unstable wooden chair with leg and foot supports. The unstable seat was built adding a polyester-resin hemisphere to the bottom (radius: 40 cm; height: 12 cm). The seats were placed on a force-plate (9286AA, Kistler, Switzerland) sampling at 1000 Hz. This support was adjustable (90º knee flexion) and the participant's legs were strapped to the seat to prevent lower limb motions. The seats were placed on a force plate (Kistler, Switzerland, Model 9286AA) located at 0.9 m height above the ground on a rigid, stable and flat surface. The force plate was sampled at 1000 samples/s. Real time visual biofeedback of the CoP displacement was projected (Hitachi, Japan, model CP-X300) in appropriate trials as a yellow dot onto a screen (106 x 138 cm) in front of the participant (Barbado et al., 2016a,b). In addition, a target point (i.e. red dot) was presented to participants in several trials, to assess the subject's ability to adjust his/her CoP position to the target location. The radius of yellow and red dots (i.e. CoP and target point position) were 60 mm. To limit the impact that arm positioning had on the outcome of performance, participants were instructed to keep their arms firmly crossed over their chest (Figure 8a) or as close to this position as possible.

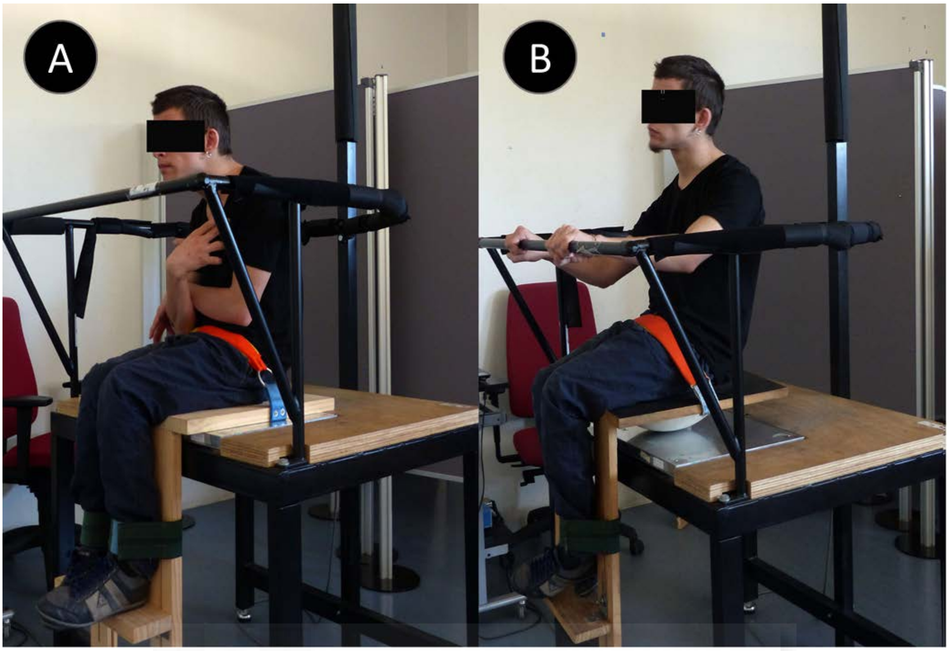


**Figure 8.** Settings for trunk control evaluation throughout posturography on stable (A) and unstable (B) surfaces. This figure shows a CP1 participant, who is unable to perform the unstable conditions.



Participants performed two static and three dynamic trials on both the stable and unstable surface. The first static trial was performed without visual feedback; whereby, the participants were instructed to sit still in their preferred seated position. The second static trial and the dynamic trails were with visual feedback; whereby, the participants were instructed to align their CoP position with the target point located in the center of the screen (Figure 9). During the dynamic trials, participants were asked to track the target, which moved through three possible trajectories (anterior-posterior, medial-lateral and circular).

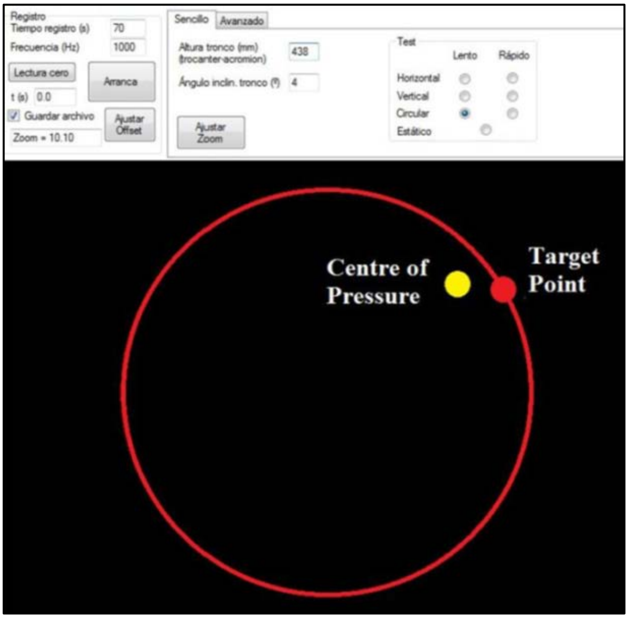


**Figure 9.** Screen feedback with the red dot representing the target and its trajectory (circular task), and the yellow dot representing participants' CoP.



The task performance was always performed in the same sequential order (from less to higher demanding tasks) (Figure 10): 1) stable sitting without feedback (SNF); 2) stable sitting with feedback (SWF); 3) stable sitting while performing medial-lateral displacements with feedback (SML); 4) stable sitting while performing anterior-posterior displacements with feedback (SAP); 5) stable sitting while performing circular displacements with feedback (SCD); 6) unstable sitting without feedback (UNF); 7) unstable sitting with feedback (UWF); 8) unstable sitting while performing medial-lateral displacements with feedback (UML); 9) unstable sitting while performing anterior-posterior displacements with feedback (UAP); 10) unstable sitting while performing circular displacements with feedback (UCD). Familiarization was provided prior to each situation (case dependent). Each assessed task was performed twice, with a 70 s test duration and 60 s rest interval. Successful completion of each task determined the progression onto the following task. A 'failure' criteria was established; whereby, the participant (1) lost control or required assistance >3 times during one 70 s period, or (2) lost control or required assistance for >15 s during the total 70 s period. If both trials of a given task were deemed unsuccessful, then the assessment was terminated at that stage.

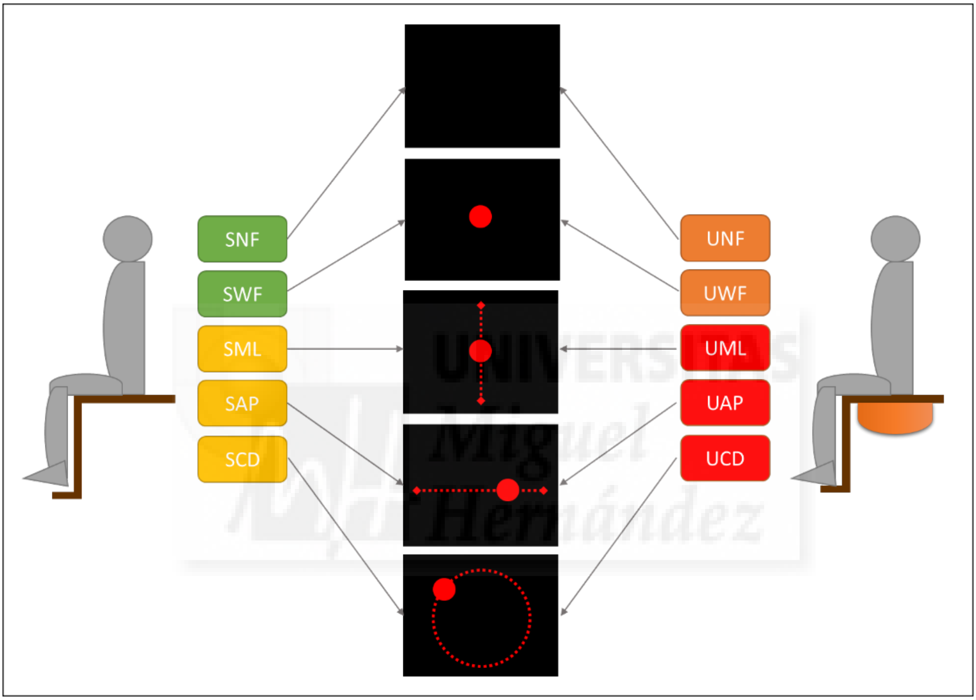


**Figure 10.** Stable (left) and unstable (right) tasks sequence.

### 3.3.3. Data reduction and parameter extraction

Firstly, the CoP signal was low-pass filtered (4th-order, zero-phase-lag, Butterworth, 5 Hz cut-off frequency) according to Lin, Seol, Nussbaum, and Madigan (2008). Then, taking into account there is little physiological significance to the CoP signal frequencies above 10 Hz (Borg and Laxaback, 2010), the CoP time series were subsampled at 20 Hz. In addition, the first 10 s of each trial were discarded to avoid non-stationarity related to the beginning of the trial (van Dieën, Koppes, & Twisk, 2010).

The mean radial error (MRE) was used as a global measure to quantify TC during the trials, and it was calculated as the average of vector distance magnitude (mm) of the CoP from the target point or from the participant's own mean CoP position (Hancock, Butler, & Fischman, 1995) for trials with and without visual feedback, respectively. Both trials of each task were used for a within-session reliability analysis. The best trial performed for each condition (lower MRE) was used for the correlational analysis. A higher score of MRE means more trunk sway with regards to the biofeedback target point, indicating a worse performance during testing.

### 3.3.4. Statistical analysis

Descriptive statistics (mean and standard deviation) were calculated for all variables. The normality of the data was examined using Kolmogorov-Smirnov statistical test. To analyze the within-session absolute reliability of each task, typical error (TE) was calculated as the standard deviation of the difference between trial 1 and 2 divided by √2 (Hopkins, 2000). This TE method was selected to avoid the influence of sample heterogeneity and to reduce the effect of systematic error (i.e. learning effect). Typical error was expressed as a percentage of the mean of the scores, facilitating extrapolation of the results to other individuals and reliability comparisons between different protocols. The relative reliability of the different measures was analyzed using the intraclass correlation coefficient ($ICC_{3,1}$), calculating 90% confidence limits (90% CL). The ICC values were categorized as follows: excellent (0.90 - 1.00), high (0.70 - 0.89), moderate (0.50 - 0.69) and low (< 0.50) (Fleiss, 1986). Reliability analyses were carried out using a spreadsheet designed by Hopkins (2015).

One-way repeated-measures ANOVAs were performed to assess repetition effect, being *trial* the within-subject factor (trial 1 and 2). A similar analysis was also conducted to check the within-groups differences across the five stable tasks, evaluating pair comparisons by a Bonferroni´s *pos hoc* analysis. A one-way ANOVA was calculated to compare TC performance in all the testing conditions between control group and adults with CP. To estimate the effect size of between-group differences, Hedges' *g* index ($d_g$) was used (Hedges and Olkin, 1985). This index is based on Cohen's *d* index; however, it provides an effect size estimation reducing the bias caused by small samples (n < 20). Effect sizes were interpreted as trivial ($d_g < 0.2$), small ($0.2 < d_g < 0.5$), moderate ($0.5 < d_g < 0.8$), and large ($d_g > 0.8$). Partial eta-square ($\eta_p^2$) values were calculated as a measure of effect size for among groups differences with the following interpretation: above 0.26, between 0.26 and 0.02, and lower than 0.02 were considered as large, medium and small, respectively (Pierce, Block, & Aguinis, 2004).

Finally, the Pearson correlation coefficient (*r*) was used to analyze the relationship between dynamic and static tasks for the participants with CP. All analyses were performed with the SPSS statistics software (version 20.0; SPSS Inc., Chicago, IL, USA), establishing significance at $p < 0.05$.

## 3.4. Results

All the control participants were able to perform the static and dynamic trials on the stable and unstable seat. On the contrary, three of participants with CP were unable to perform any task of the whole battery given their physical limitations. The remaining forty-four participants with CP (93.6%) were able to complete the stable static trials (SNF and SWF). Regarding to the stable dynamic trials, 43 (91.5%), 40 (85.1%) and 34 (72.3%) participants with CP were able to perform the SML, SAP and SCD conditions respectively. On the contrary, only 24 and 16 participants with CP (51.1% and 34.0%) were able to perform the static and dynamic conditions over the unstable seat. Therefore, unstable sitting data was not used for further analysis.

Table 1 outlines the descriptive statistics and intra-session absolute and relative reliability values for each sitting task on the stable seat. Typical error was less than 20% in all tasks, with the exception of SNF condition (TE = 24.6%). Excellent relative reliability was observed, with ICC values higher than 0.88 for all tasks. Regarding ANOVA results, only the MRE of the SWF and SML tasks showed a significant decrease between trial 1 and 2.

As Table 2 shows, the means and the standard deviations differed between both groups (adults with CP vs. control sample), with all tasks showing high significance differences ($p < 0.001$) except for the SNF condition ($p < 0.120$; $d_g = 0.42$). Effect sizes increased according to task complexity, with the SWF task displaying the smallest between group differences ($d_g = 1.12$), and the SCD the highest between group difference ($d_g = 1.95$). The repeated measures ANOVA showed significant within-groups differences, both the CP [$F(1, 33) = 42.39$; $p < 0.001$; $\eta_p^2 = 0.594$, large] and the CG [$F(1, 18) = 86.98$; $p < 0.001$; $\eta_p^2 = 0.821$, large). Figure 11 shows the within-groups comparisons across the five stable tasks for those individuals that were able to complete the posturographic battery. There were significant differences among the two static tasks (SNF and SWF) regarding the three dynamic ones; and between the SML and the SAP tasks with regard to SCD. Also, the CG showed significant differences among the two static tasks.

**Table 1.** Descriptive statistics and relative and absolute reliability of mean radial error obtained during the tasks performed on the stable seat.

| Task | N | Trial 1 | | Trial 2 | | F | *p* | $d_g$ | $ICC_{(3,1)}$ | TE (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | (SD) | Mean | (SD) | | | | (mean - 90% CL) | (mean - 90% CL) |
| **SNF** | 44 | 5.96 | (4.05) | 5.99 | (3.13) | 0.001 | 0.976 | -0.007 | 0.95 (0.89 - 0.99) | 24.6 (20.0 - 32.9) |
| **SWF** | 44 | 4.99 | (3.64) | 4.4 | (3.15) | 5.681 | 0.027 | 0.159 | 0.95 (0.91 - 0.97) | 19.7 (17.3 - 23.3) |
| **SML** | 43 | 10.29 | (5.07) | 9.18 | (4.83) | 10.445 | 0.002 | 0.215 | 0.90 (0.85 - 0.93) | 16.4 (14.5 – 19.2) |
| **SAP** | 40 | 9.32 | (4.71) | 9.33 | (5.07) | 0.001 | 0.971 | -0.002 | 0.92 (0.88 - 0.95) | 15.2 (13.0 - 17.8) |
| **SCD** | 34 | 12.19 | (5.79) | 11.57 | (5.41) | 1.868 | 0.181 | 0.105 | 0.89 (0.83 - 0.93) | 16.0 (13.9 - 19.1) |

ICC = Intra-class correlation coefficient; TE = Typical error; CL = confidence limits; $d_g$ = standardized mean difference with Hedges' adjustment.
Trunk sitting conditions: SNF = stable sitting without feedback; SWF = stable sitting with feedback; SML = stable sitting while performing medial-lateral displacements with feedback; SAP = stable sitting while performing anterior-posterior displacements with feedback; SCD = stable sitting while performing circular displacements with feedback.

**Table 2.** Difference in the mean radial error of the stable sitting conditions between participants with cerebral palsy and healthy control.

| | Control | | | Cerebral Palsy | | | F | *p* | $d_g$ (mean - 95% CL) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **N** | **Mean** | **(SD)** | **N** | **Mean** | **(SD)** | | | | |
| **SNF** | 19 | 3.62 | (2.05) | 44 | 5.38 | (4.69) | 2.477 | 0.120 | 0.42 | (-0.12 - 0.97) |
| **SWF** | 19 | 0.65 | (0.18) | 44 | 4.29 | (3.81) | 17.188 | <0.001 | 1.12 | (0.55 - 1.69) |
| **SML** | 19 | 2.12 | (0.66) | 43 | 8.77 | (4.58) | 39.332 | <0.001 | 1.71 | (1.09 - 2.33) |
| **SAP** | 19 | 1.91 | (0.49) | 40 | 8.66 | (4.65) | 39.460 | <0.001 | 1.73 | (1.10 - 2.36) |
| **SCD** | 19 | 2.91 | (1.05) | 34 | 10.92 | (4.98) | 47.640 | <0.001 | 1.95 | (1.27 - 2.62) |

$d_g$ = standardized mean differences with Hedges' adjustment; CL = confidence limit.
Trunk sitting conditions: SNF = stable sitting without feedback; SWF = stable sitting with feedback; SML = stable sitting while performing medial-lateral displacements with feedback; SAP = stable sitting while performing anterior-posterior displacements with feedback; SCD = stable sitting while performing circular displacements with feedback.

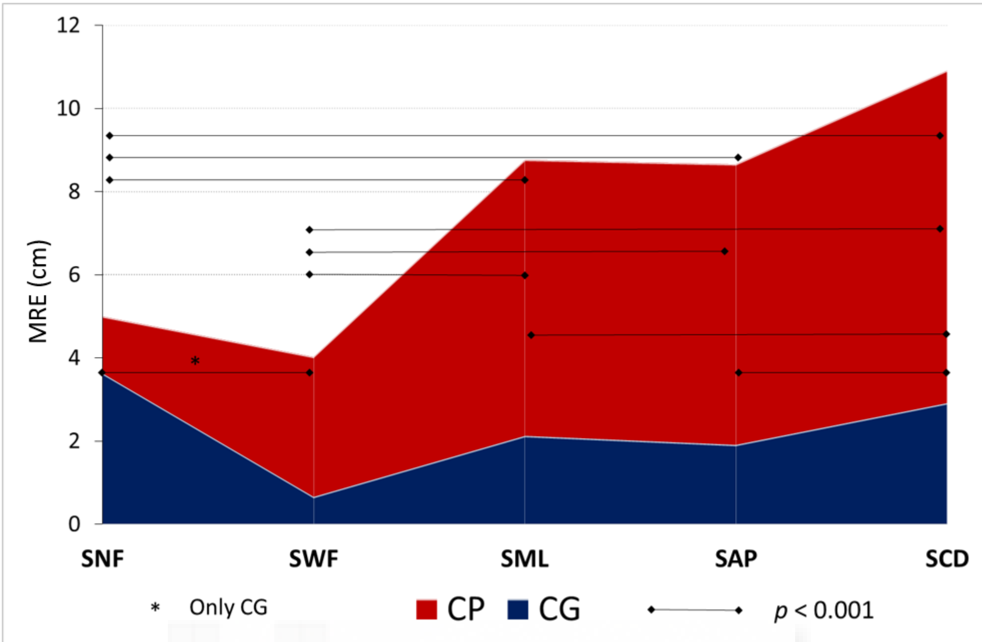


**Figure 11.** Among groups comparisons in the stable tasks.

Trunk sitting conditions: SNF = stable sitting without feedback; SWF = stable sitting with feedback; SML = stable sitting while performing medial-lateral displacements with feedback; SAP = stable sitting while performing anterior-posterior displacements with feedback; SCD = stable sitting while performing circular displacements with feedback; CP = cerebral palsy group; CG = control group; MRE = mean radial error (in cm).

For the participants with CP (Table 3), there were high significant correlations between the static tasks ($r$ = 0.835) and between the dynamic tasks (0.797 ≤ $r$ ≤ 0.868). Also moderate significant correlations were seen between the static and dynamic tasks (0.371 ≤ $r$ ≤ 0.580).

**Table 3.** Pearson correlation moment between the mean radial errors obtained by the participants with cerebral palsy in the stable sitting conditions.

| | SNF | SWF | SML | SAP | SCD |
|---|---|---|---|---|---|
| **SNF** | | .835** | .476** | .529** | .371* |
| **SWF** | | | .498** | .580** | .419* |
| **SML** | | | | .868** | .797** |
| **SAP** | | | | | .805** |
| **SCD** | | | | | |

Trunk sitting conditions: SNF = stable sitting without feedback; SWF = stable sitting with feedback; SML = stable sitting while performing medial-lateral displacements with feedback; SAP = stable sitting while performing anterior-posterior displacements with feedback; SCD = stable sitting while performing circular displacements with feedback. * $p < 0.05$; ** $p < 0.01$.

## 3.5. Discussion

Trunk control has a major impact on activities of daily living in adults with CP (Westcott et al., 1997). Due to the lack of reliable methods for assessing TC in this population, this study attempts to provide a reliable assessment of TC for adults with moderate-to-severe CP that overcomes clinical scales limitations. In addition, it has been described the extent to which TC is impaired in a group of adults with moderate-to-severe CP in comparison with individuals without CP.

A common concern with new test development are floor and ceiling effects, which are of particular importance when considering a population sample with a wide range of trunk capabilities. In particular, we have assessed the suitability of a test battery to assess TC in participants classified as having moderate to severe gross motor function impairments. The suitability of the unstable sitting methodology has been demonstrated not only in individuals without disabilities and competitive athletes (Barbado et al., 2016a,b), but also in populations with impaired TC (Verheyden et al., 2006; Willigenburg et al., 2013). However, although the hemisphere radius used in this study was higher than that used in previous studies, reducing task difficulty (Barbado et al., 2016a,b), only 51.1% and 34.0% of our participants with CP were able to complete the unstable static and unstable dynamic conditions respectively. This suggests that seated tasks on an unstable surface might not be appropriate to evaluate TC in individuals with moderate or severe trunk control impairments. On the contrary, the results of this study seems to indicate a good stable surface success rate among participants with CP, with more than 70% successfully completing the SCD condition (the most difficult task) and the 93.6% completing the static conditions (SNF and SWF).

Most of the stable sitting tasks displayed adequate between trials consistency (15.2% ≤ TE ≤ 19.7%). Therefore, they allow us to identify if the difference between separate measures of an individual are, or not, caused by within-subject variability (Hopkins, 2000; Weir, 2005). Relative consistency within these stable sitting tasks were high for both, static and dynamic conditions (0.89 ≤ TE ≤ 0.95), showing an excellent ability to rank (Hopkins, 2000; Weir, 2005) individuals with moderate to severe CP according to their TC.

Comparing our results to a previous study using CoP analysis in CP children (Kyvelidou et al., 2010), our results displayed higher ICC values than those showed by scattering variables used in posturography studies which have assessed TC while stable sitting. One explanation might be related to the fact that our participants received a real time biofeedback. Thus, those studies that did not offer such biofeedback may have achieved different equilibrium points throughout each trial making the CoP displacement non-stationary; therefore, reducing the reliability of scattering variables (Barbado et al., 2017; Caballero, Barbado, & Moreno, 2015; van Dieën et al., 2010). The TE differences found between SWF and SNF seems to support this hypothesis; and therefore, the use of biofeedback appears to be useful to improve the absolute reliability of TC tests using force platforms. Another point of interest was to assess if the protocol is suitable to assess populations with different levels of trunk control; avoiding as much as possible, floor and ceiling effects. Barbado et al. (2016a) utilized the same protocol presented here, and found that the most difficult tasks on the unstable surface displayed better reliability than those on the stable seat in young recreational athletes, whilst for individuals with CP we found greatest reliability in the static tasks conducted on the stable seat. The results of both studies provide initial indications that this protocol allows for the assessment of a large range of individuals with TC disparity.

It is also important to consider the learning effect when assessing balance tasks. Unlike previous studies (Barbado et al., 2016a; Barbado et al., 2017) which showed a performance improvement with practice, CP individuals displayed an increase in performance (decreased MRE) only in two (SWF and SML) of the five sitting conditions (Table 1). These findings suggest that TC is less susceptible to task learning (or less susceptible to change) in adults with moderate-to-severe CP impairments than in healthy individuals. However, taking into account that a learning effect was found in SWF and SML conditions, it would be necessary to perform at least one familiarization trial before testing.

Posturography revealed a significant lower performance in adults with moderate-to-severe CP in four of the five static trials compared to healthy adults (Table 2; Figure 11). Interestingly, as the effect sizes ($d_g$) showed, when the complexity of the tasks increased (i.e., adding visual biofeedback and motion to increase motor demands), differences in trunk performance became more evident between groups. In this sense, dynamic tasks seem to be more adequate than static tasks to assess impaired TC in adults with CP (SWF: $p > 0.001$, $d_g = 1.17$; SCD: $p < 0.001$; $d_g = 1.95$), which indicates that trunk performance in this population is task-specific. The moderate correlations found between conditions seems to support that static and dynamic TC although related, could not reflect the same ability. These results agree with those of Liao, Yang, Hsu, Chan, & Wei (2003), which showed that in more challenging tasks (i.e. dynamic), children with CP presented a greater sway index, which could be due to the fact that these children commonly show problems in (co)activation and coordination of the postural trunk muscles (Chen & Woollacott, 2007). Although both young and adult people with CP have an important TC deficit, future studies are needed to describe how age could affect TC.

Differences found between adults with and without CP in dynamic posturography could be related not solely to individuals' health condition, but to other factors, such as lifestyle, physical activity or technical aids. Adults with CP usually present high risk of chronic conditions that leads them towards a very sedentary lifestyle (Verschuren, McPhee, Rosenbaum, & Gorter, 2016). In addition, increasing physical condition is difficult when the therapeutic supports, commonly received during childhood, decrease dramatically with the age and when access to a sports/fitness center or household-related physical activity is limited for these individuals (Reina, 2014). Additionally, adults with moderate-to-severe CP tend to move around with powerchairs, whose typical configuration includes a high seat and other devices that fully support the wheelchair user. These supports might be reinforced by the use of straps in order to facilitate individuals' trunk function. However, the continued use of these support aids might end up having a negative result. For example, these aids could hinder individuals' trunk and head control capacities, which are crucial for maintaining an adequate body posture (da Costa, Saavedra, Rocha, & Woollacott, 2016) when performing static and dynamic tasks (Saavedra, Joshi, Woollacott, & van Donkelaar, 2009; Saavedra, Woollacott, & van Donkelaar, 2010).

In spite of the high reliability results found in this study, some limitations should be considered for future studies, as well as its potential practical applications. In this study, only the intra-session reliability was evaluated. Therefore, further works should evaluate the consistency of this assessment between sessions. In addition, although no differences were found in TC according to the GMFCS classification or age, future studies should increase the number of participants to assess the reliability of this protocol in more homogenous individuals with CP, e.g.: hemiplegia or diplegia. It could be also interesting to use a less severe group of individuals with CP (GMFCS < III), in order to check if the differences between CP and healthy adults are similar to those found in this study.

This study provide a (intra-session) reliable battery of posturography test to assess TC in adults with moderate-to-severe CP. Because the static and dynamic tasks displayed a high intra-correlation, it might be possible to reduce to one static and one dynamic task, in order to achieve a quick description of trunk postural and movement control in this population. This assessment has shown that TC is significantly affected in CP adults compared with a group without CP of similar age, demonstrating they present more difficulties to perform dynamic tasks on stable surfaces than static ones. For that reason, this study encourages physical activity practitioners to design dynamic activities that challenge trunk control to develop activities of daily living in this population.

# Chapter IV


## Study 2

Trunk Control in Boccia players with Moderate-to-Severe Cerebral Palsy: Implications for Classification.

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Submitted at *Disability and Health Journal*

# 4. STUDY 2

## 4.1. Abstract

In Paralympic sports classification is necessary to assess eligible impairments to group para-athletes with similar functionality. Boccia is a sport for individuals with neurological conditions such as cerebral palsy. Impaired trunk control (TC) is a common characteristic in this population, considered also as a key feature for sport performance. However, the current method to assess TC in Boccia is a field test based on expert observations, which may carry certain degree of subjectivity. That method has never studied or compared with a laboratory test, in order to evaluate its concurrent validity and to study its capability to discriminate between sport classes. Forty-three boccia players from sport classes BC1 (n = 14) and BC2 (n = 29) took part in this study. Impaired TC was assessed through the current Boccia assessment protocol and a posturographic test battery using a force platform, which consisting of two static tests (with and without visual feedback) and three dynamic tests (medial-lateral, anterior-posterior and circular movements). One-way ANOVA was performed for all conditions to understand how both methods evaluate trunk impairment, and their performance in static and dynamic conditions in the posturographic protocol. Results showed that the current TC assessment method in Boccia did not discriminate between classes, while the posturographic methodology did it in static conditions ($p$ = 0.002; $d$ = 1.08, large). The static TC performance in BC1 and BC2 boccia players should be considered with classification purposes.

**Keywords:** Paralympic, cerebral palsy, sitting balance, posturography.

## 4.2. Introduction

Boccia is a Paralympic sport that requires precision and high tactic skills. This Para sport has five sport classes (BC1 to BC5). Classes BC1 and BC2 only host individuals with dyskinesia (both athetosis and dystonia), ataxia or spasticity, underlying health conditions such as cerebral palsy (CP) (BISFed, 2017). Individuals with CP tend to present problems of upper limbs coordination, disruptions in postural control, and subsequent postural instability (Szopa and Domagalska-Szopa, 2015).

A good TC provides a stable base to facilitate the performance of upper limbs (hand and arms) in precision tasks, such as grasping, reaching or throwing objects (Huang, Pan, Ou, Yu, & Tsai, 2014; Kaminski, Bock, & Gentile, 1995; Pigeon, Yahia, Mitnitski, & Feldman, 2000). On the other hand, an impaired TC is a very common characteristic in individuals with CP (Desloovere and Heyrman, 2015), becoming a crucial point of study for clinical practitioners due its health implications in children with CP (Saavedra, 2015).

Beyond the clinical setting, there is a growing interest about the function of the trunk and its relationship with sports performance, especially in Para sports. Thus, it has been demonstrated in wheelchair rugby (Altman et al., 2016) or in Para athletics (Hyde et al., 2016), that TC appears to be closely related to athletes' impairment and its severity. These studies have showed that individuals with higher motor limitations tend to present poorer TC than peers with less impairment. However, to the best of our knowledge, no previous studies have been conducted with athletes with severe impairments like boccia players. The BISFed Classification Rules considers the TC, together with upper limb coordination and strength, as one key aspect to differentiate between sport classes BC1 and BC2 (BISFed, 2017), providing a description of how players' TC looks like. Thus, according to this rulebook, BC1 players tend to present "…

*spasticity and muscle weakness within trunk that will affect their sitting balance and their ability to control trunk movements without the use of some compensatory strategies. Some appreciable characteristics are loss of postural control when throwing and a limited dissociation of pelvis/trunk/upper limbs*". On the other hand, BC2 players present "…*spasticity and weakness within the trunk but in lower degree than BC1 players. They show more postural control and sitting balance during throwing preparation and, more dissociation degree of the pelvis-trunk-upper limbs, which facilitate to rotate the trunk and use some compensatory movements*".

As it can be seen from these pieces of text, TC function is very much based on a qualitative description. This approach is not in accordance with that stipulated by the International Paralympic Committee´s Athletes Classification Code (IPC, 2015), which encourages to develop classification systems based on scientific evidence, in order to avoid subjectivity in classifiers' decision-making (Tweedy and Vanlandewyck, 2011). An evidence-based classification system would allow classifiers to identify which assessment methods should be used to evaluate athletes' impairment/s, in order to group them with a similar degree of impairment. In relation to Boccia, it is necessary to address the extent to which TC is affected to understand how much activity limitation may cause.

Currently, TC is assessed in Boccia through a qualitative field test (aforementioned as *BISFed Trunk Function Scale - BISFed TFS*), which evaluates players' ability to maintain a stable sitting position in addition to perform several trunk movements in different planes: sagittal (forward and backward), frontal (sideway) and transverse (rotation) (BISFed, 2017). To score players' TC performance, classifiers base their evaluation on five qualitative items that are provided in an ordinal basis: from more to less TC function. So, classifiers should select the item that best describe player's function. However, although this method is currently used in classification due to its easy and fast implementation, this method has never been analysed, so it is still unknown to what extent this method is sensitive to discriminate between sport classes. Nor its have been compared with more objective methods such as posturography. Posturography is a computer-based laboratory methodology that usually uses force platforms (Goodworth, Wu, Felmlee, Dunklebarger, & Saavedra, 2017; Verbecque, Vereeck, & Hallemans, 2016; Lopes and David, 2013; Liao, Yang, Hsu, Chan, & Wei, 2003). This technique has been proven to be an objective and reliable tool to quantify TC in a broad range of populations, from competitive athletes (Barbado et al., 2016a; Barbado et al, 2016b) to people with moderate-to-severe CP (see Study I). However, the implementation of this methodology requires complex and expensive equipment, and long execution protocols, which may have been the reason why it has never been implemented in Boccia for classification purposes.

This study aims to explore the ability that the BISFed TFS and the posturographic protocol have to discriminate between BC1 and BC2 sport classes. A second objective will explore the relationship between both methodologies in order to assess concurrent validity of the BISFed TFS to assess TC in boccia players.

## 4.3. Methods

### 4.3.1. Participants

A sample of 43 boccia players participated in this study (age = 36.17 ± 13.72; body mass = 52.02 ± 11.04; trunk height = 55.74 ± 7.54), specifying characteristics for BC1 (n = 14) and BC2 (n = 29) groups in Table 1. The inclusion criteria adopted for selecting the players were: (1) classified as BC1 (severe spastic or athetosis quadriplegia, or mixed picture with severe ataxia) or BC2 (moderate spastic or athetoid quadriplegia, or ataxia) (BISFed, 2017); (2) no surgeries or Botulinum toxin-A injections in the six months prior to testing; and (3) able to follow the pertinent test instructions given by the researchers. The exclusion criteria were: i) athletes classified as BC3 (i.e. ramp players), BC4 (no brain impairments) or BC5 (new class after Rio Paralympic Games, not participants available yet); and ii) players who presented co-morbidity of intellectual impairments. The local University Ethics Committee (Ref. DPS-RVV-001-10) authorized this study.

**Table 4.** Descriptive data of BC1 and BC2 participants.

| **Demographic Variables** | **BC1** | **BC2** |
|---|---|---|
| Sex | ♂ = 8 , ♀ = 6 | ♂ = 17 , ♀ = 12 |
| Competition Level | R = 9, N = 4, I = 1 | R = 15, N = 13, I = 1 |
| Age (yr) | 39.00 ± 13.19 | 34.50 ± 14.13 |
| Body Mass (kg) | 53.65 ± 10.96 | 51.55 ± 11.89 |
| Trunk Height (cm) | 53.07 ± 2.59 | 55.69 ± 7.86 |
| GMFCS | 4.00 ± 0.00 | 3.03 ± 0.90 |

♂ = male participant; ♀ = female participant; R = regional competition level; N = national competition level; I = international competition level; GMFCS = Gross Motor Functional Classification Scale mean score

## 4.3.2. Procedure

### 4.3.2.1. Stable Sitting Protocol (SSP)

This study followed a posturographic protocol used with athletes without disabilities at recreational (Barbado et al., 2016b) and high performance levels (Barbado et al., 2016a), but also in adults with moderate-to-severe CP (see Study I). As seen in the first study of this dissertation, all individuals with moderate-to-severe CP were able to perform the stable sitting tasks in comparison to the unstable ones, therefore, only the stable tasks were selected for this study.

Participants were seated in a wooden chair placed over a force platform (Kistler, Switzerland, Model 9286AA) at 1000 sample/s), located at 0.9 m height above the ground on a rigid, stable and flat surface. Participants' popliteal fossa pressed lightly against the front edge of the surface, conducting a knees flexion at a 90° (individually adjusted). Two ankle straps were attached around the base of the shank to the surface, as well as one tightly secured across pelvis. To avoid arms movements, participants were instructed to keep their arms firmly crossed in front of their chest, or as closed to this position as possible (Figure 12, QR code to watch video). Real time visual feedback (VFB) of the participant center of pressure (CoP) displacement was projected (Hitachi CP-X300) onto a screen (106 x 138cm). A target point (red dot) was located in the center of the screen to assess the participant's ability to adjust his/her CoP position (yellow dot) to the target location. Both target dots had a radius of 60 mm.


**Figure 12.** Participants set up on the stable surface and QR code for video demostration.

Participants performed five tasks in the following order (Barbado et al., 2016a,b; see also Study I): two static conditions, one without (SNVF) and one with real visual feedback (SVF); and three dynamic conditions requiring medial-lateral (DML), anterior-posterior (DAP) and circular (DC) trunk displacements. In the SNVF task, participants were asked to sit as still as possible in a seated position. In these conditions, participants did not required to move, just to keep upright. In the dynamic conditions, participants were demanded to keep their CoP over the target point that was in constant motion along the medial-lateral, anterior-posterior or circular trajectory and took 20 s to complete a cycle (0.05 Hz).

Each test was performed twice, with a 70 s duration and 60 s rest interval (Barbado et al., 2016a,b). In order to continue to the next test, participants had to successfully complete the previous task, i.e.: not to lose postural control (15 s max) nor need external assistance (no more than three supports or no more than 15 s accumulative within the 70 s of testing). If these requirements were not met, a second trial was performed and if athlete was unable to complete the second trial, the whole testing was stopped, and the task was considered unsuccessful (not included in the records).

#### 4.3.2.2. Trunk assessment based on clinical and classification expertise

During the TC classification process in Boccia, individuals are asked to sit upright on a bench and lean away from the midline vertical position to the greatest distance in the sagittal (anterior-posterior displacement) and coronal (medial-lateral displacements) planes, without falling or reaching for support (BISFed, 2017). This assessment also includes trunk twist in order to evaluate trunk rotation capacity (i.e. the ability to do so implies not being eligible for classes BC1 nor BC2). Due to impairment severity, some players are assessed in their own wheelchairs, because their impossibility of keeping the trunk upright without external aids. The BISFed TFS assesses trunk movement quality using five qualitative items ascending in function as follow: i) requires restraint to prevent from falling out of chair; ii) uses head to center after throw or disturbance; iii) uses arms/hands to center after throw or disturbance; iv) can return to upright without head/hands after throw or disturbance; v) good/fair trunk rotation.

Two international classifiers, members of the BISFed Classification Committee, conducted the assessment test, and the score was extracted from the classification scoresheet. In order to correlate the BISFed TFS with the stable sitting protocol, the five items from BISFed TFS were converted in a ratio-scale assigning to each item a number. Therefore, scores ranged from minimum of 1 to a maximum of 5 points, being interpreted as 1 point as the lowest trunk function and 5 point with the highest trunk function.

### 4.3.3. Data reduction and parameters extraction

CoP time series obtained from the force platform were filtered using low-pass filter (4th-order, zero-phase-lag, Butterworth, 5 Hz cut-off frequency) (Lin, Seol, Nussbaum, & Madigan, 2008). In addition, there is little physiological significance to the CoP signal frequencies above 10 Hz (Borg, 2010), the CoP time series were subsampled at 20 Hz. In addition, the first 10 s of each trial were discarded to avoid non-stationarity related to the beginning of the trial (van Dieën, Koppes, & Twisk, 2010). The mean radial error (MRE) was used as a global measure to quantify the trunk performance during the trials. MRE was calculated as the average of vector distance magnitude (mm) of the CoP from the target point or from the participant's own mean CoP position (Hancock, Butler, & Fischman, 1995) for trials with and without visual feedback, respectively. The best trial performed for each condition (lower MRE) was used for analysis. A higher score of

MRE means more trunk sway with regards to the biofeedback target point, indicating a worse performance during testing.

### 4.3.4. Statistical Analysis

All data are reported as mean ± standard deviations. Global mean of the static (SNVF + SVF) and the dynamic (DML + DAP + DCI) tests were also calculated. To examine the differences between groups (BC1 vs BC2), a one-way ANOVA was conducted on all dependent variables. The Hedges's *g* index (Hedges, 1985) was used to calculate the effect sizes of between-groups differences. This index is based on Cohen's *d* index (Cohen, 1988), but it provides an effect size estimation reducing the bias caused by small samples ($n < 20$), such as BC1 group in our study. Interpretation of Hedge's *g* was: above 0.8 (large), between 0.5 and 0.8 (moderate), between 0.2 and 0.5 (small) and lower than 0.2 (trivial).

The relationship between the five TC tests and the BISFed TFS was analysed using the Pearson's correlation coefficient (r). To interpret those results the threshold values for Pearson product-moment were used: low ($r \leq 0.3$), moderate ($0.3 < r \leq 0.7$) and high ($r > 0.7$) (Salaj and Markovic, 2011). Data analysis was performed using the Statistical Package for Social Sciences (version 24 for Windows, SPSS Inc., Chicago, IL, USA). Statistical significance was set at an alpha level of $p < 0.05$.

## 4.4. Results

A one-way ANOVA was conducted to compare motor functional levels between groups of participants. Using the demographic data, there was a significant difference in the GMFCS score between BC1 and BC2 boccia players [$F(2,43) = 15.72$; $p = 0.001$; $d_g = 1.26$, large], having BC2 players a better overall function. The one-way ANOVA conducted with the TC test battery shows significant differences between sport classes in the total score of the static tests ($p$ = 0.002; $d_g$ = 1.08, large) and with each of the individual static conditions (SNVF and SVF) (Table 5). Although non-significant differences where obtained across the dynamic conditions, moderate effect sizes were obtained in the overall dynamic performance ($p$ = 0.154; $d_g$ = 0.51, moderate). Table 5 also shows the number of participants who were able to perform the whole test battery, observing that the dynamic test battery became more difficult for the participants of this study.

The correlation analysis among the BISFed TFS and the posturographic protocols showed a moderate negative significant correlation between the BISfed TFS and the overall score of the dynamic tasks of the posturographic protocol ($r$ = -0.475; $p$ = 0.026).

**Table 5.** Descriptive statistics and one-way ANOVA about mean radial error (MRE)

| Test | Variable | N (BC1 + BC2) | BC1 (M ± SD) | BC2 (M ± SD) | *F* | *p* | $d_g$ |
|---|---|---|---|---|---|---|---|
| **BISFed TFS** | | | 2.29 ± 1.09 | 2.07 ± 1.18 | 0.27 | 0.611 | 0.19 |
| **Stable Sitting Protocol** | **SNVF** | (14 + 29) = 43 | 7.92 ± 6.52 | 3.73 ± 2.45 | 9.41 | 0.004 | 0.98 |
| | **SVF** | (14 + 29) = 43 | 6.48 ± 4.86 | 2.86 ± 2.17 | 11.55 | 0.002 | 1.09 |
| | **DML** | (13 + 28) = 41 | 9.09 ± 5.35 | 8.13 ± 3.99 | 0.41 | 0.525 | 0.21 |
| | **DAP** | (13 + 25) = 38 | 9.45 ± 4.67 | 7.69 ± 3.60 | 1.71 | 0.199 | 0.43 |
| | **DC** | (12 + 20) = 32 | 12.24 ± 4.65 | 9.68 ± 4.61 | 2.34 | 0.136 | 0.54 |
| | **Static** | (14 + 29) = 43 | 7.19 ± 5.56 | 3.30 ± 1.95 | 11.57 | 0.002 | 1.08 |
| | **Dynamic** | (12 + 20) = 32 | 10.09 ± 4.66 | 8.02 ± 3.44 | 2.14 | 0.154 | 0.51 |

BISFed TFS = Boccia International Sport Federation trunk function scoresheet; Trunk sitting conditions: SNVF = stable sitting without feedback; SVF = stable sitting with feedback; DML = stable sitting while performing medial-lateral displacements with feedback; DAP = stable sitting while performing anterior-posterior displacements with feedback; DC = stable sitting while performing circular displacements with feedback; M = mean, SD = standard deviation; $d_g$ = Hedges´ effect size.

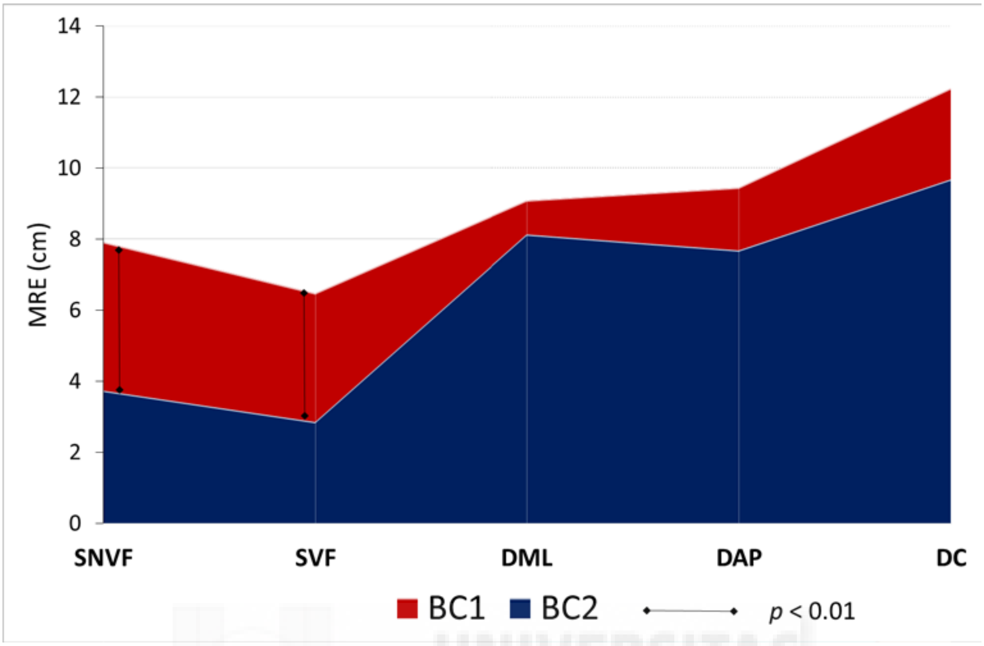



**Figure 13.** Among groups comparisons in the posturographic protocol.

SNVF = stable sitting without feedback; SVF = stable sitting with feedback; DML = stable sitting while performing medial-lateral displacements with feedback; DAP = stable sitting while performing anterior-posterior displacements with feedback; DC = stable sitting while performing circular displacements with feedback; MRE = mean radial error (in cm).

## 4.5. Discussion

The results obtained in this study showed that the BISFed TFS was not able to discriminate between current sport classes (i.e. BC1 and BC2), being only the static posturographic tasks able to do it. In addition, the correlational analysis only showed a moderate relationship between the BISFed TFS and the dynamic tasks of posturography.

These results may be explained based on the characteristics of Boccia sport. Unlike others Para sports where dynamic TC have been demonstrated to have a great impact on sport performance such as wheelchair propulsion (Vanlandewijck, Verellen, & Tweedy, 2011), throwing in Para athletics (Hyde et al., 2016), or tagging in wheelchair rugby (Altmann et al., 2016), dynamic TC in Boccia does not seem to be so relevant. This is supported by the posturographic results, where the dynamic tasks, as opposed to the static ones, were not sensitive to discriminate between sport classes. In Boccia, players need to throw the coloured balls with high accuracy to get them as close as possible to the white ball (i.e. the *Jack*). To perform this action, it is not necessary to execute broad trunk movements, just small adjustments to stabilize the trunk in order to achieve the most efficient throwing position. Therefore, it seems that a static TC is more relevant and important to carry out the throws.

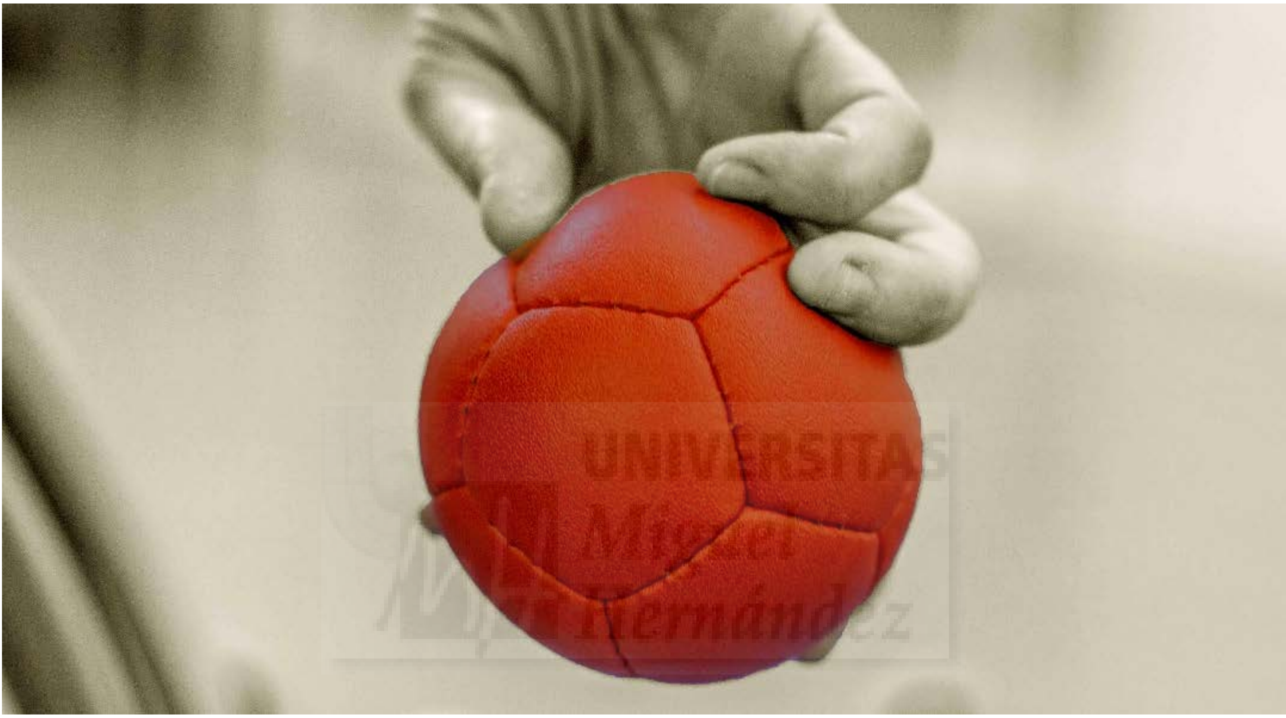
In addition to the previously mentioned, it could exist a mismatch among how TC is currently assessed in Boccia and how trunk is used for the game. On one hand, in the TC assessment during classification, players are not allowed to use straps, armrests, head-holds, lumbo-pelvic support or footrests (BISFed, 2017). Furthermore, this lack of standardization in the BISfed TFS is clear when the most severe players, who are not able to sit on the bench without external supports, can perform the assessment in their own wheelchairs, using external aids. On the other hand, during competition, no matter what level of impairment a player has, players are allowed to use any external aids (i.e. straps). Additionally, some clinical studies have demonstrated that persons with neurological impairments may achieve a good trunk stability throughout different postural strategies (Lajoie, Jehu, Richer, & Chang, 2017), such as blocking the head, trunk and limbs at the same time (Saavedra and Woollacott, 2015; Likhi, Jidesh, Kanagaraj, & George, 2013; Wee et al., 2015). These kind of strategies may be transferred in the Para sport settings, performing some compensatory strategies (e.g. holding the chair while throwing) to promote better TC (BISFed, 2017).

As it happens in other Para sports, the use of strapping equipment may affect the physiological and kinematic demands of the sport skills, influencing the performance in competition (Crespo-Ruiz, Del Ama-Espinosa, & Gil-Agudo, 2011; Mason, Van der Woude, & Goosey-Tolfrey, 2013). The posturographic protocol facilitates a large standardization with a strong legs and pelvis fixation, a situation more similar to Boccia competition, being the reason why this methodology was more sensitive to discriminate in the static tasks between sport classes. These results are supported by other authors who stated that field tests should assess athletes' impairments considering the relationship between impairment, equipment and sport regulations (Vanlandewijck, 2017; Keogh, 2011; Smits, Pepping and Hettinga, 2014).

The posturographic static conditions revealed that any task that requires to maintain a vertical position outside of their wheelchairs may be a challenge for individuals with moderate-to-severe neurological impairments. The results of this study shown that fewer players were able to complete the dynamic tasks, showing worse MRE scores. This can be explained because individuals with CP should present weak trunk muscles and impaired selective motor control (Chruscikowski, Fry, Noble, Gough, & Shortland, 2017), that difficult the adjustment to a more complex tasks. Similar results were found in other studies that shown that individuals with CP presented lower performance of postural control, causing larger scores in trunk sway in dynamic than in static tasks (Liao et al., 2003). Based on the correlation analysis, the inability of the BISFed TFS to discriminate between sport classes, and its moderate correlation with the dynamic tasks of the posturographic protocol, it is plausible to think that the BISFed TFS assesses dynamic TC, or other features of TC such as limit of stability (Domínguez, Belvis, & Reina, 2016).

Despite the deficit in postural control demonstrated by individuals with high CP affectation (Heyrman and Desloovere, 2013; Hussain, Onambele, Williams, & Morse, 2014), the effective use of the limited TC capacity seems to be important in Boccia in order to adopt suitable positions to throw, even when the range of movement of the throwing arm is limited (i.e. spasticity limits range of movement) (Reid, Elliott, Alderson, Lloyd, & Elliot, 2010). Furthermore, Boccia rulebook considers different players´ features to allocate them in a particular sport class (i.e. function of upper extremities, hand function and grip, trunk / postural control and balance, and function of lower limbs). Although static TC seems to be a relevant feature to consider when classifying boccia players, future studies should assess the weight of TC in the overall functional assessment of a boccia player, considering other parameters such as coordination and/or upper limbs strength.

# Chapter V



# Study 3

## Assessment of Impaired Manual Dexterity and Intra-Limb Coordination in Adults with Moderate-to-Severe Cerebral Palsy.

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Submitted at *Frontiers in Neurology*

# 5. STUDY 3

## 5.1. Abstract

**Background:** Boccia is a Paralympic sport competed by athletes with severe neurological impairments affecting all four limbs. An impaired manual dexterity (MD) and intra-limb coordination (ILC) may limit individuals' ability to perform certain activities such as grasping, releasing or manipulating objects, which are essential tasks or actions to play Boccia. However, there are currently no specific instruments available to assess hand/arm coordination in Boccia players.

**Purpose:** To design new coordination sport-specific tests to assess impaired coordination in boccia players, and quantifying how much is coordination impaired regarding to a control group without neurological impairments.

**Methods:** Seventy-three recreational Boccia players with severe cerebral palsy (BC1: age = 34.01 ± 16.43 yr; BC2: age = 33.97 ± 14.29 yr), and 19 healthy adults (age = 27.89 ± 7.08 yr) completed the test battery. The Box & Block (BBT) and Box & Ball (BBLT) tests were used to assess MD, and four tapping tests to assess upper ILC.

**Results:** Both MD tests were able to discriminate between sport classes. Boccia players obtained better scores in the BBLT in comparison to the BBT, showing the BBLT better appropriate testing features. On the other hand, only one of the ILC tests was able to discriminate between sport classes, presenting the highest practice significance ($d$= -1.12). CP participants scored worse in all the coordination tests compared to controls.

**Conclusions:** Using sport-specific equipment facilitates grasp function during MD assessment. Regarding the ILC, the type of movement (continuous vs discrete) seems to be more relevant for classification than the movement direction (vertical or horizontal) or with/without handling a ball.

**Key words:** Paralympic, cerebral palsy, neurological impairment, Para sport.

## 5.2. Introduction

Boccia is a strategic game that demands high coordination and control of the movements to achieve accuracy (Reina, Caballero, Roldán, Barbado, & Sabido, 2015). Boccia promotes sport practice for people with permanent and severe neurological impairments (i.e. cerebral palsy), and other severe locomotor impairments, both affecting the four limbs (BISFed, 2017). Boccia players with impairments such as dyskinesia (both athetosis and dystonia), ataxia or spasticity tend to present high coordination problems (Rönnqvist and Rosblad, 2007).

To achieve a fair competition, classification aims to cluster athletes into sport classes, in which the least impaired athletes could also have the best chances to win (IPC, 2015b). Some current Paralympic classification systems are not based on scientific evidences yet. In addition, some assessment methods to evaluate eligible impairments and its activity limitation are not either sport-specific (Tweedy, Beckman, & Connick, 2016).

The Boccia Classification Rulebook (BISFed, 2017) indicates that the coordination assessment should focus on manual dexterity (MD), and intra limb-coordination (ILC). Manual dexterity is defined as the ability to make precise hand and finger movements to grasp and manipulate objects (Kreutzer, DeLuca, & Caplan, 2011). Manual dexterity is widely assessed in people with CP as they usually present difficulties performing manual activities due to hand abnormalities, such as thumb adduction and/or flexion with limited wrist extension, causing activity limitation when performing activities of daily living (Golubović and Slavković, 2014). On the other hand, the ILC is understood as the coupling among two or more joints in the same limb (Matsuo et al., 2005). A good coupling relationship means greater coordination of the limb joints and higher flexibility in motor patterns (Sides and Wilson, 2012). The ability to perform basic skills such as grasping, releasing and following through the ball, or being able to achieve a good throwing positioning (e.g. elbow flexion-extension and shoulder abduction), seem to be relevant to succeed in Boccia. Thus, all these actions must be taken into consideration and assessed during classification (BISFed, 2017).

Currently, coordination in Boccia is assessed in classification through non standardized/qualitative methods. Some well-known tests as the finger-to-nose test, included in the Scale for the Assessment and Rating of Ataxia -SARA- (Weyer, Abele, Schmith-Hübsch, Schoch, & Frings, 2007), quantifies the degree of impaired coordination throughout a ratio-scale, but based on the observation of the tremor/inaccuracy. More specifically, MD is usually assessed asking the player to hold a ball while the classifier tries to remove it from his/her hand, or asking them to release the ball after a verbal command. On the other hand, ILC is usually assessed asking the player to throw to different areas of the boccia court, evaluating its accuracy and/or force control, and observing the preparation, releasing and follow-trough. However, for the development of evidence-based classification systems, it is necessary to develop assessment methods that quantify the level of impaired coordination and its impact on the activity limitation (Connick, Beckman, Deuble, & Tweedy, 2016).

Quantitative instruments are based on technical measures and calculations, and they usually tend to show better reliability than qualitative assessments (Garbarino and Holland, 2009). When talking about coordination, these methods are focused on assessing two main outcomes: time and accuracy (Lawrence et al., 2015). A quantitative test frequently found in the literature to assess MD in individuals with CP is the Box and Block Test (BBT). The BBT is considered as gold standard to evaluate the gross manual dexterity: grasping, holding and releasing (Arnould, Penta, Renders, & Thonnard, 2004). This test has simple execution rules and it has been validated for people with neurological impairments like stroke or CP (Gilliaux et al., 2015; Lin, Huang, Chen, Wu, & Huang, 2014), presenting good reliability (Oliveira et al., 2016; Reina et al., 2013). Although BBT requires specific skills similar to boccia (i.e. grasping and releasing actions) it may be relevant the development of a coordination test that involves specific sport equipment (i.e. boccia balls).

Regarding the assessment of ILC, the hand/finger tapping tests (HTT) are tests used in clinical settings to assess upper limbs muscle control (Barut, Kızıltan, Gelir, & Köktürk, 2013), even in individuals with mild-to-moderate CP (Blank and Kluger, 2009). This type of tests require from participants to perform discrete or reciprocal finger/hand contacts on a surface, as quickly and accurate as possible, during a specific period of time or performing a maximum of strikes. The HHT have been carried out in sport context recently with classification purposes. Connick et al. (2016) designed a reciprocal and discrete HTT battery to assess upper and lower limbs coordination in Para athletics, such as wheelchair racing, running, jumping and throwing events. Another study by Deuble et al. (2015) used similar HHT battery as a potential tool to identify intentional misrepresentation in Para athletes; aiming to identify those athletes who pretend to show greater degree of limitation by performing less ability or proficiency. However, these studies have been carried out only with individuals without disability.

The implementation of (sport-specific) coordination tests in athletes with impairments is pertinent, especially in those with severe-to-moderate coordination impairments such as boccia players. Therefore, this study aims to: i) design three sport-specific coordination tests for Boccia, evaluating their capability to discriminate between two sports classes (i.e. BC1 and BC2); ii) to evaluate the relationship between generic and sport-specific coordination tests for a better understanding if they assess similar dimensions of impaired coordination; and iii) to quantify how much is coordination impaired in boccia players compared with individuals without neurological impairments.

## 5.3. Methods

### 5.3.1. Participants

Seventy-three participants with CP (42 men and 31 women), from national (44%) and regional (56%) Boccia competition levels as BC1 (N = 33; age = 34.01 ± 16.43 years; weight = 44.35 ± 13.88 kg; Gross Motor Functioning Classification Scale (GMFCS) scores = 3.89 ± 0.46) or BC2 (N = 40; age = 33.97 ± 14.29 years; weight = 50.44 ± 11.46 kg; GMFCS = 3.12 ± 1.04), were recruited to participate voluntary in this study. All participants met the following inclusion criteria: (1) have a brain impairment from CP or similar neurological condition, (2) classified as BC1 (spastic or athetoid quadriplegia or mixed picture, including those with severe ataxia) or BC2 (spastic quadriplegia or with athetosis/ataxia) by BISFed (2017), (3) no surgeries or botulinum toxin injections in the six months prior to testing, (4) able to follow the pertinent test instructions given by the researchers. The exclusion criteria were: i) athletes classified as BC3 (i.e. not able to grasp and release a Boccia ball), BC4 or BC5 (i.e. non central nervous system impairments); and ii) players who presented intellectual impairments. In addition, a group of 19 adults without any physical impairment was also included in the study (age = 27.89 ± 7.08 years; weight = 71.18 ± 11.55 kg) as Control Group (GC). Ethics approval was obtained through the local University Ethics Committee (Ref. DPS-RVV-001-10).

### 5.3.2. Procedure

This study comprises two different data collection phases. During the first stage, a group of 45 participants with CP (BC1 = 23, BC2 = 22) and the CG (n=19) performed four tests: two to assess MD and two finger tapping tests to assess ILC. In a second stage, a different group of 28 participants with CP (BC1 = 10, BC2 = 18) performed the same four tests as given above, plus two specific tasks to assess ILC.

#### 5.3.2.1. Manual Dexterity tests

The MD tests grouped two tests that follow similar protocols based on grasping, transporting and releasing an object. Both MD tests registered the number of objects (blocks or balls) that participants were able to handle during 1 min.

*Box and Block Test (BBT)*

This test was conducted according to the original instructions proposed by Mathiowetz and Volland (1985). Participants used their throwing hand and performed two trials of 1 min with 1 min resting between trials. Participants had 10 s of practice to familiarize with the test. Excellent and high intra-class correlation coefficient have been demonstrated previously in a similar sample (ICC = 0.97) and healthy adults (ICC = 0.85), respectively (Reina et al., 2014). The outcome of the test is the number of blocks passed in the 1 min testing period.

*Box and Ball Test (BBLT)*

The BBLT follows the same than the BBT's. The only difference is the BBLT measure the number of Boccia balls (Handi Life Sport, Skibby, Denmark: hard hardness, 278 gr., 274 mm circumference, Figure 14a) an individual can transport, in 1 min, from the first compartment to the second one. Due to the size of the compartment, only six balls were able to fit at time (Figure 14b). Two researchers were required, one at each side of the table. One researcher was picking up the balls from the second compartment left by participants, and sending them (rolling onto the table) to the second researcher, who was refilling the first compartment when participants were releasing the ball. Reina et al. (2014) reported excellent reliability for this adaptation of the BBT, both for participants with CP (ICC = 0.98) and healthy adults (ICC = 0.93). The outcome of the test is also the number of balls passed during 1 min.

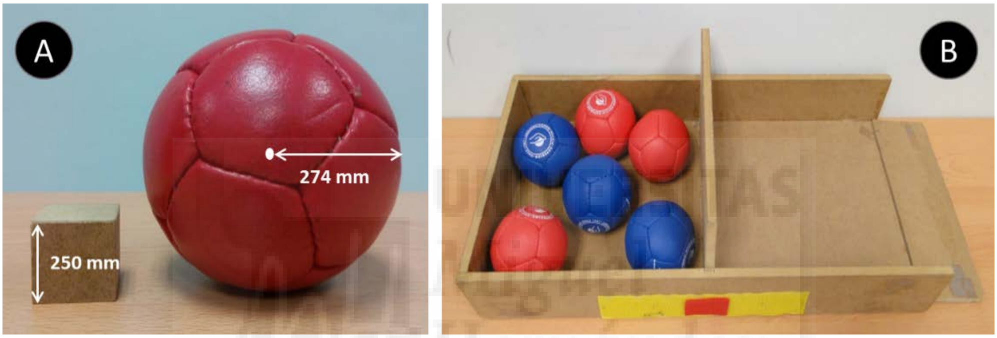


**Figure 14.** Block and boccia ball sizes (A), and Box and Ball equipment (B)

#### 5.3.2.2. Intra-Limb Coordination (ILC)

The test battery to assess arm coordination grouped four different tapping tests, following similar protocols to those described by Connick et al. (2016) and Deuble et al. (2015) with good reliability. The three discrete ILC tests assessed mean movement time (in seconds) of the arm, while the continuous test assessed the number of contacts that each participant was able to perform between plates during testing time.

*Discrete Horizontal Finger Tapping Test (DHFTT)*

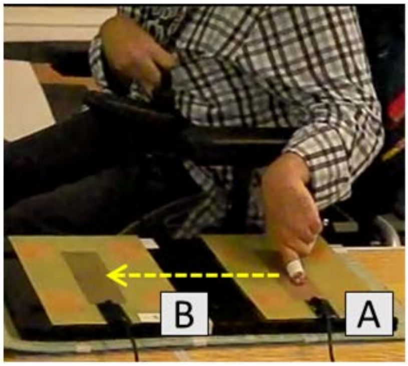


**Figure 15.** Discrete Horizontal Tapping Test.

Participants seated in their own wheelchairs and they were placed parallel to a table at 10 cm from the edge of the tapping plates (Figure 15). The table was adjustable to be able to align players' hip (greater trochanter) with the bottom of the table. The shoulder of the dominant arm was in line with plate A (start position). Participants were asked to place the non-throwing arm across the chest and the throwing hand closed with the index finger extended. However, due to some motor limitations (i.e. severe spasticity), not all the participants were able to place the shoulder and/or finger as demanded, so they were allowed to place them in the most comfortable position as long as it did not interfere with the test execution. To complete the tests, participants needed to complete a cycle of 10 tapping contacts, reporting the performance as the mean score of the 10 contacts (in seconds). A cycle happens when participants release of plate A to hit the plate B (finish position), as fastest as possible. Plates were displaced in horizontal where distance between both plates' centers was 30 cm. The dimensions for the metal plate were 30 cm (length) x 20 cm (width). The target area, placed in the center of both plates, have 5 cm (width) x 18 cm (length). Any contact out of the band was not registered. Once participants touched plate B, they had to return the finger to plate A. A period of at least 3 s has to pass between trials and participants were instructed not to move their finger until the instructor gave the start signal "Go!". This test assess how fast (in seconds) an individual move his/her finger from one plate to the other. Connick et al. (2016) reported high-to-excellent inter-session reliability for this test with young participants without impairments (ICC = 0.85).

*Discrete Vertical Finger Tapping Test (DVFTT)*

The plates were displaced in an “L” shape (90º), where plate A keeps on horizontal but plate B is placed on the vertical edge (Figure 16). Distance between both plates’ centers was 30 cm as the previous test. The same protocol was used as in DHFTT. This test assess how fast (in seconds) an individual move his/her finger from one plate to the other. Connick et al. (2016) also reported high-to-excellent inter-session reliability for this test (ICC = 0.92), also in healthy individuals.

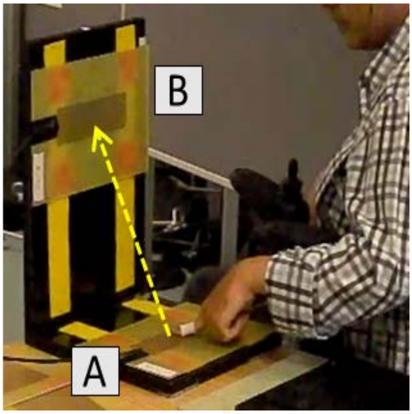


**Figure 16.** Discrete Vertical Tapping Test.

*Discrete Vertical Tapping Test with Ball (DVTTB)*

A new “L” shape structure and a new set of plates were built, using plates that work through a spring system, this is, the plates moved backward when a contact with the ball was made. Contacts could be made at any point on the plates (14 cm x 17 cm). This test followed the same protocol than DVFTT, using the throwing hand to complete a cycle of 10 tapping trials (i.e. contacts on the vertical plate). Participants sat in front of the table, with their throwing shoulder in middle line of plate A and 30 cm from the edge of the tapping plate. This test assess how fast (in seconds) an individual move his/her finger from one plate to the other. Intra-session reliability for this test was explored (ICC = 0.87).

*Continuous Vertical Tapping Test with Ball (CVTTB)*

Participants performed a continuous movement grasping the ball, hitting plate A and B alternatively during 60 s "as fast as possible". Ball Contacts could be made at any point on the plates. The start position in this test was outside of the plate *A*, activating data logging with the first contact (in plate A) after the signal "Go!". Participants performed 10 s of familiarization before recording. The total number of contact cycles (i.e. touching plates A and B) is recorded (Figure 17). In this study, this test showed a high intra-session reliability (ICC = 0.88).

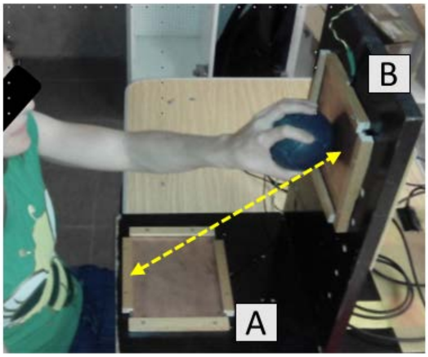


**Figure 17.** Discrete Vertical Tapping Test with Ball.

### 5.3.3. Data Acquisition

Performance in both MD tests (BBT and BBLT) was recorded using a timekeeper (Casio HS-30W-1V). In addition, a video camera (Sony HDR-PJ410B) was placed on a tripod (Hama Star 63) in front of the participants, for blocks and balls counting. To record the finger contacts on the plate surface (DHFTT and DHFTT) the participants wore a metallic thimble. Each contact with the plate surface closed an electric loop, sending a signal that was registered with an A/D converter (USB-6001, National Instruments, Austin, Texas, USA). In tapping tests involving boccia ball (DVTTB and CVTTB), two pressure plates were designed to register the ball contact in each movement. The contact in that plates produce an electric impulse registered with the A/D converter mentioned previously. Data from A/D converter were registered with a program developed within LabVIEW® 2009 software (version 2.04, National Instruments, Texas, USA). All participants had a period of familiarization with each tests before recording the real data.

### 5.3.4. Statistical Analysis

Descriptive results are presented as mean (M) and standard deviations (SD). The normal distribution of the coordination tests results was tested using the Kolmogorov-Smirnov test with the Lilliefors correction, and subsequently, statistical parametric techniques were carried out. The coefficient of variation (CV, in %) was calculated within groups using the following formula: CV = [(SD/M)*100] (Atkinson and Nevill, 1998). Interpretation of intra-class correlations (ICC) as reliability index included in previous sections was done according to Portney and Watkins (2008): ICC values > 0.90 were considered excellent, 0.75 – 0.90 good and < 0.75 as poor to moderate.

The relationships among different coordination tests performed by participants with CP were assessed using Pearson's product moment correlation (*r*). The following scale of magnitudes was used to evaluate correlation coefficients: < 0.1, trivial; 0.1 – 0.3, small; < 0.3 – 0.5, moderate; < 0.5 – 0.7, large; < 0.7 – 0.9, very large; and < 0.9 – 1.0, almost perfect (Hopkins, Marshall, Batterham, & Hanin, 2009).

A one-way analysis of variance (ANOVA) with least significant difference post hoc comparison (Tukey´s correction) was used to examine the mean differences between CP sub-groups (i.e. BC1 and BC2) and the CG. Practical significance was assessed by calculating Cohen's effect size. In addition, a repeated measures t-test was conducted to evaluate the next performance differences within groups: 1) MD tests (BBT vs BBLT), 2) discrete finger tapping tests (horizontal vs vertical), and 3) discrete vertical tapping tests (without vs with ball). Effect sizes (ES) of above 0.8, between 0.8 and 0.5, between 0.5 and 0.2 and lower than 0.2 were considered as large, moderate, small, and trivial, respectively (Cohen, 1988); and a correction by Hedges' *g* index ($d_g$) was used for the within-groups comparisons (Hedges and Olkin, 1985).

All the data analyses were performed using the Statistical Package for Social Sciences (SPSS Inc, version 24.0 for Windows, Chicago, IL, USA). Statistical significance was set at $p < 0.05$.

## 5.4. Results

A correlation analysis was conducted among tests (Table 8) in order to study if the new specific sport tests assessed the same coordination dimensions than the generic tests. A very large correlation was obtained among the two MD tests ($r$ = 0.80; $p < 0.01$), moderate-to-very large negative significant correlations of these tests with regards to the discrete tapping tests ($-0.35 < r < -0.80$), and a large positive correlation with the continuous tapping test with ball ($0.66 < r < 0.59$). A moderate negative significant correlation was also obtained among the two tapping test (continuous vs discrete) which required grasping a ball ($r = -0.43$), and large-to-very large positive significant correlations among the discrete coordination tests ($0.67 < r < 0.85$).

**Table 6.** Pearson's product moment correlation between coordination tests in participants with CP.

| | BBT | BBLT | CVTTB | DVTTB | DVFTT | DHFTT |
|---|---|---|---|---|---|---|
| **BBT** (N blocks) | -- | 0.802** | 0.656** | -0.802** | -0.350* | -0.488** |
| **BBLT** (N balls) | | | 0.593* | -0.694** | -0.418** | -0.495** |
| **CVTTB** (N contacts) | | | | -0.429* | -0.431* | -0.576** |
| **DVTTB** (s) | | | | | 0.852** | 0.752** |
| **DVFTT** (s) | | | | | | 0.669** |
| **DHFTT** (s) | | | | | | -- |

BBT = Box and Block Test; BBLT = Box and Ball Test; CVTTB = Continuous Vertical Tapping Test with Ball; DVTTB = Discrete Vertical Tapping Test with Ball; DVFTT = Discrete Vertical Finger Tapping Test; DHFTT = Discrete Horizontal Finger Tapping Test. * p < 0.05; ** p < 0.01.

Table 7 shows the performance scores by the two boccia players groups and the CG. Between-groups differences ($p < 0.001$) were obtained in all the coordination tests. The honestly significant difference (HSD) between groups was calculated by a Tukey´s post hoc analysis, and differences between the CG with respect to both groups of participants with CP ($p < 0.01$; $1.60 < d < 10.28$, large). Comparing between the two groups of boccia players, significant differences were also obtained in the two MD tests ($p < 0.01$; $0.93 < d < 1.13$, large) and in the continuous tapping test that required grasping a ball ($p < 0.01$; $d = 1.12$, large). However, no significant differences were obtained between the two groups of participants with CP in the three discrete finger and ball tapping tests ($0.41 < d < 0.55$, small-to-moderate).

**Table 7**. Performance scores by participants with CP (BC1 and BC2) and CG.

| Test | Group | N | M | ± | SD | CV (%) | F(*df*) | *p* | *d* (Tukey´s post-hoc differences) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | **BC1 – BC2** | **BC1 – CG** | **BC2 – CG** |
| **BBT** (N blocks) | BC1 | 33 | 19.29 | ± | 6.86 | 35.56 | 710.41 (2, 89) | < 0.001 | -0.93** | -10.28** | -7.21** |
| | BC2 | 40 | 27.12 | ± | 9.83 | 36.25 | | | | | |
| | GC | 19 | 86.16 | ± | 6.12 | 7.10 | | | | | |
| **BBLT** (N balls) | BC1 | 33 | 23.46 | ± | 11.36 | 48.42 | 601.37 (2, 89) | < 0.001 | -1.13** | -7.93** | -6.98** |
| | BC2 | 40 | 35.81 | ± | 10.51 | 29.35 | | | | | |
| | GC | 19 | 96.78 | ± | 6.48 | 6.70 | | | | | |
| **CVTTB** (N contacts) | BC1 | 10 | 28.60 | ± | 13.46 | 47.06 | 205.40 (2, 44) | < 0.001 | -1.12** | -8.46** | -6.40** |
| | BC2 | 18 | 44.90 | ± | 15.69 | 34.92 | | | | | |
| | GC | 19 | 129.33 | ± | 10.11 | 7.82 | | | | | |
| **DVTTB** (s) | BC1 | 10 | 1.21 | ± | 0.86 | 71.04 | 16.19 (2, 44) | < 0.001 | 0.50 | 1.60** | 2.00** |
| | BC2 | 18 | 0.87 | ± | 0.44 | 50.88 | | | | | |
| | GC | 19 | 0.24 | ± | 0.07 | 30.35 | | | | | |
| **DVFTT** (s) | BC1 | 33 | 0.98 | ± | 0.53 | 53.81 | 28.11 (2, 89) | < 0.001 | 0.41 | 1.90** | 2.62** |
| | BC2 | 40 | 0.80 | ± | 0.28 | 35.31 | | | | | |
| | GC | 19 | 0.27 | ± | 0.06 | 24.44 | | | | | |
| **DHFTT** (s) | BC1 | 33 | 1.05 | ± | 0.64 | 61.62 | 37.72 (2, 89) | < 0.001 | 0.55 | 1.76** | 3.07** |
| | BC2 | 40 | 0.78 | ± | 0.24 | 30.95 | | | | | |
| | GC | 19 | 0.24 | ± | 0.06 | 23.43 | | | | | |

BBT = Box and Block Test; BBLT = Box and Ball Test; CVTTB = Continuous Vertical Tapping Test with Ball; DVTTB = Discrete Vertical Tapping Test with Ball; DVTTF = Discrete Vertical Finger Tapping Test; DHTTF = Discrete Horizontal Finger Tapping Test; BC1/BC2 = participants with severe neurological impairments, Boccia classes; CG = control group; df = degrees of freedom; *d* = Effect size. ** $p < 0.01$

Table 8 shows the within-groups comparisons among MD tests (BBT vs BBLT), discrete tapping tests without ball (DHFTT vs DVFTT), and using or not a boccia ball during the discrete vertical tapping test (DVFTT vs DVTTB). Comparing the scores among the two MD test, the three groups passed a higher number of balls than blocks. In addition, bringing together the two boccia groups to compare the performance among the two discrete vertical tapping test (i.e. with and without grasping a boccia ball), a slower performance is observed when they grasp the ball [t(27) = 2.86; *p* = 0.009; *d* = 0.97, large].

**Table 8**. Within-groups pair comparisons in MD and ILC coordination tests.

| | BBT vs BBLT | | | DHFTT vs DVFTT | | | DVFTT vs DVTTB | | |
|---|---|---|---|---|---|---|---|---|---|
| | t | *p* | $d_g$ | t | *p* | $d_g$ | t | *p* | $d_g$ |
| **BC1** | -3.94 | < 0.001 | -0.59 | 1.16 | 0.259 | 0.11 | -2.22 | 0.062 | -0.42 |
| **BC2** | -7.97 | < 0.001 | -0.87 | -0.66 | 0.516 | -0.08 | -1.99 | 0.066 | -0.24 |
| **CG** | -10.72 | < 0.001 | -1.66 | -0.37 | 0.713 | -0.48 | -0.70 | 0.494 | 0.48 |

BBT = Box and Block Test; BBLT = Box and Ball Test; DVTTB = Discrete Vertical Tapping Test with Ball; DVTTF = Discrete Vertical Finger Tapping Test; DHTTF = Discrete Horizontal Finger Tapping Test; BC1/BC2 = participants with severe neurological impairments, Boccia classes; CG = control group; $d_g$ = effect size with Hedges´s correction.

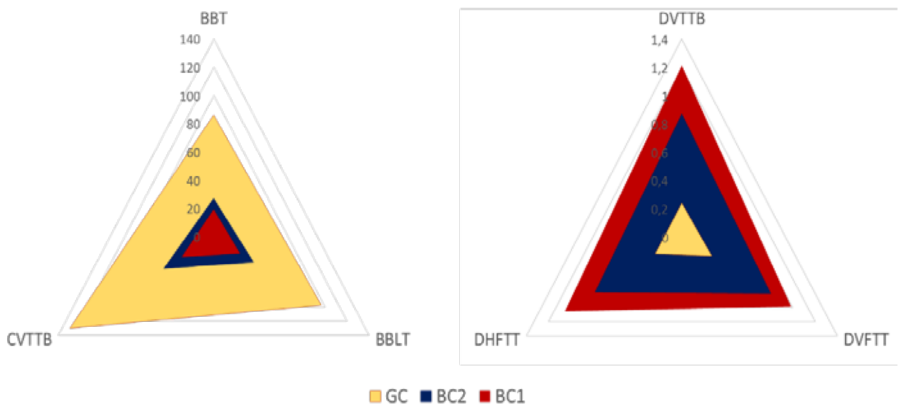


**Figure 18.** Spider graphs to describe the overall performance across the all coordination tests. BBT = Box and Block Test; BBLT = Box and Ball Test; DVTTB = Discrete Vertical Tapping Test with Ball; DVTTF = Discrete Vertical Finger Tapping Test; DHTTF = Discrete Horizontal Finger Tapping Test; BC1/BC2 = participants with severe neurological impairments, Boccia classes; CG = control group

## 5.5. Discussion

This study aimed to develop sport-specific coordination tests for boccia, comparing its concurrent validity with other generic coordination tests, in order to: i) discriminate between BC1 and BC2 sport classes, and ii) to quantify the level of impaired coordination that these players present compared to controls.

Significant correlations were obtained among all the coordination tests: very large for the MD tests and moderate-to-large for the ILC tests. These results supports the hypothesis that the new sport-specific coordination tests assess similar dimensions of impaired coordination than generic tests in individuals with CP, eligible for Boccia. The different magnitudes of the correlations across the coordination tests may indicate that the test protocol and its demands might constrain the participant's performance.

### 5.5.1. Manual Dexterity Tests

Our results demonstrated that boccia players present MD limitations in comparison to the CG. The MD tests were able to discriminate between individuals with different sport classes (BC1 vs BC2), presenting the BC1 players the worse performance scores. These results are in accordance to Golubovic et al. (2014), who carried out the BBT with children with different degrees of CP, showing that children with higher impairments (i.e. quadriplegia) transferred the smallest number of blocks compared to less affected children.

When comparing performance levels in the MD tests (see Table 7), it can be observed that all the groups obtained better performance scores in the BBLT than in the BBT (i.e. transporting higher number of balls than blocks). Considering the effect sizes between the two boccia classes, it is also plausible to think that the new BBLT has a higher discriminant capacity. Some specific features of the new sport-specific test might have influenced on participants´ proficiency. For example, the object size and the object shape were shown to influence on the type of grip used, and also in the kinematic features when children with CP transport any object (Utley, Steenbergen, & Sugden, 2004; Wright, Hunt, & Stanley, 2001). Extrapolating this information to the MD tests of this study, it is observed that the boccia balls presented a bigger size and a curve design, which sat better in the participants' hand. This lead in a more precise coordination of the hand muscles and, therefore, in a higher power grip (Enders, Engel, & Seo, 2010). Wright et al. (2001) found that children with hemiplegic CP needed more motor adjustments (i.e. slowness in flexing and overextension of the fingers) when manipulative task became more difficult (e.g. manipulation of a cylinder versus a triangle shape object). A second aspect to take into account is the grip objects' frictional surfaces. Some materials facilitate the coupling between hand/finger and object. In our case, blocks, with wood surface easily slipped from participants' fingers, requiring more precise fingertips coordination to perform the test (Cary et al., 2010). However, the leather surface of the boccia balls improved players handgrip function, increasing the hand-object frictional coupling (Seo and Amstrong, 2008). So, the BBLT demands a more realistic grasp ability by the players due the size and specificity of the object.

It is important to mention that all players in this study were able to grasp a ball and throw it with direction and intention (BISFed, 2017), being a main criteria to be eligible as hand player in Boccia.

### 5.5.2. Intra-Limb Coordination

Discrete tasks are understood as actions that require a single response with a clear beginning and ending, while continuous tasks are understood as reciprocal actions with no recognizable beginning and end, which flows on for a specific period (Everitt, Fletcher, & Caird-Daley, 2015). Furthermore, each type of task presents different kinematic features (Huys, Jirsa, Studenka, Rheaume, & Zelaznik, 2008) that should consider during arm coordination assessment.

Our results demonstrated that boccia players tend to present ILC limitations in comparison to individuals without CP. Significant differences were found within the battery of tapping tests between the CP and the CG. The CG showed better performance than boccia players, presenting shorter movement times in the discrete tapping tests (DVFTT, DHFTT and DVTTB) and higher rate (i.e. number of contacts) in the continuous tapping test (CVTTB). On the other hand, boccia players presented worse performance due to typical muscle weakness, impaired voluntary muscle activation and problems regarding muscles co-activation, as it have been found in similar studies with children with CP (Huang, Pan, Ou, Yu, & Tsai, 2014; Steenbergen and Meulenbroek, 2006).

Comparing between sport classes, BC1 players showed an overall worse performance in all the coordination tests (Table 7). However, only the continuous tapping test handling a boccia ball was able to discriminate between sport classes ($d$ = 1.12). Given the motor characteristics of a throw, discrete tasks were expected to be more sensitive to discriminate between sport classes, but no statistically significance was found. However, effect sizes of the three discrete tasks (DVFTT, DHFTT and DVTTB) were moderate ($0.41 < d < 0.55$), indicating some practical differences. These results can be explained by a potential ceiling effect on the discrete tasks due to the simplicity nature of the tasks. Discrete tests usually require less motor control, adjustments and movement planning to perform more controlled and accurate movements (Everitt et al., 2015). In these tasks, boccia players were able to self-regulate, accordingly to their impairment level, choosing the most optimal pacing to perform the tasks as fast as possible. Therefore, not presenting a great challenge for boccia players can explain why discrete tasks were not sensitive to discriminate between sport classes. Lajoie et al. (2017) got similar results working with elderly, not finding significant differences when participants performed the simple discrete conditions compared to other tasks that required a greater cognitive engagement (i.e. more difficult).

The continuous test was a major challenge for the boccia players, as it required more motor control, movement planning and sensory information processing to perform it (Kukke, de Campos, Alter, Hallett, & Damiano, 2016). An altered muscle tone and muscle co-activation is a typical feature in players with hypertonia, especially in antigravity muscles (Tedroff, Knutson, & Soderberg, 2008). This impairment could cause a worse performance, decreasing players' movement efficiency (Xu, Mai, He, Yan, & Chen, 2015), reducing movements' velocity (Sanger, 2003) and hindering continuous elbow flexo-extension movements. On the other hand, players with severe dyskinetic or ataxic profiles may present uncontrollably muscle contractions, tending to activate the antagonist muscles before the agonist (Sanger et al., 2010). Therefore, when they tried to perform the continuous test with abnormal force, pacing and accuracy, it is required more time to complete the coordination task. Similar results were found in young individuals with dystonic CP, who showed abnormal timing and coordination during functional arm movements with affecting the upper extremity (Kukke et al., 2016). Thus, it was expected that most severe players present worse timing scores, as BC1 players showed.

Another aspect to consider in the continuous tasks was the use of the implement (i.e. boccia ball). Therapists has repeatedly shown that the use of added-purpose activity enhance motor performance in comparison with isolate and repetitive exercise (Duncan et al., 2011). Handling an implement (i.e. a boccia ball) may increase the task difficulty, demanding several actions at the same time: grasping and transporting the ball to aim the target. The challenge is more complex still if one considers the hand and arm coordination problems present by individuals with CP. This idea is supported by the large effect size presented by the CVTTB (*d* = -1.12). Grabbing a ball while performing reaching movements might cause, due a diminished selective motor control, an increase of hand and arm muscle tone (Wagner, Davids, & Hardin, 2015).

However, these results must be interpreted with caution, because BC1 players have a large coefficient of variation (53.81 < CV < 71.04), indicating that this group present a huge heterogeneous proficiency. In any case, continuous tasks seem to be more relevant to assess impaired coordination in individuals with eligible impairments for Boccia. However, future studies should address how much impaired coordination determines boccia performance.

# Chapter VI



# Conclusions, Limitations and Future Research

# 6. CONCLUSIONS, LIMITATIONS, FUTURE RESEARCH

Little is known about what are the factors that determine Boccia performance, and scarce is the information about classification based on scientific evidence in this Para sport. The overall purpose of this dissertation was: i) to explore how much trunk control and upper limbs are impaired in boccia players; ii) to perform a critical analysis of some current assessment methods in order to know if they match with the standards provided by the International Paralympic Committee (IPC, 2015b; Tweedy and Vanlandewijck, 2011); and iii) to develop specific tests to assess upper limb coordination, with the aim of studying their potential use for evidence-based classification in Boccia.

## 6.1. Trunk Control Function in Adults with Cerebral Palsy.

Having poor trunk function has been suggested to be a common characteristic in people with CP, leading in serious difficulties to cope with activities of daily living, such as sitting or walking. The first study had two focus of interest: the population involved and the methodology implemented. Although CP is a lifelong disability, current evidence has been mainly focused on children with CP, but little is known in adults with moderate-to-severe CP.

### 6.1.1. Conclusions of the Study 1

- Posturography is a reliable tool to evaluate the trunk function in individuals with moderate-to-severe CP.
- Adults with CP present a deterioration of the motor function due to musculoskeletal problems, limiting certain actions that require complex and dynamic movements.
- Dynamic tasks present a major motor challenge for this group of individuals and, therefore, it is recommended to consider for trunk function assessment.

- There were significant differences in the static conditions for the CG, but no for the CP individuals.
- None participants showed performance differences in the medial-lateral and anterior-posterior movements.

#### 6.1.2. Limitations of the Study 1

- Many individuals in this study were not able to perform the unstable conditions, lacking the opportunity to delve into how an unstable surface may constrain TC in individuals with severe-to-moderate CP.
- The unstable conditions were performed just after the stable tasks. This could lead to develop more fatigue in those players who were able to perform the whole protocol (stable → unstable conditions).

### 6.2. Trunk Control in Boccia Players and its Implications for Classification.

BC1 and BC2 boccia players usually present deficits in trunk control, which may be considered as a key performance aspect in this Para sport. However, the way that TC is currently assessed in Boccia has never been studied and none scientific data is available yet.

#### 6.2.1. Conclusions of the Study 2

- This study highlighted the limitations of the current boccia assessment method to assess trunk control (i.e. discriminating among impairment levels, allocated in BC1 and BC2 sport classes) in players with moderate-to-severe neurological impairments.
- Posturography has proven to be a valid method to assess trunk function (Study I), discriminating here among current classification boccia profiles for individual with severe-to-moderate CP belonging to BC1 and BC2 classes.

- Static tasks seem to discriminate better between sport classes, while dynamic ones did not.

#### 6.2.2. Limitations of the Study 2

- Converting the boccia trunk assessment scores into an ad hoc ordinal scale.
- Some of the players were assessed in their own wheelchairs as their impairment severity impeded them to sit on a bench without external aids.

### 6.3. Manual Dexterity and Intra-Limb Coordination in Boccia Players with Moderate-to-Severe Impairments and its Implications for Classification.

Cerebral Palsy may influence the hand and arm components, such as muscles, joints and bones, limiting the performance of manual activities such as grasping, releasing or manipulating objects. The ability to execute those essential tasks or actions is crucial to play Boccia. However, there are currently not specific methods available to assess hand/arm coordination in boccia players.

#### 6.3.1. Conclusions of the Study 3

- The battery of tests presented in this third study seems to be feasible to assess impaired coordination in adults with moderate-to-severe CP, eligible for Boccia.
- It is important to consider aspects regarding upper limb movements or the features of the handled objects, for the design of sport-specific tests.
- Tests that demands two or more actions at the same time seem to discriminate better among individuals with moderate-to-severe CP.

#### 6.3.2. Limitations of the Study 3

- It would have been pertinent to carry out a reliability study with this population (i.e. inter-sessions assessments).

- Due to players' impairment severity, some participants performed some coordination tests in their own wheelchairs and, therefore, it was not possible to fully normalize the players' position regarding the testing protocol.
- It might be interesting to include a vertical continuous tapping test without ball, comparing the performance with regards to the test conducted handling a boccia ball (CVTTB).
- There was a difference in the number of individuals who performed phases one and two of this particular study.

## 6.4. General Limitations

- Participants´ heterogeneity was evident in some features such as age, level of competition or GMFCS.
- Limited player's availability for testing (i.e. transport needs and personal supports).
- A lot of measurement equipment and research staff was required for data collection, being not possible to involve the same researchers during all the testing sessions.
- Some of the testing sessions exceed the expected time (i.e. equipment calibration, room conditions, athlete's understanding, etc.)

## 6.5. Future Research

- To explore the strength of the relationships between trunk and the upper limbs function in boccia performance such as precision and distance outcomes. Reina, Dominguez, Urban, and Roldán (forthcoming publication) demonstrated that accuracy decreases when players need to accomplish certain areas of the boccia court, especially those closer to the end line, due to their impairment severity.

- To implement field test to evaluate TC using other technologies (i.e. smartphone apps, accelerometers), evaluating its validity and reliability.
- It would be interesting to carry out the specific coordination tests using balls with different hardness.
- It would be important to group boccia players according to their eligible impairment (i.e. dyskinesia or ataxia or spasticity), as the BISFed Classification Rulebook does. With a larger and more homogenous sample it might be possible to understand the interaction between the type of impairment and the sport proficiency.
- To assess players' hand function through other scales such as the Manual Ability Classification System (MACS) (e.g. Shi et al., 2015).
- The Gross Motor Function Classification Scale is only validated until the age of 18.
- Use other mathematical analysis to determine the weight of each of the factors evaluated in this study (i.e. trunk, arm and hand function) on the performance to take into consideration when classifying. Having valid methods to assess eligible impairments and sport-specific tests, the last step should be to build Boccia sport classes according their levels of functionality and its influence on Boccia performance (i.e. Clusters analysis, decision trees, etc.)

# Chapter VII



# Conclusiones, Limitaciones y Prospectivas de Investigación

# 7. CONCLUSIONES, LIMITACIONES Y PROSPECTIVAS DE INVESTIGACIÓN

Poco se sabe acerca de cuáles son los factores que determinan el rendimiento en Boccia, además de la poca literatura disponible sobre la clasificación basada en evidencia científica en este paradeporte. El propósito general de esta tesis ha sido: i) explorar en qué medida están afectados el control del tronco y la coordinación del brazo de lanzamiento en jugadores de Boccia; ii) realizar un análisis crítico sobre algunos de los métodos actuales de evaluación en Boccia, analizando si éstos se ajustan a los estándares proporcionados por el Comité Paralímpico Internacional (IPC, 2015b, Tweedy y Vanlandewijck, 2011); y iii) desarrollar test específicos del deporte para evaluar la coordinación del brazo de lanzamiento, con el objetivo de estudiar el potencial de estos test para con una clasificación basada en evidencias en Boccia.

## 7.1. Función del control del tronco en adultos con Parálisis Cerebral.

Una limitación funcional del tronco se ha sugerido como una característica común en personas con parálisis cerebral (PC), conllevando serias dificultades a la hora de realizar actividades básicas de la vida diaria. Aunque la PC es una discapacidad permanente, la mayor parte de la evidencia disponible se ha centrado en estudiar principalmente a niños con PC, por lo que se conoce muy poco acerca de los adultos con PC moderadas a severas. Así, el primer estudio de esta tesis doctoral tuvo dos aspectos de interés: la población involucrada y la metodología implementada para la evaluación de su control postural.

### 7.1.1. Conclusiones del Estudio 1

- Se ha demostrado que la posturografía puede ser una herramienta válida para evaluar la función del tronco en individuos con PC moderada a severa.

- Debido al deterioro funcional de los músculos del tronco, los adultos con PC presentan ciertas limitaciones cuando necesitan realizar movimientos más complejos y dinámicos.
- Se ha demostrado que las tareas dinámicas representan un mayor desafío motor para este colectivo, recomendándose su uso para la evaluación de la función del tronco.
- El grupo control presentó diferencias significativas entre las dos tareas realizadas en condiciones estáticas, mientras que el grupo de personas con PC no las presentó.
- Ninguno de los grupos de este estudio mostró diferencias significativas entre las dos tareas dinámicas que requerían movimientos medio-laterales y antero-posteriores.

### 7.1.2. Limitaciones del Estudio 1

- Un gran porcentaje de los participantes con PC de este estudio no fueron capaces de realizar las condiciones inestables del protocolo de posturografía, por lo que no pudo ser posible realizar un estudio en mayor profundidad sobre cómo una superficie inestable puede influir en el control del tronco en individuos con PC severa a moderada.
- Las tareas sobre el asiento inestable se realizaron justo después de las estables. Esto pudo haber conllevado a los participantes con PC a desarrollar más fatiga, especialmente en aquellos que fueron capaces de completar todo el protocolo (estable → condiciones inestables).

## 7.2. El control del tronco en jugadores de Boccia y sus implicaciones para la clasificación.

Los jugadores de Boccia pertenecientes a las clases deportivas BC1 y BC2 suelen presentar un gran déficit de control postural, el cual puede ser considerado como un aspecto clave para el rendimiento en este paradeporte. Sin embargo, el proceso por el cual se evalúa el control postural en jugadores de Boccia no ha sido estudiado hasta la fecha, siendo muy escasos los datos científicos disponibles.

### 7.2.1. Conclusiones del Estudio 2

- Se destacan las limitaciones del método de evaluación de tronco que se utiliza actualmente en Boccia (i.e. la capacidad de dicho método para discriminar entre diferentes perfiles funcionales consignados a las clases deportivas BC1 y BC2) en jugadores con impedimentos neurológicos de moderados a severos.
- La posturografía ha demostrado ser un método válido para evaluar la función del tronco (ver Estudio I), siendo capaz de discriminar entre dos clases deportivas de boccia para individuos con PC de moderada a severa.
- Las tareas estáticas, a diferencia de las dinámicas, parecen tener capacidad para poder discriminar entre ambas clases deportivas.

### 7.2.2. Limitaciones del Estudio 2

- La conversión *ad hoc* del sistema de puntuación del método actual de la evaluación del tronco en Boccia a una escala ordinal.
- Un porcentaje pequeño de participantes de este estudio tuvo que ser evaluado en sus propias sillas de ruedas, ya que la gran afectación que presentaban les impedía sentarse en un banco sin ayuda externa.

## 7.3. Destreza Manual y Coordinación entre Segmentos en Jugadores de Boccia con Impedimentos de Moderados a Severos. Implicaciones para la Clasificación.

La Parálisis Cerebral puede afectar a funciones y estructuras de la mano y el brazo, tales como los músculos, las articulaciones y los huesos, limitando así el desempeño de ciertas actividades de la vida diaria como agarrar, soltar o manipular un objeto. La capacidad de poder realizar las tareas previamente mencionadas es fundamental para poder jugar a Boccia. Sin embargo, actualmente no se dispone de métodos específicos para poder evaluar la coordinación manual y de los miembros superiores en jugadores de Boccia.

### 7.3.1. Conclusiones del Estudio 3

- La batería de tests presentada en este tercer estudio parece ser factible para evaluar la coordinación los adultos con CP de moderada a severa, elegibles para jugar a la Boccia.
- Se ha observado que a la hora de diseñar un test de coordinación específico para este Para deporte, es importante considerar el tipo de movimiento que las extremidades superiores deben realizar, así como el tipo de objeto a manipular.
- Las pruebas que requieren realizar de dos o más acciones al mismo tiempo, parecen discriminar mejor entre los individuos con CP de moderada a severa.

### 7.3.2. Limitaciones del Estudio 3

- Habría sido pertinente llevar a cabo un estudio de fiabilidad (evaluación entre-sesiones) con esta población.
- Debido a las grandes afectaciones presentadas por algunos de los participantes de este estudio, éstos tuvieron que realizar ciertas pruebas de coordinación en

sus propias sillas de ruedas, por lo que no fue posible estandarizar la posición de dichos jugadores con respecto al protocolo de prueba.

- Podría ser interesante incluir una prueba de golpeo vertical continuo sin bola, para comparar el rendimiento de dicho test con respecto a la prueba llevada a cabo en este estudio en la que se implementaba el manejando una bola de boccia (CVTTB).
- La diferencia de participantes que hubo entre la fase uno y la fase dos del estudio es una clara limitación.

## 7.4. Limitaciones Generales

- La heterogeneidad de la muestra fue evidente en algunas de sus características, tales como la edad, el nivel de competición o su clasificación funcional según la GMFCS.
- La limitada disponibilidad de la muestra a la hora de participar en nuestro estudio, debido a factores como las necesidades especiales de transporte y apoyos de personal externo.
- Este trabajo requirió de un material y un equipo de trabajo muy numeroso para poder realizar la toma de datos. Este hecho conllevó a tener que contar con algunos investigadores diferentes entre la fase uno y dos de la toma de datos.
- El exceso de tiempo que conllevaron algunas de las tomas de datos para/debido, por ejemplo, la calibración del equipo, las condiciones de la sala, la comprensión del atleta, etc.

## 7.5. Prospectivas de Investigación

- Explorar la relación entre la función del tronco y la coordinación de los miembros superiores con respecto al rendimiento en Boccia en aspectos tales como la precisión y el lanzamiento a distancia. Reina, Domínguez, Urbán y Roldán (próxima publicación) demostraron que la precisión disminuye cuando los jugadores necesitan alcanzar determinadas áreas en el campo de Boccia, especialmente las distancias más próximas a la línea de fondo debido a la severidad del impedimento.

- Implementar pruebas/test de campo para evaluar el control del tronco utilizando otras tecnologías (e.g. aplicaciones móviles, acelerómetros), evaluando además su validez y fiabilidad.
- Sería interesante realizar las pruebas de coordinación específicas utilizando bolas con diferente dureza.
- Sería importante agrupar a los jugadores de Boccia en función de su impedimento elegible (e.g. discinesia, ataxia y/o espasticidad), tal y como hace el Reglamento de Clasificación de BISFed. Con una muestra más grande y más homogénea quizás sería posible entender la interacción entre el tipo de discapacidad y el rendimiento deportivo.
- Evaluar la función de la mano de los jugadores de Boccia a través de otras escalas estandarizadas como podría ser la *Manual Ability Classification System* (e.g. Shi et al., 2015).
- La escala *Gross Motor Function Classification* sólo es válida hasta la edad de 18 años.
- Utilizar análisis matemáticos avanzados para determinar qué peso tiene de cada uno de los factores evaluados en este estudio (e.g. el tronco, el brazo y la mano) con respecto al rendimiento, teniéndoles por tanto en cuenta a la hora de clasificar. Contar con métodos válidos para evaluar los impedimentos elegibles y test específicos del paradeporte permitirá, en última instancia, configurar clases deportivas de Boccia según niveles de funcionalidad y su impacto en el rendimiento de Boccia (e.g. análisis de clusters, árboles de decisión, etc.)

# Chapter VII

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