UNIVERSIDADE DO PORTO
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CENTRO DE INVESTIGAÇÃO FORMAÇÃO INOVAÇÃO E INTERVENÇÃO EM DESPORTO
CIFI2D

Profiling world-class athletes with Cerebral Palsy: Health and performance related-variables

Supervisor

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Porto, 2025

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Academic thesis submitted with the purpose of obtaining a doctoral degree in Sport Sciences, organized by the Centre of Research, Education, Innovation and Intervention in Sport (CIFI$_2$D), Faculty of Sport, University of Porto, according to the Decree-Law 65/2018 of March 16th.

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PALAVRAS-CHAVE: PARALISIA CEREBRAL, NATAÇÃO ADAPTADA, BOCCIA, PERFIL FÍSICO.

Para a minha afilhada
Bárbara, uma recorda-
ção da madrinha
Adoro-te !!!
Né

“Estou cansado, é claro,
Porque, a certa altura, a gente tem que estar cansado.
De que estou cansado, não sei:
De nada me serviria sabê-lo,
Pois o cansaço fica na mesma.
A ferida dói como dói
E não em função da causa que a produziu.
Sim, estou cansado,
E um pouco sorridente
De o cansaço ser só isto —
Uma vontade de sono no corpo,
Um desejo de não pensar na alma,
E por cima de tudo uma transparência lúcida
Do entendimento retrospectivo...

E a luxúria única de não ter já esperanças?
Sou inteligente: eis tudo.
Tenho visto muito e entendido muito o que tenho visto,
E há um certo prazer até no cansaço que isto me dá,
Que afinal a cabeça sempre serve para qualquer coisa.”

Álvaro de Campos

Poesias de Álvaro de Campos. Fernando Pessoa. Lisboa: Ática, 1944 (imp. 1993). P.78

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Abstract

This thesis intended to draw the physical profile of world-class athletes with Cerebral Palsy (CP) characterizing health and performance related-variables interfering in sports performance. Specifically, Study 1 aimed (1) to describe the anthropometric characteristics and somatotype of world-class para swimmers with spastic CP and (2) to analyze the associations between anthropometric characteristics, training and competition time, walking ability and sports' classification; Study 2 aimed (1) to characterize upper body strength and ROM of world-class para swimmers with spastic CP; (2) to compare strength and ROM across different sports classes; and (3) to investigate the associations between strength, ROM and locomotion type; Study 3 aimed (1) to provide a descriptive analysis of body composition and bone health, including fat mass, lean mass and Bone Mineral Density (BMD) among a group of world-class boccia players with CP using Dual-Energy X-Ray Scan (DXA), (2) to identify health-related risk factors such as underweight or obesity, sarcopenia and osteoporosis and (3) to explore strategies to optimize sports participation and health maintenance in players with CP; Study 4 aimed (1) to characterize the kinematic parameters involved in the throwing motion, such as upper body angles, angular velocity of joint movements in the same angles and throwing velocity of different types of boccia throws performed by world-class boccia players with CP and (2) to analyze the associations between the different kinematic parameters and sports-related variables. Two groups of athletes participated in the data collection, namely a group of world-class para swimmers (n=16, 6 females and 10 males aged between 17 and 30 years old) competing during the World Para Swimming Championship, and boccia players (n=5, 2 females and 3 males aged between 15 and 42 years old) from the Portuguese national team. All participants completed a sociodemographic questionnaire with personal, clinical and sports-related information. The assessments of para swimmers included: anthropometric measures, namely skinfolds, girths, bone breadths and somatotypes; strength using a 2kg medicine ball (MB) throw, and ROM of the shoulder, elbow and wrist using goniometry. The assessments of boccia players included: body composition, namely total fat mass, total body% fat, total lean mass, appendicular lean mass, BMD and content (BMC) for radius, lumbar spine and whole body using DXA. Also, kinematic analysis were made to the throwing technique in underarm (UA) and overarm (OA) throw. Results showed: in Study 1 (1) the total

sample of para swimmers was classified as "Ectomorph-Endomorph", with predominance of “Endomorph-Ectomorph”; (2) no associations were found between anthropometric variables, training and competition time and sports’ classification and a strong association was reported between the sum of skinfolds and the use of electric wheelchair and sports classification; in Study 2 (1) MB throwing distance increased with the functional classes and S5 para swimmers presented the worst results of ROM; (2) shoulder and elbow flexion showed a significant positive correlation with MB throwing distance; (3) comparing ROM and MB throwing distance according to locomotion type, significant differences were observed only in MB throwing distance; in Study 3 (1) 60% of the boccia players were categorized in obesity class I and 40% presented normal fat levels; (2) 66.7% may be at risk for sarcopenia; 60% exhibited BMD levels below the expected range for age and; in Study 4 (1) UA presented a higher flexion in the thorax, a lower flexion, abduction and internal rotation of the shoulder and a lower elbow extension than OA; (2) UA showed higher angular velocities and velocity than UA; (3) higher frequency of strength and conditioning (S&C) training was associated to a higher magnitude of the ball throw velocity of the UA and a higher frequency of specific and S&C training was associated to a higher magnitude of the velocity and higher shoulder angle on the Y axis of the OA. This thesis intended to offer valuable insights for multidisciplinary teams concerning anthropometry, strength and ROM of para swimmers, and body composition, bone health and kinematics parameters of throwing technique of boccia players.

Resumo

Esta tese teve como objetivo traçar o perfil físico de atletas de elite com Paralisia Cerebral (PC), caracterizando variáveis relacionadas com a saúde e o desempenho que interferem na performance desportiva. Especificamente, o Estudo 1 teve como objetivos: (1) descrever as características antropométricas e o somatótipo de nadadores de elite de natação adaptada com PC espástica e (2) analisar as associações entre características antropométricas, tempo de treino e competição, capacidade de marcha e classificação desportiva. O Estudo 2 teve como objetivos: (1) caracterizar a força do tronco superior e a amplitude de movimento (ROM) de nadadores de elite de natação adaptada com PC espástica; (2) comparar a força e a ROM entre diferentes classes desportivas; e (3) investigar as associações entre força, ROM e tipo de locomoção. O Estudo 3 teve como objetivos: (1) fornecer uma análise descritiva da composição corporal e da saúde óssea, incluindo massa gorda, massa magra e densidade mineral óssea (BMD) num grupo de jogadores de boccia de elite com PC através do DXA; (2) identificar fatores de risco para a saúde, tais como baixo peso ou obesidade, sarcopenia e osteoporose; e (3) explorar estratégias para otimizar a participação desportiva e a manutenção da saúde nos jogadores com PC. O Estudo 4 teve como objetivos: (1) caracterizar os parâmetros cinemáticos envolvidos no movimento de lançamento, tais como ângulos do tronco superior, velocidade angular dos movimentos articulares nos mesmos ângulos e velocidade de lançamento de diferentes tipos de lançamentos em boccia realizados por jogadores de elite com PC; e (2) analisar as associações entre os diferentes parâmetros cinemáticos e variáveis relacionadas com o desporto. Dois grupos de atletas participaram na recolha de dados, nomeadamente um grupo de nadadores de elite de natação adaptada (n=16, 6 mulheres e 10 homens, com idades entre 17 e 30 anos) a competir no Campeonato do Mundo de natação adaptada, e jogadores de boccia (n=5, 2 mulheres e 3 homens, com idades entre 15 e 42 anos) da seleção nacional portuguesa. Todos os participantes preencheram um questionário sociodemográfico com informações pessoais, clínicas e desportivas. As avaliações dos nadadores paralímpicos incluíram: medidas antropométricas, nomeadamente pregas cutâneas, perímetros, perímetros ósseos, diâmetros e somatótipo; força, avaliada através do lançamento de uma bola medicinal (MB) de 2kg; e ROM do ombro, cotovelo e punho, utilizando goniometria. As avaliações dos jogadores de boccia incluíram: composição corporal,

nomeadamente massa gorda total, percentagem de gordura corporal total, massa magra total, massa magra apendicular, BMD e conteúdo mineral ósseo (BMC) do rádio, coluna lombar e corpo inteiro, utilizando DXA. Além disso, foi realizada uma análise cinemática da técnica de lançamento, incluindo lançamentos por baixo (UA) e por cima (OA). Os resultados mostraram que no Estudo 1 (1) a amostra total de nadadores de elite de natação adaptada foi classificada como "Ectomorfo-Endomorfo", com predominância de "Endomorfo-Ectomorfo"; (2) não foram encontradas associações entre variáveis antropométricas, tempo de treino e competição e classificação desportiva, mas foi reportada uma forte associação entre a soma das pregas cutâneas e o uso de cadeira de rodas elétrica e a classificação desportiva; no Estudo 2 (1) a distância de lançamento da MB aumentou com as classes funcionais, sendo que os nadadores da classe S5 apresentaram os piores resultados de ROM; (2) a flexão do ombro e do cotovelo mostrou uma correlação positiva significativa com a distância do lançamento da MB; (3) comparando ROM e a distância do lançamento da MB de acordo com o tipo de locomoção, foram observadas diferenças significativas apenas na distância do lançamento da MB; no Estudo 3 (1) 60% dos jogadores de boccia foram categorizados na classe I de obesidade e 40% apresentaram níveis normais de gordura; (2) 66,7% podem estar em risco de sarcopenia; (3) 60% apresentaram níveis de BMD abaixo do esperado para a idade; no Estudo 4 (1) o UA apresentou maior flexão do tronco, menor flexão, abdução e rotação interna do ombro e menor extensão do cotovelo do que o OA; (2) o UA apresentou maiores velocidades angulares e velocidade de lançamento do que o OA; (3) uma maior frequência de treino de força e condição física (S&C) foi associada a uma maior magnitude da velocidade de lançamento da bola no UA, e uma maior frequência de treino específico e de S&C foi associada a uma maior magnitude da velocidade e maior ângulo do ombro no eixo Y no OA. Esta tese pretendeu oferecer contributos valiosos para equipas multidisciplinares no que respeita à antropometria, força e ROM dos nadadores paralímpicos, bem como à composição corporal, saúde óssea e parâmetros cinemáticos da técnica de lançamento dos jogadores de boccia.

List of abbreviations

AHSN	Athlete with high support needs
ALM	Appendicular lean mass
ALMI	Appendicular lean mass index
BMC	Bone mineral content
BMD	Bone mineral density
BMI	Body mass index
BR	Ball release
cm	Centimetres
CP	Cerebral Palsy
CVD	Cardiovascular disease
DXA	Dual X-ray Absorptiometry
e.g.	Example given
FM	Fat mass
FMI	Fat mass index
g	Grams
GMFCS	Gross Motor Function Classification System
HWR	Height-weight ratio
Hz	Heartz
kg	Kilograms
m	Meters
min	Minutes
OA	Overarm throw
OSO	Osteosarcopenic obesity
PCAND	Paralisia Cerebral – Associação Nacional de Desporto
PI	Ponderal index
r	Person’s correlation coefficient
rad	Radians
ROM	Range of motion
s	Seconds
SCPE	Surveillance of Cerebral Palsy in Europe
S&C	Strength and Conditioning
UA	Underarm throw

WPS	World Para Swimming

CHAPTER I

GENERAL INTRODUCTION

The present thesis will focus on world-class athletes with Cerebral Palsy (CP) engaged in para swimming and boccia, and the variables influencing health and performance. Athletes with CP face unique challenges in sports technique due to motor disorders that affect coordination, balance, and precision of movement (Graham et al., 2016). Additionally, secondary complications associated with CP, such as hypertonia joint deformities (Nahm et al., 2018) may contribute to health-related issues, further impacting their sports performance and overall well-being. Para swimming and boccia are Paralympic sports approached in this dissertation because they hold significant historical importance for the Paralympic movement in Portugal, ranking among the top three Paralympic sports in terms of medals won by Portuguese athletes between 1972 and 2024. The Portuguese boccia national team won 27 Paralympic medals, while para swimming won 10 Paralympic medals (Comité Paralímpico de Portugal, 2024), highlighting the historical and contemporary success of these sports. Portugal is widely known as a global leader in boccia, not only because of the exceptional achievements of the Portuguese athletes but also because of the contributions of highly qualified coaches and coaches educators, international classifiers and referees, and also approved equipment suppliers that act worldwide to the development of the sport. Para swimming has also demonstrated a consistent growth and success on the international stage, further establish the significance of this sport in Portugal.

Despite the relevance of both above mentioned sports, there is a significant lack of scientific studies focusing on para swimming and boccia, at national and international levels, particularly with focus on the upper body. Firstly, analyzing CP in general, a systematic review of the literature on the scales and methods most often used for the evaluation of upper limb function in people with CP only found 9 studies (Santos et al., 2015). Conversely, States et al. (2021) found 909 studies investigating instrumented gait analysis, in a scoping review to describe and categorize the range of existing literature about instrumented gait analysis. Particularly concerning sports, in swimming, upper limbs contribute with 70% of the generated propulsion (Morouço et al., 2015). Similarly, upper limbs function is one of the key-performance indicators for boccia players (Boccia Canada, n.d.). Therefore, due to the lack of studies concerning upper body in people with

CP, it is important to increase research with this focus. And, considering the relevance of para swimming and boccia in the Paralympic movement, at both national and international level, research with world-class athletes gains even more importance.

Therefore, it is important to conduct research that explores physical variables that may influence health and performance of world-class athletes with CP. The present thesis aims to fill existing gaps in the scientific literature and to contribute to improvements of evidence-based practices in training, monitoring, and competition for world-class athletes with CP, supporting coaches and multidisciplinary teams working at world-class level. This general introduction will provide an update literature review about the most important theoretical concepts underpinning the different empirical studies. Specifically, the following topics related with CP will be approached: definition of CP, aetiology, classification and prevalence. Also, a brief contextualization of para swimming and boccia will be presented. The different variables related with sport performance and health will also be conceptualized. Lastly this section will include the thesis objectives and research design.

1. Cerebral Palsy

1.1 Definition, aetiology, classification and prevalence

Cerebral Palsy, originally defined as cerebral paresis, was first described by an English orthopaedic surgeon named William Little in one of a series of lectures in 1843 designated *Deformities of the Human Frame* (Rosenbaum et al., 2006). Dr. William Little reported that long-standing spasticity and paralysis, resulting from brain damage during infancy, in particular preterm birth and perinatal asphyxia, caused joint contractures and deformities (Rosenbaum et al., 2006). Over time, the definition of CP evolved, and a group of international experts updated the definition to “CP describes 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. The motor disorders of CP are often accompanied by disturbances of sensation, perception, cognition, communication, and behaviour, epilepsy, and secondary musculoskeletal problems” (Rosenbaum et al., 2006, pg.9).

Regarding the aetiology of CP, the most common factors are premature birth and difficulties during birth with neonatal asphyxia (or oxygen deprivation) (Graham et al., 2016b). McIntyre et al. (2013) listed risk factors linked with CP in children born at term, namely: placental dysfunction or abnormalities, major and minor birth defects and low birthweight (concerning prenatal risk factors); meconium aspiration (intrapartum risk factor), caesarean section, vacuum, breech; birth asphyxia; neonatal seizures (neonatal risk factor); respiratory distress syndrome; hypoglycaemia and infections including meningitis and sepsis. However, CP may be diagnosed until 5 years of age, being called post-natal CP (Paul et al., 2022).

There are different types of CP defined according to body areas affected and/or by type of muscular involvement. In terms of body areas, it can be classified as monoplegia (one limb affected), hemiplegia (one side of the body affected), quadriplegia (affecting all four limbs), and diplegia (predominantly involving both legs) (Paul et al., 2022).

The classification according to type of muscular involvement is related to the location of the brain injury (Figure 1) and the definitions adopted (Paul et al., 2022) are:

- Spastic: characterized by abnormal pattern of posture and/or movement, increased tone (not necessarily constant), pathological reflexes (increased reflexes: hyperreflexia and/or pyramidal signs e.g., Babinski response). This type of CP is due to injury in the motor cortex (Cerebral Palsy Alliance Research Foundation, n.d.).
- Ataxic CP: characterized by abnormal pattern of posture and/or movement, Loss of orderly muscular coordination so that movements are performed with abnormal force, rhythm, and accuracy. This type of CP is due to injury in the cerebellum (Cerebral Palsy Alliance Research Foundation, n.d.)
- Dyskinetic CP: characterized by abnormal pattern of posture and/or movement, involuntary, uncontrolled, recurring, occasionally stereotyped movements. This type of CP is due to injury in the basal ganglia (Cerebral Palsy Alliance Research Foundation, n.d.). It can be divided in:

- Dystonic CP: characterized by hypokinesia (reduced activity, i.e., stiff movement) and hypertonia (usually increased tone)
- Choreo-athetotic CP: characterized by hyperkinesia (increased activity, i.e., stormy movement) and hypotonia (usually decreased tone).

Figure 1 present the decision tree suggested by Surveillance of Cerebral Palsy in Europe (2000) as a reliable system to a hierarchical classification of CP.

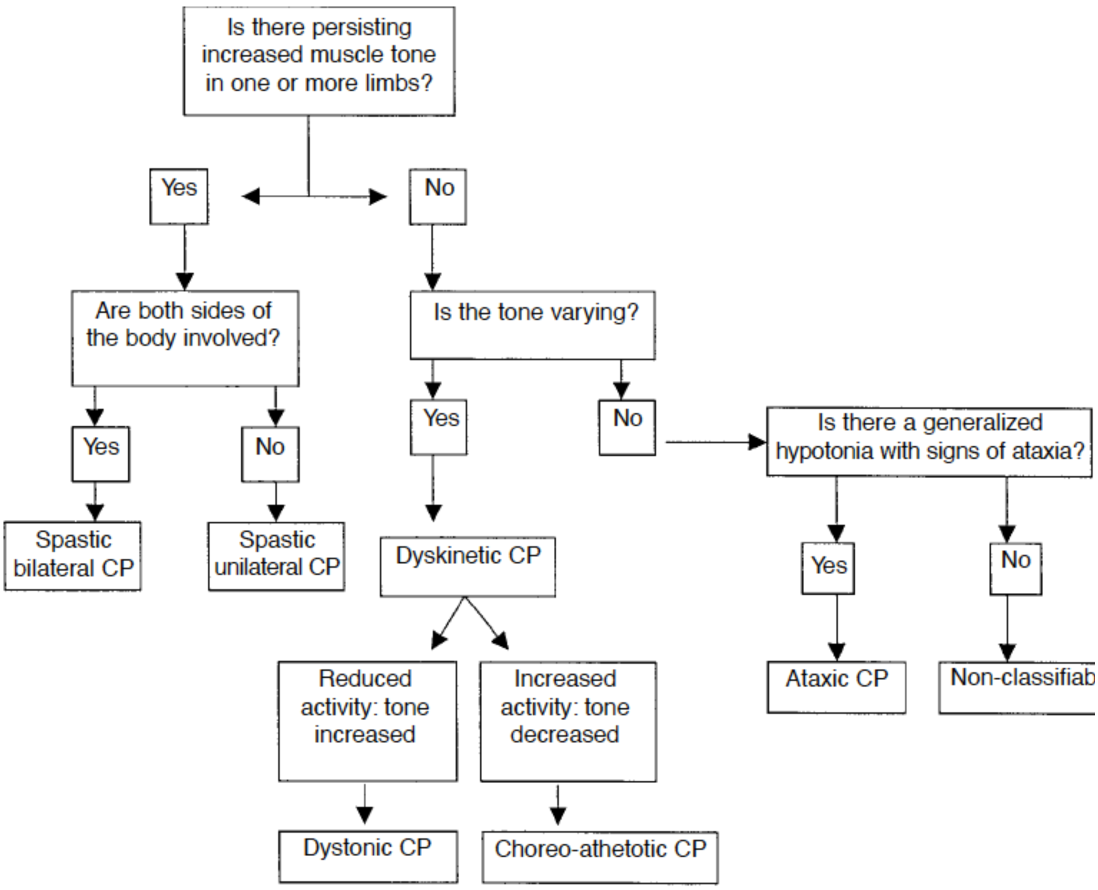

Figure 1: Cerebral Palsy hierarchical classification tree (adapted from Surveillance of Cerebral Palsy in Europe, 2000)

Even though people with CP may have other impairments related to brain damage, such as epilepsy, intellectual delays and psychosocial abnormalities, lifelong motor impairments are present in all cases of CP (Aisen et al., 2011).

The prevalence of CP in the world has remained relatively consistent over the last decades, affecting approximately 2 to 3 out of every 1,000 live births (Vitrikas et al., 2020). In Europe, a network of CP surveys was created, and registers monitor trends in CP rate, to provide a framework for collaborative research, and a basis for services planning among European countries - Surveillance of Cerebral Palsy in Europe (SCPE) (Cans, 2000). Specifically in Portugal, the group collaborating with SCPE, the National Cerebral Palsy Surveillance Program, released the latest report in 2022, and communicated that a total of 1,787 children with CP born between 2001 and 2010 registered in the National Cerebral Palsy Surveillance Program, 1,719 were living in Portugal at the age of 5, corresponding to 1.65 ‰ (IC95%: 1.57 – 1.73) of the total population aged 5 years living in Portugal during that period.

Regarding the prevalence according to types of CP, most of the cases were classified as spastic CP, followed by dyskinetic (10.7%) and ataxic (3.4%). Specifically in children with spastic CP, the majority exhibited a bilateral form (64.8%) followed by unilateral presentation (35.2%). Regarding the bilateral form, the majority was affected in all four limbs (63.5%), followed by signs in the two limbs (28.7%) and in the three limbs (7.7%). From a functional perspective, around 40% of the children were placed in levels IV or V of the Gross Motor Function Classification System (GMFCS) (Direção-Geral da Saúde, 2023).

Motor impairments can affect all of the four limbs and the trunk, so early intervention is important to minimize damaging modifications to muscle and bone growth (Novak et al., 2017). Considering magnitude and the heterogeneity of the population with CP, a better awareness of the muscular adaptations, among clinicians and therapists, may lead to improvements in treatments and therapeutic strategies (Mathewson & Lieber, 2015). Also, Graham et al. (2019) stated that multidisciplinary settings are the best option to manage intervention in children with CP. In this sense, Rosenbaum and Gorter (2012) proposed a novel framework where clinicians and families work together, using 6 F's: function, family, fitness, fun, friends and future. Specifically, fitness is emphasized as a critical need to understand the factors that enable children with disabilities to stay physically active and to provide more inclusive recreational opportunities (therapeutic or not), considering that environmental and social policies play a vital role in the youth's well-being. In this context, para sports arises as a strategy to promote physical activity for children and adults with CP.

2. Para Sports

Physical activity is characterized as movement produced by skeletal muscles resulting in energy expenditure (e.g., households, sports), with exercise being a planned, structured and repetitive form of physical activity with the aim of improving or maintaining physical fitness (Caspersen et al., 1985). Consequently, physical activity is important for everyone, especially for people with disabilities, who are more likely to face inactivity and increasing risk of chronic diseases linked to sedentary lifestyle. Although in the past, physical activity was not traditionally regarded as a core element of rehabilitation or standard clinical care for people with brain injuries, such as CP, scientific research related with the inclusion of physical activity in rehabilitation programs lead to changes in this matter (Runciman & Derman, 2018).

Exercise provides significant benefits, such as better physical and mental health, stronger social connections, and support for disease prevention and management (Fagher et al., 2023). In this sense, participation in Paralympic sports, which are sports in the schedule of Paralympic games, for people with disabilities, is the pinnacle of an elite participation in physical activity and exercise for people with disabilities, where world-class athletes compete.

Recently, Paris 2024 Paralympic Games hosted a record-breaking of 169 national delegations overcoming the 164 achieved during the London 2012 and Tokyo 2020 Games. The participation of 4,400 athletes across 549 medal events in 22 sports including an unprecedented number of 1,983 female athletes, marked a significant progress in gender representation and in the Paralympic Movement in general. A fair and meaningful competition in the Paralympic Games and in every event of para sports, is achieved through para sport classification. Para sport classification is a process to determine which athletes are eligible to compete in each para sport and to group them according to the degree of activity limitation resulting from their impairment, with the main goal of minimise the impact of the impairments on sport performance in order to acclaim sport excellence (International Paralympic Committee, 2019). The classification code has been revised and the most update International Standards will be published in January 2025 (International Paralympic Committee, 2024a). However, a final version published on the 29th April 2024 (International Paralympic Committee, 2024b) identified seven eligible impairments, including five physical impairments: impaired muscle power, impaired passive range of movement, limb deficiency and/or limb length difference, short stature, and coordination impairments (considering one or more of the three movement disorders – hypertonia/spasticity, motor ataxia and dyskinesia (athetosis, dystonia and chorea) alongside visual impairment and intellectual impairment, all defined by underlying health conditions affecting specific structures or functions. As the new IPC Athlete Classification Code is set to take effect in January 2025 for summer sports (International Paralympic Committee, 2024a), changes will not be mentioned in the following sections.

2.1 Para Swimming

Swimming is a popular physical activity practised by over 2.5 million people, including those with and without long-term limiting conditions or disabilities (Bush, 2017). Aquatic activities including adapted aquatic exercises, are highly recommended to be included in rehabilitation programs due to its therapeutic effect in children and adults with CP (Dimitrijevic et al., 2012).

The goal of competitive swimming is to swim a specific distance in the lower time possible. Therefore, para swimmers spend the most of the training time focusing on performance (Dutia et al., 2024). People with neurologic impairments, including CP reported that, even though training for performance may not have therapeutic goals, it appears to be a tool to improve clinical outcomes (Tweedy et al., 2016). Consequently, competitive sports for people with disabilities have expanded significantly over the past few decades, with more opportunities for participation available across all levels, from developmental to elite (Blauwet & Willick, 2012).

Specifically, para swimming is one of the initial eight sport being included in the inaugural Rome 1960 Paralympic Games experiencing a substantial grown in terms of number of athletes and medal events. Since Toronto 1976 Paralympic Games, para swimming was firmly established as a key para sport. At London

2012 Paralympic Games, para swimming accounted for approximately 600 competitors and 148 medal events being only overcome by athletics with 1,000 athletes (Bush, 2017). Recently, para swimming continued to be the second largest sport at Paris 2024 Paralympic Games, with 608 athletes competing for 141 medal events (International Paralympic Committee, 2024c). Currently, in Portugal, there are 209 para swimmers with different disabilities registered in 2024/2025 season, 22 of them with CP which also demonstrated the increasing growth of this sport in Portugal[1].

Although para swimmers with physical, visual, or intellectual impairments are eligible for competition, the schedule for Paris 2024 comprised 99 medal events destinated to para swimmers with physical impairments (Olympics, 2024), emphasizing the high representation of this area of disability in comparison to visual and intellectual impairment. Hence, research focusing on para swimmers with physical disabilities is highly needed to contribute to sports performance improvements of this group of para swimmers.

The governance of para swimming in Portugal is overseen by the Federação Portuguesa de Natação (Federação Portuguesa de Natação, 2024) which is responsible for promoting, regulating, and supporting para swimming at the national level. The Federação Portuguesa Natação collaborates with the Portuguese Paralympic Committee to ensure the inclusion of athletes with disabilities in competitive and recreational aquatic activities. Internationally, para swimming is governed by World Para Swimming (WPS), a division of the International Paralympic Committee (2024e). WPS establishes classification standards, organizes international competitions, and ensures that the sport adheres to principles of fairness and inclusion.

Para swimming events, for swimmers with physical disabilities, include freestyle, backstroke, butterfly, breaststroke, and medley across distances ranging from 50m to 400m. Competitions occur in standard 50m pools, with starting methods adapted to athletes' functional abilities (e.g., individualized adapted starting devices, unconventional starting techniques with a Sport Assistant helping).

Para swimming classification is determined on how the impairment affects the swimmers' performance in water, rather than the presence of the condition alone

[1] Information received via email from the Federação Portuguesa de Natação.

(Bush, 2017). The International Paralympic Committee (2022) employs a functional classification system that involves both medical (e.g., bench tests) and swimming evaluations. Points are awarded in accordance with the event the swimmer intends to compete in. Sport classes are designated with prefixes "S" (freestyle, butterfly, backstroke), "SB" (breaststroke), and "SM" (individual medley), followed by a number indicating the degree of impairment. For physical disabilities, a lower classification corresponds to greater severity (S1-S10, SB1-SB9, SM1-SM10), as described below (International Paralympic Committee, 2022):

- S1: Swimmers experience significant loss in muscle power or control in legs, arms, and hands, often due to conditions like tetraplegia. They typically rely on wheelchairs in daily life.
- S2: Swimmers primarily depend on arms for swimming due to limited hand, trunk, and leg function resulting from conditions like tetraplegia or coordination issues.
- S3: Swimmers with double amputations of arms and legs, specifically those with substantial arm movement but no leg or trunk function, and with severe coordination problems in all limbs are eligible for this class.
- S4: Swimmers using arms and hands reasonably well but lack trunk and leg function and those with three-limb amputations are eligible for this class.
- S5: Swimmers with short stature and additional impairments, such as hemiplegia or paraplegia are eligible for this class;
- S6: Swimmers with short stature, both arm amputations, or moderate coordination problems on one side of the body are included in this class.
- S7: Swimmers who have either one leg and one arm amputation on opposite sides or paralysis of one arm and one leg on the same side and swimmers with good arm and trunk control and some leg function are eligible for this class;
- S8: Swimmers with one arm amputation or significant restrictions across hip, knee, and ankle joints are eligible for this class;
- S9: Swimmers with joint restrictions in one leg or double below-the-knee amputations are eligible for this class.

- S10: Swimmers with minimal physical impairments, such as the loss of one hand or limited movement in one hip joint are eligible for this class.

2.1.1 Key-performance indicators

Competitive swimming aims to cover the race distance as quickly as possible, which depends on a swimmer’s ability to generate propulsion through coordinated limb and trunk movements while minimizing resistance, all of which rely, not only, but also on technique (Figueiredo et al., 2014). Key aspects of performance include maintaining streamlined body positions and minimizing resistive drag, which are directly influenced by an athlete's anthropometric profile, technical skills, and power output (Dingley et al., 2015). Specifically, swimmers with CP face additional challenges in optimizing hydrodynamics due to the diverse physical profiles associated with different CP types (Dingley et al., 2015). These motor impairments often limit fundamental skills such as stroke techniques and race starts (Zhou et al., 2023). Therefore, in order to achieve high performance and, consequently, world-class level, para swimmers with CP require a combination of muscular strength endurance, core stability, flexibility, optimal body composition, and precise technique (Dummer & Watkinds, 2008). However, this performance may be affected by other factors related to the impairment (e.g., energy expenditure may vary according to CP type being spastic or athetoid) (van de Vliet et al., 2011).

2.2 Boccia

Boccia is a Paralympic sport introduced in the Stoke Mandeville & New York 1984 Paralympic Games and was originally conceived for players with severe CP. Nowadays, boccia is one of the few Paralympic sports including competitors with severe physical disabilities and has no equivalent sport in the Olympic Games (Brittain, 2017). In the Paris Paralympic Games 2024, boccia had 124 participants competing for 11 medal events, with gender-specific medal events in individual competition being introduced for the first time (International Paralympic Committee, 2024d), highlighting the growth of this sport.

In Portugal, boccia is ruled by Paralisia Cerebral – Associação Nacional de Desporto (PCAND), which is responsible for organizing national competitions and supporting athletes with CP and related neurological conditions (Paralisia Cerebral - Associação Nacional de Desporto, n.d.). According to Paralisia Cerebral - Associação Nacional de Desporto (2024), there are 157 players competing in the 2024/2025 season, in representing 26 clubs in Portugal. Internationally, the sport is governed by World Boccia, the global federation responsible for setting the rules, managing classifications, and organizing major events, including the Boccia World Championships and Paralympic competitions (World Boccia, n.d.-a).

The aim of the game is to throw, kick, or use a ramp to propel balls toward a target ball, known as the "jack," with the goal of placing them as close as possible, making it a precision and strategy game (World Boccia, 2024). It can be played individually, in pairs or in teams. The court should be set in a smooth and polished surface and have 12.5m x 6m, with six throwing boxes (World Boccia, 2021a). Individual games have 4 ends, with each player having 6 balls (red or blue), plus one jack, win the winner being the player/pair or team with more points won during the game. While pairs (BC3 and BC4) also play 4 ends and each player has 3 balls with one jack for the pair, teams BC1/BC2 play 6 ends, with 2 balls for each player (World Boccia, 2021a).

Boccia functional classification categorises players into four classes ranging from BC1 to BC4 and comprises 6 eligible impairments, namely: impaired muscle power, limb deficiency, hypertonia, ataxia, athetosis and impaired passive range of movement (World Boccia, 2021a). All players must use a wheelchair and may use assistant devices (e.g., ramps, pointers, gloves), accordingly to their classification.

According to World Boccia (2021a):

- BC1: players face severe limitations in legs, arms, and trunk movements due to coordination impairments, often relying on powered wheelchairs. They possess the ability to grasp and throw the ball without assistive devices. Those with partial leg control are allowed to use their foot to propel the ball. Players may compete with a Sport Assistant, who stays outside of the competitor’s playing box, to stabilize or adjust their playing chair and give the ball to the player when requested.

- BC2: players exhibit better trunk control and arm function when compared to BC1. Consequently, players are able to perform different throwing techniques, including overhand, underhand, and using different grasps. The players included in this category don't qualify for a Sport Assistant during play.
- BC3: players experience significant limitations in both arm and leg functions, combined with poor or absent trunk control from either cerebral or non-cerebral origins. They struggle to consistently grasp or release the ball and rely on ramps and assistive tools, guided by a Ramp Operator, to roll the ball into the court.
- BC4: comprises players whose impairments don't originate from cerebral causes. They have severe locomotor dysfunction affecting all four limbs and the trunk. These may include conditions like muscular dystrophy, spinal cord injuries, or four-limb amputations leading to progressive weakness or muscle loss.

Specially concerning BC2 sport class, according to World Boccia (2021a), players present a neurological impairment affecting all four limbs (e.g., CP/stroke/acquired brain injury), with spasticity with or without Dyskinesia (Athetosis/Dystonia) or with Dyskinesia (Athetosis) or Ataxia. BC2 players also present moderate impairment of function and may have some limitation in active functional range of movement due to weakness or spasticity or lack of control affecting the upper limbs/trunk. Players may walk short to moderate distances with or without a walking aid and may use a manual or powered chair for everyday mobility (World Boccia, 2021a).

Boccia players are considered athletes with high support needs (AHSN) or severe physical disabilities. AHSN players' are described as requiring assistance during competition, based on the rules of the sport and/or requiring support staff in the sport environment and daily living functions, including players with a greater degree of physical impairment resulting in more extensive disability (i.e., athletes with tetraplegia or CP) (Slocum et al., 2018).

Initially, in the Stoke Mandeville & New York 1984 Paralympic Games only players classified under today's BC1 and BC2 categories were included in boccia competition. In the 1996 Atlanta Paralympic Games, a category for players using assistive devices, corresponding to the current BC3 classification was included in the competition schedule. Later, in the 2004 Athens Paralympic Games, the BC4 category was added, further expanding the sport's inclusivity (Brittain, 2017). More recently, a new sport class – BC5 was created for players who don’t meet the minimum impairment criteria and exhibited less impairment than BC2 and BC4 players, with conditions of cerebral and non-cerebral origin and the throwing arm impacted by the impairment (World Boccia, 2021b). However, this class is not included at World Boccia sanctioned international events (e.g., Paralympic Games) (Boccia England, n.d.) and only few countries included it in the national events schedule (e.g., Portugal).

2.2.1 Key-performance indicators

Boccia requires a high level of skill, accuracy, strategy and concentration. The key-performance indicators influencing a boccia player’s sports performance include hand function (such as grip and ball release), upper limb function (throwing arm mechanics and compensatory use of the auxiliary arm), lower limb function (including stabilization or playing with the foot), trunk control (stabilizing the body on the wheelchair), and the ability to manoeuvre the wheelchair effectively within the playing area (Boccia Canada, n.d.; Sportability, n.d.). In addition, tactical skills, psychological and decision-making capabilities are also crucial (Reina et al., 2018). In world-class athletes, these tactical decisions involve managing shot risks effectively, make independent tactical decisions, and adapt strategies based on the strengths and weaknesses of both themselves and their opponents (World Boccia, n.d.-b). Regarding technique, it is expected that world-class players consistently execute all shot types with precision, demonstrating control over line, pace, and trajectory. Maintaining a high level of technical consistency is essential for effective court coverage and efficient tactical decisions (World Boccia, n.d.-b).

The throwing action is the fundamental technique gesture in boccia game. Even though there are other actions to play the ball, the throwing is the most used one (i.e., BC1 throwers, BC2 and BC4). There are five different throwing technique namely: overarm, underarm, dart, chest and pendulum (Sportability, n.d.).

- The overarm throw is performed using one hand, beginning with the ball positioned around shoulder or head level. From this starting point, the athlete utilizes coordinated shoulder and elbow movements to execute the throwing action. Additionally, players may incorporate trunk movement to assist with propulsion.

Figure 2: Player performing an overarm throw.

- The underarm throw is performed close to court level, typically using one hand. Beginning with minimal backswing, the athlete releases the ball in a controlled motion. The arm moves as a single unit, with limited elbow movement, and is primarily controlled by the shoulder. Additionally, players might engage their trunk to assist with the throw.

Figure 3: Player performing an underarm throw.

Romero and Hernández (2000) studied Spanish boccia players during one local and one national championship and concluded that in local championships half of the BC2 players used the overarm throw, and in national championships also half of the BC2 players used the underarm throw, regardless of the impairment levels.

Although boccia is one of the main sports in the Paralympic program, there is a dearth of studies providing scientific-based evidence. Therefore, it is urgent to develop research that will help coaches to optimize training methodologies, improve athlete performance, and reduce injury risks. In an up-to-date systematic review about the status of boccia research, Ferreira et al. (2023) only identified 9 studies and mostly focusing on variables involved in the technique of boccia throwing. Specifically, on the boccia throwing patterns among children (Huang et al., 2014), different genders (Hendarto, 2023) and elite players (Reina et al., 2018). The relationship between throwing distance and competitive performance Kataoka et al. (2020) was also investigated.

Overall, research highlighted the crucial role of biomechanical analysis in improving Boccia throwing performance. Players with quadriplegic athetosis, ataxia, or hypertonia often experience neuromuscular fluctuations that lead to variability in body segment movements, including changes in speed and acceleration (Reina et al., 2018) which justifies the need for a detailed biomechanical analysis of the different throwing techniques. Therefore, future research should analyse types of throws and well as explore the relationships with sports-related variables (e.g., participation in S&C training). Specially in world-class players, where minimal details make the difference, these biomechanical analyses are important to improve sports performance.

2.2.2 Kinematic analysis

Gaining deeper insights into Paralympic sports and the factors that influence performance requires a comprehensive review of biomechanical research and its relevance to optimizing outcomes (Morrien et al., 2017). Specially, technique fluctuations experienced by players with CP (Reina et al., 2018) should be analyzed using kinetic and/or kinematic variables to better understand the movement challenges associated with CP (Urban et al., 2015). These kinematic variables usually involve quantitative measurement of motion of a body joint during the execution of an exercise (Das et al., 2023), such as joint angles, angular position and velocities.

The marker-based motion capture system is a three-dimensional kinematic analysis, relying on reflective markers placed on anatomical landmarks and multiple cameras to track body segment movements (Das et al., 2023). However, this a challenging approach as soft tissue artifacts (Peters et al., 2010) and variability in manual marker placement can introduce inconsistencies both within and across research facilities (Gorton et al., 2009). Furthermore, marker-based methods require a controlled environment, which may restrict natural movement, as well as skilled operators and considerable time for marker placement.

In contrast, other used system is the video-based markerless motion capture technology, which offers a non-invasive, fully automated alternative that eliminates the challenges associated with marker placement and soft tissue artifacts (Das et al., 2023), reducing both data collection and processing times (Poomulna et al., 2025). Additionally, it allows for the capture of unrestricted movement and is more practical for use outside of controlled laboratory settings (Kanko et al., 2021).

Therefore, the markerless system may be the best option to use with people with CP, specially with boccia players, as it enables not only the analysis of unrestricted movements without the discomfort constraints associated with marker placement, but also the time used, reducing possible disturbances for world-class players.

3. Health and Performance

Athletes with CP may be influenced by different health-related factors that impact sports performance. Hence, continuous health monitoring, supported by effective integration and communication between the elements of the multidisciplinary team, is essential to balance optimal performance with the athlete's long-term well-being (Dijkstra et al., 2014). Understating these variables and the interaction between them will play a crucial role in improving health and performance in world-class athlete with CP.

3.1 Body composition

Body composition is described as the relative proportions of all main components of the body, including fat, bone, muscle, and water mass (Ratamess, 2012) and its interactions with physical activity and athletic performance are widely explored in the literature. Understanding the body composition of athletes with CP holds significant importance for multidisciplinary teams working in high performance level. It provides valuable insights that enhance overall athletic performance, health, and well-being. Following a holistic approach, may tailor customized dietary plans to support the athletes' unique nutritional requirements and promote healthy body composition changes with the work of the nutritionist or even design targeted workouts to increase muscle mass or decrease fat mass, to improve strength or overall functional capacity through their S&C coach (van de Vliet et al., 2011). Considering the importance of enhancing the sports' performance of each athlete as an individual, assessing body composition may be one useful tool to reach world-class level.

Therefore, assessing the morphological attributes of para-athletes with CP and to explore the impact of the body structure in the sports performance may provide valuable insights related with technical and physical capabilities (Cherif et al., 2022). Also, understanding specific anthropometric characteristics of athletes with CP may also play an important role not only in training, but also in talent identification (Sarabia et al., 2020). Additionally, these measurements provide important information about individual's physical characteristics and are used for different purposes, such as monitoring changes over time, comparing different athletes, and evaluating the effects of different impairments (Szkoda et al., 2022).

3.1.1 Assessment

Indirect methods for assessing body composition rely on measuring variables linked to body composition rather than directly measuring it. True direct measurement of body composition is only possible through cadaver dissection (considered a level 1 method) (van de Vliet et al., 2011). Due to their high cost and limited portability, level 2 indirect methods (e.g., DXA) are primarily used in research contexts and to validate level 3 body composition assessment techniques (van de Vliet et al., 2011), such as anthropometry. When deciding which method to use to assess body composition, different factors should be taken in consideration, such as the athlete's needs, the information that the multidisciplinary team values, the instruments availability, the costs and logistics (van de Vliet et al., 2011).

3.1.2 Dual X-ray Absorptiometry (DXA)

Dual X-ray Absorptiometry (DXA) is a level 2 assessment measurement (Ratamess, 2012). DXA measures fat, bone mass and other fat free soft tissues, with the specificity of being able to measure specific body segments. It is considered the best method when there is a specific body part of interest to be assessed (Meyer & Edwards, 2004). DXA offers several advantages such as ease of use, speed, accuracy and the possibility of regional measurements. However, there are some important limitations regarding the use of this methodology namely high cost, the need for ensuring standardization of protocols to control subject placement, monitoring dietary and hydration status, and minimizing diurnal and inter-machine variations (van de Vliet et al., 2011). Therefore, DXA may be a valuable tool to assess Paralympic athletes namely variations in muscle mass across different body segments and for monitoring changes in specific anatomical regions as a consequence of training (van de Vliet et al., 2011). However, Keil et al. (2014) argued that the precision and accuracy of DXA scans might be compromised in athletes with disabilities due to different specific disability factors such as muscle spasms, that can disrupt the scanning process, making it challenging for the athlete to remain still throughout the assessment procedure.

3.1.3 Anthropometry

Anthropometry refers to the systematic measurement of the human body, focusing on dimensions like height, weight, circumferences, girths, and skinfold (Ratamess, 2012). It is a level 3 method, and offers several advantages due to its simplicity, low-cost and portability. Anthropometry can be extended to incorporate girths, and bone breadths, providing a comprehensive description of athlete's overall body composition (van de Vliet et al., 2011). Usually, the skinfolds thickness is assessed at seven to eight sites across the body (e.g., biceps, triceps, subscapular, iliac crest, supraspinale, abdominal, mid-thigh, and maximal calf) (van de Vliet et al., 2011). Using methods like the sum of skinfolds to evaluate body composition is reliable especially when consistent methodology is maintained for subsequent comparisons (Medeiros et al., 2016). However, when assessing skinfolds in athletes with CP, adjustments to the standardized procedures should be made (e.g., in an athlete with right sided hemiplegia, it may be more appropriate to undertake skinfold on the left side of their body) (Crosland & Boyd, 2004).

3.1.4 Metrics

Somatotypes are described as a quantifiable representation of an individual's morphological configuration and its distinct characteristics are classified according to the following components: endomorphy, mesomorphy, and ectomorphy (Carter et al., 1983). It is made through a three-number system that represents endomorphy, mesomorphy, and ectomorphy in sequence. Endomorphy indicates the degree of body fat, mesomorphy reflects musculo-skeletal robustness, and ectomorphy measures the body's linearity or slimness (Carter, 2002).

The somatotype may be determined by entering the data onto a somatotype rating form or using equations derived from the rating form. The first method presents some limitations, namely concerning different body types from the considered norm (e.g., children, heavy weightlifters) (Carter, 2002). In this sense, and even though there are no equations validated for people with CP, the three equations present in Carter (2002), each one related to each component, appear to be a preferred method:

$$\text{Endomorphy} = -0.7182 + 0.1451 (X) - 0.00068 (X^2) + 0.0000014 (X^3)$$

where X = (sum of triceps, subscapular and supraspinale skinfolds) multiplied by (170.18/height in cm).

Mesomorphy = (0.858 x humerus breadth + 0.601 x femur breadth + 0.188 x corrected arm girth + 0.161 x corrected calf girth) – height 0.131 + 4.5.

Three different equations are used to calculate ectomorphy according to the height-weight ratio (HWR):

If HWR 40.75 then ectomorphy = 0.732 HWR - 28.58
If 38.25 < HWR < 40.75, then ectomorphy = 0.463 HWR - 17.63
If HWR 38.25 then ectomorphy = 0.1

Ectomorphy is determined by considering the ponderal index (PI): PI = stretch/ and computed based on these formulas:

If PI > 40.75, then Ectomorphy = (PI x 0.732) - 28.58.
If 38.25 < PI < 40.75, then Ectomorphy = (PI x 0.463) - 17.63.
If PI < 38.25, then Ectomorphy = 0.1.

Regarding the use of somatotypes in athletes with disabilities, there are no validated equations to apply to people with disabilities. However, calculating somatotype of world-class athletes with CP is important to understand the morphological configuration of these athletes and how it relates to sports performance. There are some studies about the somatotypes of football players with CP at both national (Gorla et al., 2019; Macedo et al., 2022) and international (Domenech et al., 2023) levels and with shot put athletes with amputations and spinal cord injuries (Garcia-Carrillo et al., 2023). Football players with CP (Domenech et al., 2023; Gorla et al., 2019), presented a predominant mesomorphic component (musculo-skeletal robustness) regardless of the functional profile (hypertonia, athetosis, or ataxia). On the other hand, shot put athletes with amputations and spinal cord injuries were characterized by higher skeletal muscle and adipose tissue (endomorph-mesomorph). Therefore, Domenech et al. (2023) argued that CP athletes with endomorph profile should periodize their training in order to manage adiposity and enhance lean body mass and Garcia-Carrillo et al. (2023) that and endomorph-mesomorph somatotype favours muscle power and strength which is an advantage in throwing long distances, highlighting the importance of tailoring somatotype recommendations to the unique demands and characteristics of each sport and disability.

Other metrics used to assess body composition are also important when characterizing body composition, namely Body Mass Index (BMI), Fat Mass Index (FMI), total body% fat mass and appendicular lean mass index.

Body mass index (BMI) = $\frac{body\ mass\ (kg)}{height^2}$

BMI is a frequently used method to estimate body composition, but it is not accurate to assess overall adiposity for adults with CP given the diversity of body morphology and lifestyles (Shin & Jung, 2021).

Fat mass index (FMI) =$\frac{FM\ (kg)}{height^2}$

The FMI results are categorized as (Kelly et al., 2009):

- severe fat deficit:
  Men: FM < 2 kg/m^2; women: FM < 3.5 kg/m^2;
- moderate fat deficit:
  Men: 2 kg/m^2 ≤FM < 2.3 kg/m^2; women 3.5 kg/m^2 ≤ FM < 4 kg/m^2;
- mild fat deficit:
  Men: 2.3 kg/m^2 ≤ FM <3 kg/m^2; women 4 kg/m^2 ≤ FM < 5 kg/m^2;
- normal fat levels:
  Men: 3 kg/m^2 ≤ FM <6 kg/m^2; women 5 kg/m^2 ≤ FM < 9 kg/m^2;
- excess fat levels
  Men: 6 kg/m^2 ≤ FM <9 kg/m^2; women 9 kg/m^2 ≤ FM < 13 kg/m^2;
- obesity class 1:
  Men: 9 kg/m^2 ≤ FM <12 kg/m^2; women 13 kg/m^2 ≤ FM < 17 kg/m^2;
- obesity class 2:
  Men: 12 kg/m^2 ≤ FM <15 kg/m^2; women 17 kg/m^2 ≤ FM < 21 kg/m^2;
- obesity class 3:
  Men: FM < 15 kg/m^2; FM < 21 kg/m^2;

Total body %FM = $\frac{FM\ (kg)}{total\ body\ mass\ (kg)}$.

Appendicular lean mass index (kg/m^2) = $\frac{\text{appendicular lean mass (kg)}}{height^2}$

The appendicular lean mass index is used to establish sarcopenia risk.

3.2 Sarcopenia

Sarcopenia is a progressive condition that affects skeletal muscles, characterized by a decrease in either muscle mass, quality, or function. It is typically diagnosed when two or more criteria are met, including reduced muscle strength, decreased muscle quality or quantity, and/or impaired physical performance (Cruz-Jentoft et al., 2019). According to Su et al. (2023), people with CP commonly present an overlapping of different criteria. Also, in adults with CP, there is a higher prevalence of sarcopenia compared to the general population (Jeon et al., 2019).

In terms of muscle quantity, the appendicular lean mass index is calculated and the cut-off points for sarcopenia risk according to gender were ≤ to 7.0 kg/m2 (men) and ≤ 5.5 kg/m2 (women) (Cruz-Jentoft et al., 2019).

The central inhibition of muscle recruitment, which limits the activation of motor units in affected muscles, combined with the characteristic neuromuscular deficits of CP, can substantially impact muscle size, function, and overall physiology (Stackhouse et al., 2005). Alterations in the neural drive to muscles and to the muscles themselves cause changes in motor function (Rose & McGill, 2007).

According to Britz et al. (2020), spinal deformities such as scoliosis, hyperkyphosis, hyperlordosis, and conditions like spondylolysis or spondylolisthesis are frequently observed in people with CP. More severe forms of sarcopenia were observed in non-ambulatory people with neuromuscular disorders, including CP, with severe scoliosis (Kim et al., 2023). These findings suggest that, while neurological impairments play a significant role in muscle loss, secondary factors such as spinal deformities and gait abnormalities further aggravate sarcopenia, leading to a greater decline in gross motor function.

Consequently, in persons with CP sarcopenia is influenced by an interplay of neurological and musculoskeletal factors (Kim et al., 2023).

A conceptual framework illustrating the cyclical decline in health and functional abilities in people with CP (Figure 4) identifies muscle weakness and fatigue as central contributors to the early onset of sarcopenia (Peterson et al., 2015). For people with CP, muscle impairments often persist from childhood into adulthood, leading to an accelerated decline in functional capacity and increasing the likelihood of premature, age-related sarcopenia (Multani et al., 2019).

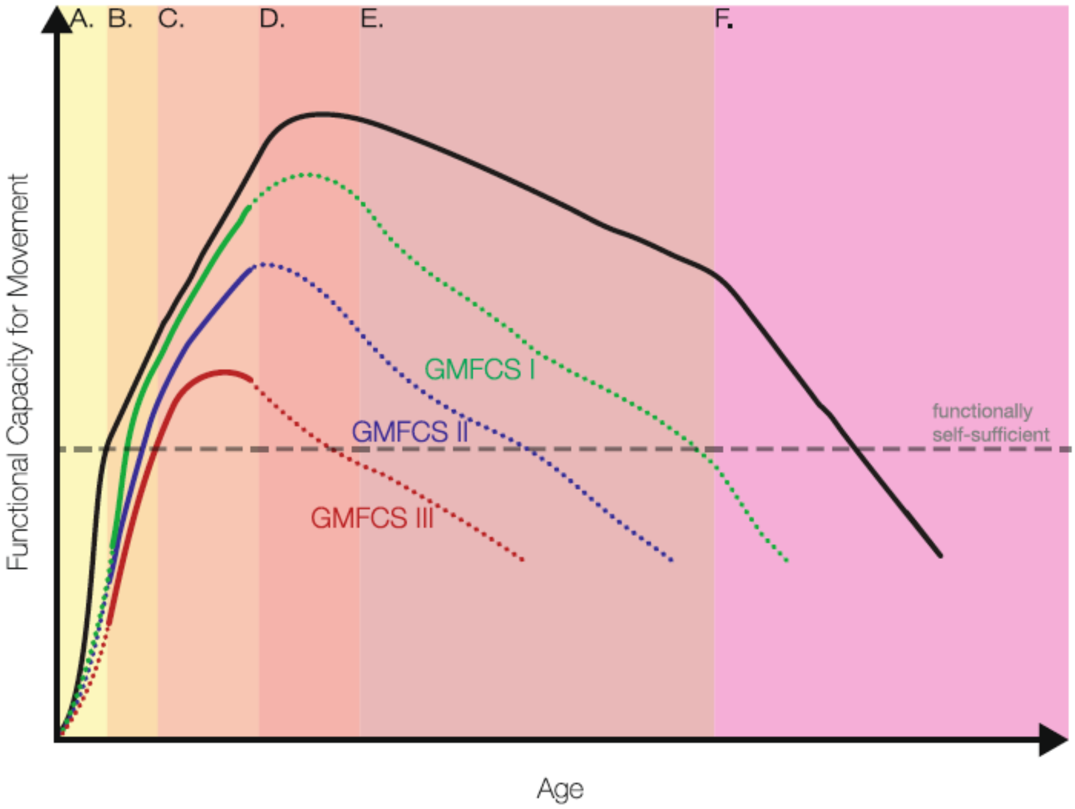

Figure 4. Hypothetical trajectory of muscle function (y-axis) across the lifespan (age, x-axis) in healthy typically developing (TD) people and people with CP, plotted for GMFCS Levels I, II, and III (adapted from (Handsfield et al., 2022; Shortland, 2009)).

In this context, it is important to highlight the discussion about sarcopenia in pediatric ages and clarify different concepts. Children with CP also experience muscle weakness; however this is not an age-related condition but related with the disability itself, malnutrition of limited mobility (Aksakal et al., 2024).

Therefore, terms like "muscle wasting" or "atrophy" offer a more precise description of this condition in children (Aksakal et al., 2024).
Consequently, given the early onset and compounding nature of muscle decline in CP, timely interventions are essential (Shortland, 2009). Strategies such as specific strength training, nutritional optimization, and innovative molecular therapies have shown benefits in enhancing skeletal muscle mass, strength, and resilience (Multani et al., 2019). In this sense, Verschuren et al. (2016) emphasised the importance of exercise and physical activity to improve muscle health in people with CP.

3.3 Strength

Strength may be defined as the ability of the neuromuscular system to produce force against an external resistance (Bompa & Buzzichell, 2019). Also, strength improves force and rate of force development, general and sport-specific skill performance as well as decreases the risk of non-contact injuries (Suchomel et al., 2016). However, children with CP present decreased strength (Graham et al., 2016a).
Moreover, as previously stated, muscle weakness is common in people with CP which represents a major factor contributing to the loss of physical function over lifespan (Auld & Johnston, 2014; Wiley & Damiano, 1998). Direção-Geral da Saúde (2023) published several guidelines for physical activity for people with CP highlighting the importance of fitness and strength training in this population, to address sedentary lifestyles often present in people with CP.
Strength training should focus on building muscle strength and endurance for a better body posture. In an initial phase, strength programs may include 1–2 sets of 8–12 repetitions performed until fatigue is reached and progress to 1–4 sets of 6–15 repetitions at 50–70% of the individual's one-repetition maximum (1RM). Strength training should be done 2–3 times per week on non-consecutive days. Exercises should target major muscle groups using functional and multi-joint movements, incorporating body weight, machines, free weights, and resistance bands. Progression should start with longer recovery periods between sets, with single-joint exercises recommended for persons with lower strength levels or

those using compensatory strategies during multi-joint movements (Direção-Geral da Saúde, 2023).

According to Bhambhani (2011) evidence suggests that resistance training programs significantly improve muscle strength in people with CP. Also, the CP Rehabilitation Guidelines (New South Wales Ministry of Health, 2018), states that, in cases of mild CP with GMFCS levels between I–III, muscle strength and endurance training are effective in improving those physical capacities in people with CP. However, in cases of severe CP with GMFCS levels IV–V its benefits remain unknown due to the difficulty in performing movements involved in intervention methods used for mild CP (Yahagi et al., 2024). Therefore, when working with severe CP it is important to select proper training equipment according to the level of motor function (Kholod et al., 2013).

Considering that boccia is played by people with severe CP (Yahagi et al., 2024), these guidelines should be taken in consideration during strength and conditioning (S&C) training sessions. Strength training programs are crucial for performance factors related with the ability to throw at longer distance (Kataoka, 2020) and should include resistance training for strength and power levels (Boccia Canada, n.d.). Moreover, training contributes to maintain a balanced body composition and avoid the development of multiple metabolic and cardiovascular risk factors, when players are exposed to high levels of exercise training (Runciman et al., 2016).

In the context of para swimming, strength training also plays a vital role not only for improving performance but also from a rehabilitation and injury prevention perspective. Zwierzchowska et al. (2023) emphasized that strength training helps prevent injuries by addressing muscular imbalances and improving ROM, which are common issues in para swimmers.

3.4 Range of motion

The range of motion (ROM) measures movement, and its extent, around a specific joint or body part (Mourcou et al., 2015). Flanagan (2012) defined it as the amplitude in which the joint can move due to the amount of motion available at a joint (or series of joints). There are 2 types of dynamic range of motion, dependent on the purpose of the assessment, passive and active (Keogh et al., 2019): when an assessor passively moves a joint, passive ROM is assessed, when the muscular contraction moves a joint, active ROM is assessed. The measurement of a joint ROM is an essential skill in the musculoskeletal assessments commonly performed by physiotherapists, as well as S&C coaches, to examine joint function, detect joint asymmetry and evaluate treatment efficacy as an objective outcome measure (Milanese et al., 2014). The most common device to measure ROM is the goniometer, due its availability, low-cost and simplicity (Marcano-Fernandez et al., 2020).

According to Herrero et al. (2011), ROM measurements are often used to assess muscular shortening and joint stiffness in CP population. Moreover, extensive literature (e.g., Damiano et al., 2001; Fosdahl et al., 2020; Low et al., 2020; Ross & Engsberg, 2007) showed that most of the studies were performed in a rehabilitation and quality-of-life related context, and mostly in children and adults, not focusing on sports performance or world-class athletes with CP.

As upper limb impairments occur in 50% to 70% of people with CP, limited mobility can be a result of secondary musculoskeletal complications such as contractures and deformities that are trigger by spasticity, muscle weakness and insufficient motor control (Santos et al., 2015). The typical posture of the upper extremities in spastic CP is characterized by inward rotation of the shoulder, flexion of the elbow and pronated forearm, flexion of the wrist with ulnar deviation, and deformity of the fingers (flexion contracture, swan-neck, and thumbs-in-palm) (Gharbaoui et al., 2016).

In para swimming, ROM is particularly crucial for effective limb positioning, as it enhances force production, reduces drag, increases stroke efficiency, and helps reduce the risk of injuries (Dummer & Watkinds, 2008). Nevertheless, para swimmers with physical disabilities frequently experience restricted joint ROM. For instance, swimmers with elbow or shoulder contractures may have limited mobility and might compensate by avoiding the use of the affected limb, which reduces even more force production and propulsion capacity (Dummer & Watkinds, 2008). Therefore, ROM assessment would be beneficial to find strategies to improve it and, consequently, improve force production and propulsion of para swimmers.

For boccia players, ROM plays an important role, namely concerning throwing technique. In this sense, Boccia Canada (n.d.) reported that S&C programs for boccia players should incorporate stretching and mobility exercises to help maintaining ROM and postural stability.

3.5 Bone health

Bone health is a critical health parameter for people with CP as low bone mineral density (BMD) is a prevalent concern in this population. BMD (g/m^2) is the measurement of inorganic mineral content in the bone and is a critical indicator of bone quality, influenced by factors such as age, sex, genetics, lifestyle, and medical conditions, being widely used in clinical and forensic evaluations (Kranioti et al., 2019). Assessed with DXA, is a globally accepted standard for evaluating the risk of fragility fractures (Haseltine et al., 2021). To proceed to this risk evaluation, the Z-score for each individual a reference population accounting for age, sex and ethnicity is used (Koivisto-Mork et al., 2023).

Reduced BMD is associated with an increased risk of fractures, even under minimal stress, which negatively impacts quality of life (Won & Jung, 2021). Neurological disorders that result in quadriplegia pose a significant risk for conditions such as osteopenia and osteoporosis due to diminished bone density (King et al., 2003). Among ambulatory people with CP, children classified as GMFCS levels II (independent walking with limitations) and III (walking with adaptive equipment) are particularly at risk for low BMD (Mus-Peters et al., 2019). Similarly, in young adults with CP, factors such as ambulatory status, CP subtype, and GMFCS classification were strongly linked to variations in BMD (Fowler et al., 2015; Kim et al., 2015; Marciniak et al., 2016).

The trend of low BMD persists into adulthood, with studies indicating that 25% of adults with CP have osteoporosis, and the prevalence rises to 65% in people over 50 years old (Won & Jung, 2021). Men, non-ambulatory, and those with bilateral CP face the highest risk. In people with CP, low BMD is a lifelong issue, leading to an annual fracture rate of approximately 5%, which is double that of age-matched general populations (Sheung-Tung, 2012; Su et al., 2023; Whitney et al., 2019), Bone health is also a critical parameter for sports performance. Mainly, because a good bone health early in life can prevent health issues not only during the athlete's career, but also after it (Weijer et al., 2024). Koivisto-Mork et al. (2023) observed that half of Norwegian Paralympic athletes had low BMD, with 29% exhibiting osteoporotic levels. Non-ambulant athletes with congenital conditions were at a higher risk compared to other para-athletes, highlighting the influence of ambulatory status on bone health. Similarly, wheelchair-dependent athletes with SCI had significantly lower BMD Z-scores than their non-wheelchair-dependent counterparts (Cavedon et al., 2021; Miyahara et al., 2008).

Key risk factors for reduced BMD in Paralympic athletes include mechanical loading patterns, such as wheelchair use, sport type, and body mass (Weijer et al., 2024). Weight-bearing and dynamic loading activities have shown potential benefits for bone health. For instance, dynamic loading has been reported to improve BMD in children with CP (Damcott et al., 2013). Additionally, long-term training in athletes without disabilities has been associated with increased BMD, suggesting similar potential benefits for people with CP (Oliveira et al., 2023; Verschuren et al., 2016).

To the best of the author knowledge, there are no studies concerning bone health in boccia players. However, assessing the risk of poor bone health in these players is crucial. Usually, boccia players are AHSN, and may present neurological disorders that cause quadriplegia, they present a significant risk of developing osteopenia or osteoporosis, due to reduced bone density (King et al., 2003). Therefore, world-class boccia players should be monitored to assess the risk of osteoporosis, not only due to health status, but also to decrease the interference in sports performance.

4. Research design and thesis objectives

This thesis will be based on quantitative research, with four cross-sectional studies what will be present in the form of scientific papers, which will be organized in the Scandinavian structure thesis model.

The main goal of the thesis is to draw the physical profile of world-class athletes with CP characterizing health and performance variables interfering in sports performance. In order to achieve it, four studies were design according to the following specific goals:

Study 1: Anthropometric characteristics and somatotype of world-class para swimmers with spastic Cerebral Palsy.

- to describe the anthropometric characteristics and somatotype of world-class para swimmers with spastic CP;
- to analyze the associations between anthropometric characteristics, training and competition time, walking ability and sports' classification.

Study 2: Upper body strength and range of motion of world-class para swimmers with spastic Cerebral Palsy

- to characterize upper body strength and ROM of world-class para swimmers with spastic CP;
- to compare strength and range of motion across different sports classes;
- to investigate the associations between strength, range of motion and locomotion type.

Study 3: Assessment of health-related parameters in world-class boccia players using DXA.

- to provide a descriptive analysis of body composition and bone health, including fat mass, lean mass and BMD among a group of world-class boccia players with CP using DXA;
- to identify health-related risk factors such as underweight or obesity, sarcopenia and osteoporosis;
- to explore strategies to optimize sports participation and health maintenance in players with CP.

Study 4: Kinematical analysis of different types of boccia throws in BC2 world-class players with spastic Cerebral Palsy.

- to characterize the kinematic parameters involved in the throwing motion, such as upper body angles, angular velocity of joint movements and throwing velocity of different types of boccia throws performed by world-class boccia players with CP;

- to analyze the associations between the different kinematic parameters and sports-related variables.

5. References

Aisen, M. L., Kerkovich, D., Mast, J., Mulroy, S., Wren, T. A. L., Kay, R. M., & Rethlefsen, S. A. (2011). Cerebral palsy: Clinical care and neurological rehabilitation. *The Lancet Neurology*, *10*(9), 844-852. https://doi.org/10.1016/s1474-4422(11)70176-4

Aksakal, M. F., Abdulsalam, A. J., Kara, M., & Ozcakar, L. (2024). Grip strength and sarcopenia in children with cerebral palsy: A level playing field? *Pediatric Neurology*, *161*, 84. https://doi.org/10.1016/j.pediatrneurol.2024.09.002

Auld, M. L., & Johnston, L. M. (2014). "Strong and steady": A community-based strength and balance exercise group for children with cerebral palsy. *Disability and Rehabilitation*, *36*(24), 2065-2071. https://doi.org/10.3109/09638288.2014.891054

Bhambhani, Y. (2011). Physiology. In Yves C. Vanlandewijck & W. R. Thompson (Eds.), *Handbook of sports medicine and science: The Paralympic athlete* (pp. 51-73). Wiley-Blackwell.

Blauwet, C., & Willick, S. E. (2012). The Paralympic movement: Using sports to promote health, disability rights, and social integration for athletes with disabilities. *PM R*, *4*(11), 851-856. https://doi.org/10.1016/j.pmrj.2012.08.015

Boccia Canada. (n.d.). *Long-term athlete development model*. Retrieved 21.Dec.2024 from https://bocciacanada.ca/wp-content/uploads/2021/08/Long-Term-Athlete-Development-Model-en.pdf

Boccia England. (n.d.). *BISFed BC5 Classification*. Retrieved 11.Jan.2025 from https://www.bocciaengland.org.uk/news/bisfed-bc5-classification

Bompa, T. O., & Buzzichell, C. A. (2019). *Periodization: Theory and methodology of training* (6th ed.). Human Kinetics.

Brittain, I. (2017). Glynn Tromans: in search of “fearless” boccia and the “big hairy audacious goal”. In Geoffery Z. Kohe & D. M. Peters (Eds.), *High Performance Disability Sport Coaching* (pp. 145-162). Routledge.

Britz, E., Langerak, N. G., & Lamberts, R. P. (2020). A narrative review on spinal deformities in people with cerebral palsy: Measurement, norm values, incidence, risk factors and treatment. *South African Medical Journal*, *110*(8), 767-776. https://doi.org/10.7196/SAMJ.2020.v110i6.14472

Bush, A. J. (2017). From Melksham to Rio: a coach's 20-year journey in para-swimming. In Geoffery Z. Kohe & D. M. Peters (Eds.), *High Performance Disability Sport Coaching* (pp. 163-185). Routledge.

Cans, C. (2000). Surveillance of cerebral palsy in Europe: A collaboration of cerebral palsy surveys and registers. *Developmental Medicine and Child Neurology*, *42*, 816–824.

Carter, J. E. L. (2002). *The Heath-Carter antropometric somatotype: Instruction manual*. San Diego State University.

Carter, J. E. L., Ross, W. D., Duquet, W., & Aubry, S. P. (1983). Advances in somatotype methodology and analysis. *American Journal of Physical Anthropology*, *26*, 193-213. https://doi.org/10.1002/ajpa.1330260509

Caspersen, C., Powell, K., & Christenson, G. (1985). Physical activity, exercise, and physical fitness: Definitions and distinctions for health-related research. *Public Health Reports*, *100*(2), 126-131.

Cavedon, V., Sandri, M., Peluso, I., Zancanaro, C., & Milanese, C. (2021). Body composition and bone mineral density in athletes with a physical impairment. *PeerJ*, *9*, e11296. https://doi.org/10.7717/peerj.11296

Cerebral Palsy Alliance Research Foundation. (n.d.). *Types of Cerebral Palsy*. Retrieved 2.Jan.2025 from https://cparf.org/what-is-cerebral-palsy/types-of-cerebralpalsy/?gad_source=1&gbraid=0AAAADLC7nCVDCCaA1tOvCEMO_rXWjSs5&gclid=CjwKCAiAtNK8BhBBEiwA8wVt98irB-pYwYcqBHC-AmFIyeqwsQnmXtjAxL-YF0p4dzGp3zQrYhyo3RoCCtEQAvD_BwE#

Cherif, M., Said, M. A., Bannour, K., Alhumaid, M. M., Chaifa, M. B., Khammassi, M., & Aouidet, A. (2022). Anthropometry, body composition, and athletic performance in specific field tests in Paralympic athletes with different disabilities. *Heliyon*, *8*(3). https://doi.org/10.1016/j.heliyon.2022.e09023

Comité Paralímpico de Portugal. (2024). *Atletas & medalhas paralímpicos*. Retrieved 9.Jan.2025 from https://paralimpicos.pt/documents/20181/0/Medalheiro+Paralímpico+2024/03c1d45c-dcf6-4444-82db-a7328fda8c1d?version=1.0

Crosland, J., & Boyd, C. (2004). Cerebral palsy and acquired brain injuries. In E. Broad (Ed.), *Sports Nutrition for Paralympic Athletes* (pp. 91-105). Taylor & Francis Group.

Cruz-Jentoft, A. J., Bahat, G., Bauer, J., Boirie, Y., Bruyere, O., Cederholm, T., Cooper, C., Landi, F., Rolland, Y., Sayer, A. A., Schneider, S. M., Sieber, C. C., Topinkova, E., Vandewoude, M., Visser, M., Zamboni, M., Writing Group for the European Working Group on Sarcopenia in Older, P., & the Extended Group for, E. (2019). Sarcopenia: Revised European consensus on definition and diagnosis. *Age Ageing*, *48*(1), 16-31. https://doi.org/10.1093/ageing/afy169

Damcott, M., Blochlinger, S., & Foulds, R. (2013). Effects of passive versus dynamic loading interventions on bone health in children who are nonambulatory. *Pediatric Physical Therapy*, *25*(3), 248-255. https://doi.org/10.1097/PEP.0b013e318299127d

Damiano, D. L., Quinlivan, J., Owen, B. F., Shaffrey, M., & Abel, M. F. (2001). Spasticity versus strength in cerebral palsy: Relationships among involuntary resistance, voluntary torque, and motor function. *European Journal of Neurology*, *8*(5), 40-49. http://doi.org/10.1046/j.1468-1331.2001.00037.x

Das, K., de Paula Oliveira, T., & Newell, J. (2023). Comparison of markerless and marker-based motion capture systems using 95% functional limits of agreement in a linear mixed-effects modelling framework. *Scientific Reports*, *13*(1), 22880. https://doi.org/10.1038/s41598-023-49360-2

Dijkstra, H. P., Pollock, N., Chakraverty, R., & Alonso, J. M. (2014). Managing the health of the elite athlete: A new integrated performance health management and coaching model. *British Journal of Sports Medicine*, *48*(7), 523-531. https://doi.org/10.1136/bjsports-2013-093222

Dimitrijevic, L., Aleksandrovic, M., Madic, D., Okicic, T., Radovanovic, D., & Daly, D. (2012). The effect of aquatic intervention on the gross motor function and aquatic skills in children with cerebral palsy. *Journal of Human Kinetics*, *32*, 167-174. https://doi.org/10.2478/v10078-012-0033-5

Dingley, A. A., Pyne, D. B., & Burkett, B. (2015). Relationships between propulsion and anthropometry in Paralympic swimmers. *International Journal of Sports Physiology Performance*, *10*(8), 978-985. https://doi.org/10.1123/ijspp.2014-0186

Direção-Geral da Saúde**.** (2023). *Manual de atividade física adaptada para pessoas com paralisia cerebral* (Coord. Leonor Moniz Pereira; Autores: Filipa João, Fábio Vila-Nova, Leonor Moniz Pereira, Patrícia Mota, Jorge Vilela de Carvalho, Daniel Virella, & José Alvarelhão). Ministério da Saúde. https://www.dgs.pt/programa-nacional-para-a-promocao-da-atvidade-fisica/ficheiros-externos-pnpaf/manual-afadaptada_paralisiacerebral-pdf.aspx

Domenech, C., Roche, E., Reina, R., & Sarabia, J. M. (2023). Somatotype analysis of international football players with cerebral palsy: A comparison with non-disabled football players. *Journal of Functional Morphology and Kinesiology*, *8*(166), 1-11. https://doi.org/10.3390/jfmk8040166

Dummer, G. M., & Watkinds, D. H. (2008). *Training and conditioning for swimmers with disabilities.* 37th National Adapted Physical Education Conference, Promoting Physical Activity for All, California.

Dutia, I. M., Connick, M., Beckman, E., Johnston, L., Wilson, P., Macaro, A., O'Sullivan, J., & Tweedy, S. (2024). The power of Para sport: The effect of performance-focused swimming training on motor function in adolescents with cerebral palsy and high support needs (GMFCS IV) - a single-case experimental design with 30-month follow-up. *British Journal of Sports Medicine*, *58*(14), 777-784. https://doi.org/10.1136/bjsports-2023-107689

Fagher, K., DeLuca, S., Derman, W., & Blauwet, C. (2023). Optimising health equity through para sport. *British Journal of Sports Medicine*, *57*(3), 131-132. https://doi.org/10.1136/bjsports-2022-106229

Federação Portuguesa de Natação. (2024). *Federação Portuguesa de Natação*. Retrieved 2.Jan.2024 from https://fpnatacao.pt

Ferreira, C. C., Espada, M. C., M. Gamonales, J., & Muñoz-Jiménez, J. (2023). Current status of sport performance in Boccia: Systematic review of the literature. *Retos*, *48*, 1070-1077. https://doi.org/10.47197/retos.v48.95110

Figueiredo, P., Willig, R., Alves, F., Vilas-Boas, J. P., & Fernandes, R. J. (2014). Biophysical characterization of a swimmer with a unilateral arm amputation: A case study. *International Journal of Environmental Research and Public Health*, *9*(6), 1050-1053. https://doi.org/10.1123/ijspp.2013-0438

Flanagan, S. P. (2012). Mobility. In T. Miller (Ed.), *NSCA's guide to tests and assessments* (pp. 275-294). Human Kinetics.

Fosdahl, M. A., Jahnsen, R., Pripp, A. H., & Holm, I. (2020). Change in popliteal angle and hamstrings spasticity during childhood in ambulant children with spastic bilateral cerebral palsy. A register-based cohort study. *BMC Pediatrics*, *20*(11), 1-9. https://doi.org/10.1186/s12887-019-1891-y

Fowler, E. G., Rao, S., Nattiv, A., Heberer, K., & Oppenheim, W. L. (2015). Bone density in premenopausal women and men under 50 years of age with cerebral palsy. *Archives of Physical Medicine and Rehabilitation*, *96*(7), 1304-1309. https://doi.org/10.1016/j.apmr.2015.03.012

Garcia-Carrillo, E., Yáñez-Sepúlveda, R., Cortés-Roco, G., Ramirez-Campillo, R., & Izquierdo, M. (2023). Anthropometric characteristics, handgrip strength, and upper limb asymmetries in highly trained Chilean shot put para-athletes. *International Journal of Morphology*, *41*(4), 1123-1127. https://doi.org/10.4067/S0717-95022023000401123

Gharbaoui, I., Kania, K., & Cole, P. (2016). Spastic paralysis of the elbow and forearm. *Seminars in Plastic Surgery*, *30*(1), 39-44. https://doi.org/10.1055/s-0035-1571255

Gorla, J., Nogueira, C., Gonçalves, H., Faria, F., Buratti, J., Nunes, N., Rêgo, J., Borges, M., Vieira, I., & Roca, V. (2019). Composición corporal y perfil somatotípico de jugadores brasileños de fútbol siete con parálisis cerebral de acuerdo con la clasificación funcional. Contribución al deporte Paralímpico. *Retos*, *35*(1), 326-328. https://doi.org/https://doi.org/10.47197/retos.v0i35.58931

Gorton, G. E., 3rd, Hebert, D. A., & Gannotti, M. E. (2009). Assessment of the kinematic variability among 12 motion analysis laboratories. *Gait Posture*, *29*(3), 398-402. https://doi.org/10.1016/j.gaitpost.2008.10.060

Graham, D., Paget, S. P., & Wimalasundera, N. (2019). Current thinking in the health care management of children with cerebral palsy. *Medical Journal of Australia*, *210*(3), 129-135. https://doi.org/10.5694/mja2.12106

Graham, H. K., Rosenbaum, P., Paneth, N., Dan, B., Lin, J. P., Damiano, D. L., Becher, J. G., Gaebler-Spira, D., Colver, A., Reddihough, D. S., Crompton, K. E., & Lieber, R. L. (2016). Cerebral palsy. *Nature Reviews Disease Primers*, *2*, 15082. https://doi.org/10.1038/nrdp.2015.82

Handsfield, G. G., Williams, S., Khuu, S., Lichtwark, G., & Stott, N. S. (2022). Muscle architecture, growth, and biological remodelling in cerebral palsy: A narrative review. *BMC Musculoskelet Disord*, *23*(1), 233. https://doi.org/10.1186/s12891-022-05110-5

Haseltine, K. N., Chukir, T., Smith, P. J., Jacob, J. T., Bilezikian, J. P., & Farooki, A. (2021). Bone mineral density: Clinical relevance and quantitative assessment. *Journal of Nuclear Medicine*, *62*(4), 446-454. https://doi.org/10.2967/jnumed.120.256180

Hendarto, S. (2023). Gender differences in boccia underhand throw biomechanics. *Revista Iberoamericana de Psícologia del Ejercicio y el Deporte*, *18*(2), 228-234.

Herrero, P., Carrera, P., Garcia, E., Gomez-Trullen, E. M., & Olivan-Blazquez, B. (2011). Reliability of goniometric measurements in children with cerebral palsy: a comparative analysis of universal goniometer and electronic inclinometer. A pilot study. *BMC Musculoskeletal Disorders*, *12*, 155. https://doi.org/10.1186/1471-2474-12-155

Huang, P. C., Pan, P. J., Ou, Y. C., Yu, Y. C., & Tsai, Y. S. (2014). Motion analysis of throwing Boccia balls in children with cerebral palsy. *Research in Developmental Disabiities*, *35*(2), 393-399. https://doi.org/10.1016/j.ridd.2013.11.017

International Paralympic Committee. (2019). *Explanatory guide to classification: Paralympic summer sports*. Retrieved 1.Nov.2020 from https://gtimg.tokyo2020.org/image/upload/production/n4fd9qx81mgkd9hjllgd.pdf

International Paralympic Committee. (2022). *World para swimming classification: Rules and regulations*. World Para Swimming. Retrieved 12.Out.23 from https://www.paralympic.org/sites/default/files/2024-08/2022%20World%20Para%20Swimming%20Classification%20Rules%20and%20Regulations_FINAL.pdf

International Paralympic Committee. (2024a). *Classification code review*. Retrieved 14.Jan.2025 from https://www.paralympic.org/classification-code-review

International Paralympic Committee. (2024b). *Final IPC classification code (Version 29 April 2024)*. Retrieved 14.Jan.2025 from https://www.paralympic.org/classification-code-review

International Paralympic Committee. (2024c). *Paris 2024: Introduction to Para swimming*. Retrieved 01.Aug.2024 from https://www.paralympic.org/feature/paris-2024-introduction-para-swimming

International Paralympic Committee. (2024d). *Paris 2024: Record number of delegations and females to compete*. Retrieved 13.Jan.2025 from https://www.paralympic.org/paris-2024/news/paris-2024-record-number-delegations-and-females-compete#:~:text=Para%20athletics%20will%20feature%20the,compete%20in%2031%20medal%20events.

International Paralympic Committee. (2024e). *World Para Swimming*. Retrieved 2.Jan.2024 from https://www.paralympic.org/swimming

Kanko, R. M., Laende, E. K., Davis, E. M., Selbie, W. S., & Deluzio, K. J. (2021). Concurrent assessment of gait kinematics using marker-based and markerless motion capture. *Journal of Biomechanics*, *127*, 110665. https://doi.org/10.1016/j.jbiomech.2021.110665

Kataoka, M., Okuda, K., Iwata, A., Imura, S., Yahagi, K., & Matsuo, Y. (2020). Throwing distance and competitive performance of Boccia players. *Journal of Physical Therapy Science*, *32*, 574–577. https://doi.org/https://doi.org/10.55860/BOUA9793

Keil, M., Totosy de Zepetnek, J. O., Brooke-Wavell, K., & Goosey-Tolfrey, V. L. (2014). Measurement precision of body composition variables in elite wheelchair athletes, using dual-energy X-ray absorptiometry. *European Journal of Sport Science*, *16*(1), 65-71. https://doi.org/10.1080/17461391.2014.966763

Kelly, T. L., Wilson, K. E., & Heymsfield, S. B. (2009). Dual energy X-Ray absorptiometry body composition reference values from NHANES. *Plos One*, *4*(9), e7038. https://doi.org/10.1371/journal.pone.0007038

Keogh, J. W. L., Cox, A., Anderson, S., Liew, B., Olsen, A., Schram, B., & Furness, J. (2019). Reliability and validity of clinically accessible smartphone applications to measure joint range of motion: A systematic review. *Plos One*, *14*(5), e0215806. https://doi.org/10.1371/journal.pone.0215806

Kholod, H., Jamil, A., & Katz-Leurer, M. (2013). The associations between motor ability, walking activity and heart rate and heart rate variability parameters among children with cerebral palsy and typically developed controls. *NeuroRehabilitation*, *33*(1), 113-119. https://doi.org/10.3233/NRE-130934

Kim, W., Lee, S. J., Yoon, Y. K., Shin, Y. K., Cho, S. R., & Rhee, Y. (2015). Adults with spastic cerebral palsy have lower bone mass than those with dyskinetic cerebral palsy. *Bone*, *71*, 89-93. https://doi.org/10.1016/j.bone.2014.10.003

King, W., Levin, R., Schmidt, R., Oestreich, A., & Heubi, J. E. (2003). Prevalence of reduced bone mass in children and adults with spastic quadriplegia. *Developmental Medicine and Child Neurology*, *45*(1), 12-16. https://doi.org/10.1111/j.1469-8749.2003.tb00853.x

Koivisto-Mork, A. E., Steffen, K., Finnes, T. E., Pretorius, M., & Berge, H. M. (2023). High prevalence of low bone mineral density but normal trabecular bone score in Norwegian elite Para athletes. *Frontiers in Sports Active Living*, *5*, 1246828. https://doi.org/10.3389/fspor.2023.1246828

Kranioti, E. F., Bonicelli, A., & García-Donas, J. G. (2019). Bone-mineral density: Clinical significance, methods of quantification and forensic applications.

Research and Reports in Forensic Medical Science, *Volume 9*, 9-21. https://doi.org/10.2147/rrfms.S164933

Low, W. M., Wang, S. M., Yeh, K. K., & Chang, C. H. (2020). Spontaneous decrease in gastrocnemius spasticity after correction of knee flexion gait in children with cerebral palsy. *Journal of Orthopaedic Surgery*, *28*(1), 1-6. https://doi.org/10.1177/2309499019890252

Macedo, O. G., Cunha, C. L., Ferreira, V. M., & Soares, M. F. (2022). Differences in body composition between affected and nonaffected sides in cerebral palsy football athletes: Preliminary findings. *Retos*, *44*(2), 416-420. https://doi.org/10.47197/retos.v44i0.89905

Marcano-Fernandez, F., Prada, C., & Johal, H. (2020). Physical outcome measures: The role of strength and range of motion in orthopaedic research. *Injury*, *51 Suppl 2*, S106-S110. https://doi.org/10.1016/j.injury.2019.11.017

Marciniak, C., Gabet, J., Lee, J., Ma, M., Brander, K., & Wysocki, N. (2016). Osteoporosis in adults with cerebral palsy: Feasibility of DXA screening and risk factors for low bone density. *Osteoporos Int*, *27*(4), 1477-1484. https://doi.org/10.1007/s00198-015-3393-6

Mathewson, M. A., & Lieber, R. L. (2015). Pathophysiology of muscle contractures in cerebral palsy. *Physical and Medice Rehabilitation Clinic of North America*, *26*(1), 57-67. https://doi.org/10.1016/j.pmr.2014.09.005

McIntyre, S., Taitz, D., Keogh, J., Goldsmith, S., Badawi, N., & Blair, E. V. E. (2013). A systematic review of risk factors for cerebral palsy in children born at term in developed countries. *Developmental Medicine and Child Neurology*, *55*(6), 499-508. https://doi.org/10.1111/dmcn.12017

Medeiros, R. M., Alves, E. S., Lemos, V. A., Schwingel, P. A., da Silva, A., Vital, R., Vieira, A. S., Barreto, M. M., Rocha, E. A., Tufik, S., & de Mello, M. T. (2016). Assessment of body composition and sport performance of Brazilian Paralympic swimming team athletes. *Journal of Sports Rehabilitation*, *25*(4), 364-370. https://doi.org/10.1123/jsr.2015-0036

Meyer, N. L., & Edwards, S. (2004). Amputees. In E. Broad (Ed.), *Sports Nutrition for Paralympic Athletes* (pp. 107-126). Taylor & Francis Group.

Milanese, S., Gordon, S., Buettner, P., Flavell, C., Ruston, S., Coe, D., O'Sullivan, W., & McCormack, S. (2014). Reliability and concurrent validity of knee angle measurement: smart phone app versus universal goniometer used by experienced and novice clinicians. *Manual Therapy*, *19*(6), 569-574. https://doi.org/10.1016/j.math.2014.05.009

Miyahara, K., Wang, D. H., Mori, K., Takahashi, K., Miyatake, N., Wang, B. L., Takigawa, T., Takaki, J., & Ogino, K. (2008). Effect of sports activity on bone mineral density in wheelchair athletes. *Journal of Bone and Mineral Metabolism*, *26*(1), 101-106. https://doi.org/10.1007/s00774-007-0789-1

Morrien, F., Taylor, M. J. D., & Hettinga, F. J. (2017). Biomechanics in Paralympics: Implications for performance. *International Journal Sports Physiology Performance*, *12*(5), 578-589. https://doi.org/10.1123/ijspp.2016-0199

Morouço, P. G., Marinho, D. A., Izquierdo, M., Neiva, H., & Marques, M. C. (2015). Relative contribution of arms and legs in 30s fully tethered front crawl swimming. *Biomed Research International*, *2015*, 563206. https://doi.org/10.1155/2015/563206

Mourcou, Q., Fleury, A., Diot, B., Franco, C., & Vuillerme, N. (2015). Mobile phone-based joint angle measurement for functional assessment and rehabilitation of proprioception. *Biomed Research International*, *2015*, 328142. https://doi.org/10.1155/2015/328142

Multani, I., Manji, J., Tang, M. J., Herzog, W., Howard, J. J., & Graham, H. K. (2019). Sarcopenia, cerebral palsy, and botulinum toxin type A. *Journal of Bone & Joint Surgery*, *7*(8), e4. https://doi.org/10.2106/JBJS.RVW.18.00153

Mus-Peters, C. T. R., Huisstede, B. M. A., Noten, S., Hitters, M., van der Slot, W. M. A., & van den Berg-Emons, R. J. G. (2019). Low bone mineral density in ambulatory persons with cerebral palsy? A systematic review. *Disability Rehabiitation*, *41*(20), 2392-2402. https://doi.org/10.1080/09638288.2018.1470261

Nahm, N. J., Graham, H. K., Gormley, M. E., Jr., & Georgiadis, A. G. (2018). Management of hypertonia in cerebral palsy. *Currently Opinion in*

Pediatrics, *30*(1), 57-64. https://doi.org/10.1097/MOP.0000000000000567

New South Wales Ministry of Health. (2018). *Management of cerebral palsy in children: A guide for allied health professionals*. NSW Ministry of Health.

Novak, I., Morgan, C., Adde, L., Blackman, J., Boyd, R. N., Brunstrom-Hernandez, J., Cioni, G., Damiano, D., Darrah, J., Eliasson, A. C., de Vries, L. S., Einspieler, C., Fahey, M., Fehlings, D., Ferriero, D. M., Fetters, L., Fiori, S., Forssberg, H., Gordon, A. M., Badawi, N. (2017). Early, accurate diagnosis and early intervention in Cerebral palsy: Advances in diagnosis and treatment. *JAMA Pediatrics*, *171*(9), 897-907. https://doi.org/10.1001/jamapediatrics.2017.1689

Oliveira, T. P., Espada, M. C., Massini, D. A., Robalo, R. A. M., Almeida, T. A. F., Hernandez-Beltran, V., Gamonales, J. M., Castro, E. A., & Pessoa Filho, D. M. (2023). Effects of exercise and sports intervention and the involvement level on the mineral health of different bone sites in the leg, hip, and spine: A systematic review and meta-analysis. *International Journal of Environmental Research and Public Health*, *20*(15). https://doi.org/10.3390/ijerph20156537

Olympics. (2024). *Paralympic Schedule & Results: Para swimming*. Retrieved 13.Jan.25 from https://olympics.com/en/paris-2024/paralympic-games/schedule/para-swimming?day=29-august

Palisano, R., Rosenbaum, P., Bartlett, D., & Livingston, M. (2007). *GMFCS-E&R: Gross Motor Function Classification System Expanded and Revised*. Retrieved 20.Jan.2025 from https://canchild.ca/system/tenon/assets/attachments/000/004/471/original/GMFCS-ER_English-ACCESS.pdf

Palisano, R., Rosenbaum, P., Walter, S., Russell, D., Wood, E., & Galuppi, B. (1997). Development and reliability of a system to classify gross motor function in children with cerebral palsy. *Developmental Medicine and Child Neurology*, *39*(4), 214-223. https://doi.org/10.1111/j.1469-8749.1997.tb07414.x

Palisano, R. J., Rosenbaum, P., Bartlett, D., & Livingston, M. H. (2008). Content validity of the expanded and revised Gross Motor Function Classification

System. *Developmental Medicine and Child Neurology*, *50*(10), 744-750. https://doi.org/10.1111/j.1469-8749.2008.03089.x

Paralisia Cerebral - Associação Nacional de Desporto. (2024). *Ranking nacional de boccia 2024-25*. https://pcand.pt/sites/default/files/documentos/ranking_nacional_de_boccia_2024-25_18-11-2024_2.pdf

Paralisia Cerebral - Associação Nacional de Desporto. (n.d.). *Quem somos*. Retrieved 21.Jan.25 from http://pcand.pt/quem-somos

Paul, S., Nahar, A., Bhagawati, M., & Kunwar, A. J. (2022). A review on recent advances of cerebral palsy. *Oxidative Medicine and Celularl Longevity*, *2022*, 2622310. https://doi.org/10.1155/2022/2622310

Peters, A., Galna, B., Sangeux, M., Morris, M., & Baker, R. (2010). Quantification of soft tissue artifact in lower limb human motion analysis: A systematic review. *Gait Posture*, *31*(1), 1-8. https://doi.org/10.1016/j.gaitpost.2009.09.004

Peterson, M. D., Zhang, P., Haapala, H. J., Wang, S. C., & Hurvitz, E. A. (2015). Greater adipose tissue distribution and diminished spinal musculoskeletal density in adults with cerebral palsy. *Archives of Physical Medicine and Rehabilitation*, *96*(10), 1828-1833. https://doi.org/10.1016/j.apmr.2015.06.007

Poomulna, J., Knarr, B. A., Dutt, V., & Kingston, D. C. (2025). Comparison of gait deviation index (GDI) and gait variability index (GVI) measured by marker-based and markerless motion capture systems in children with cerebral palsy (CP). *Gait Posture*, *115*, 7-13. https://doi.org/10.1016/j.gaitpost.2024.10.018

Ratamess, N. A. (2012). Body composition. In T. Miller (Ed.), *NSCA's Guide To Tests and Assessments* (pp. 15-42). Human Kinetics.

Reina, R., Domínguez-Díez, M., Urbán, T., & Roldán, A. (2018). Throwing distance constraints regarding kinematics and accuracy in high-level boccia players. *Science & Sports*, *33*(5), 299-306. https://doi.org/10.1016/j.scispo.2018.03.078

Romero, F. Á., & Hernández, F. J. M. (2000). The perception and neuromuscular activity in individuals with cerebral palsy playing Boccia: Methodological evalutation. *Apunts: Educación física y deportes.*, *2000*(60), 59-65.

Rose, J., & McGill, K. C. (2007). Neuromuscular activation and motor-unit firing characteristics in cerebral palsy. *Developmental Medicine and Child Neurology*, *47*(5), 329-336. https://doi.org/10.1111/j.1469-8749.2005.tb01144.x

Rosenbaum, P., & Gorter, J. W. (2012). The 'F-words' in childhood disability: I swear this is how we should think! *Child: Care, Health and Development*, *38*(4), 457-463. https://doi.org/10.1111/j.1365-2214.2011.01338.x

Rosenbaum, P. L., Jacobsson, B., & Damiano, D. (2006). A report: The definition and classification of cerebral palsy April 2006. *Developmental Medicine and Child Neurology*, *49*, 8-14. https://doi.org/10.1111/j.1469-8749.2007.tb12610.x

Ross, S. A., & Engsberg, J. R. (2007). Relationships between spasticity, strength, gait, and the GMFM-66 in persons with spastic diplegia cerebral palsy. *Archives of Physical Medicine & Rehabilitation*, *88*(9), 1114-1120. https://doi.org/10.1016/j.apmr.2007.06.011

Runciman, P., & Derman, W. (2018). Athletes with brain injury: Pathophysiologic and medical challenges. *Physical Medicine Rehabilitation Clinics of North America*, *29*(2), 267-281. https://doi.org/10.1016/j.pmr.2018.01.004

Runciman, P., Tucker, R., Ferreira, S., Albertus-Kajee, Y., Micklesfield, L., & Derman, W. (2016). Site-specific bone mineral density is unaltered despite differences in fat-free soft tissue mass between affected and nonaffected sides in hemiplegic paralympic athletes with cerebral palsy: Preliminary findings. *American Journal of Physical Medicine & Rehabiitationl*, *95*(10), 771-778. https://doi.org/10.1097/PHM.0000000000000532

Santos, C. A., Moura, R. C. F. d., Lazzari, R. D., Dumont, A. J. L., Braun, L. A. F., & Oliveira, C. S. (2015). Upper limb function evaluation scales for individuals with cerebral palsy: A systematic review. *Journal of Physical Therapy Science*, *27*(5), 1617-1620. http://doi.org/10.1589/jpts.27.1617

Sarabia, J. M., Domenech, C., Roche, E., Vicente-Salar, N., & Reina, R. (2020). Anthropometrical features of para-footballers according to their cerebral palsy profiles and compared to controls. *International Journal of Environmental Research and Public Health*, *17*(23), 9071. https://doi.org/10.3390/ijerph17239071

Sheung-Tung, H. (2012). Review of fractures and low bone mass in children with cerebral palsy. *Journal of Orthopaedics, Trauma and Rehabilitation*, *16*(2), 45-50. https://doi.org/10.1016/j.jotr.2012.09.001

Shin, H. I., & Jung, S. H. (2021). Body fat distribution and associated risk of cardiovascular disease in adults with cerebral palsy. *Frontiers in Neurology*, *12*, 733294. https://doi.org/10.3389/fneur.2021.733294

Shortland, A. (2009). Muscle deficits in cerebral palsy and early loss of mobility: Can we learn something from our elders? *Developmental Medicine and Child Neurology*, *51 Suppl 4*, 59-63. https://doi.org/10.1111/j.1469-8749.2009.03434.x

Slocum, C., Kim, S., & Blauwet, C. (2018). Women and athletes with high support needs in paralympic sport: Progress and further opportunities for underrepresented populations. In *The Palgrave Handbook of Paralympic Studies* (pp. 371-388). https://doi.org/10.1057/978-1-137-47901-3_17

Sportability. (n.d.). *Sportability's Boccia Coaching Resource* Retrieved 27.Dec.2024 from https://sportabilitybc.ca/boccia-resource/

Stackhouse, S. K., Binder-Macleod, S. A., & Lee, S. C. (2005). Voluntary muscle activation, contractile properties, and fatigability in children with and without cerebral palsy. *Muscle Nerve*, *31*(5), 594-601. https://doi.org/10.1002/mus.20302

States, R. A., Krzak, J. J., Salem, Y., Godwin, E. M., Bodkin, A. W., & McMulkin, M. L. (2021). Instrumented gait analysis for management of gait disorders in children with cerebral palsy: A scoping review. *Gait Posture*, *90*, 1-8. https://doi.org/10.1016/j.gaitpost.2021.07.009

Su, Y. C., Tsai, M. C., Lin, C. Y., Yang, J., Wu, P. S., Yang, H. C., & Lin, Y. C. (2023). Does botulinum toxin injection exacerbate sarcopenia and bone mass in individuals with cerebral calsy? *Pediatric Neurology*, *149*, 32-38. https://doi.org/10.1016/j.pediatrneurol.2023.09.002

Suchomel, T. J., Nimphius, S., & Stone, M. H. (2016). The importance of muscular strength in athletic performance. *Sports Medicine*, *46*(10), 1419-1449. https://doi.org/10.1007/s40279-016-0486-0

Surveillance of Cerebral Palsy in Europe, C. G. (2000). Surveillance of cerebral palsy in Europe: A collaboration of cerebral palsy surveys and registers. *Developmental Medicine and Child Neurology*, *2000*(42), 816-824.

Szkoda, L., Szopa, A., Siwiec, A., Kwiecien-Czerwieniec, I., & Domagalska-Szopa, M. (2022). Body composition and spasticity in children with unilateral cerebral palsy: A case-control study. *Children*, *9*(12). https://doi.org/10.3390/children9121904

Tweedy, S. M., Beckman, E. M., Johnston, L. M., & Connick, M. J. (2016). Performance-Focussed Sport – An avenue to gold-medal clinical outcomes for people with neurological impairments? *Brain Impairment*, *17*(1), 99-110. https://doi.org/10.1017/BrImp.2016.5

Urban, T., Gutierrez, O., & Moreno, F. J. (2015). Effects of unstable conditions on kinematics and performance variables in young handball players. *Journal of Human Kinetics*, *46*, 39-48. https://doi.org/10.1515/hukin-2015-0032

van de Vliet, Broad, E., & Strupler, M. (2011). Nutrition, body composition and pharmacology. In Y. C. Vanlandewijck & W. R. Thomposon (Eds.), *Handbook of sports medicine and science: The Paralympic athlete* (pp. 172-197). Wiley-Blackwell.

Verschuren, O., Peterson, M. D., Balemans, A. C., & Hurvitz, E. A. (2016). Exercise and physical activity recommendations for people with cerebral palsy. *Developmental Medicine and Child Neurology*, *58*(8), 798-808. https://doi.org/10.1111/dmcn.13053

Vitrikas, K., Dalton, H., & Breish, D. (2020). Cerebral palsy: An overview. *American Family Physician*, *101*(4), 2130-2220.

Weijer, V. C. R., van Dijk, J. W., van Dam, L., Risvang, L., Bons, J., Raastad, T., van Loon, L. J. C., & Jonvik, K. L. (2024). Do Paralympic athletes suffer from brittle bones? Prevalence and risk factors of low bone mineral density in Paralympic athletes. *Bone Reports*, *21*, 101767. https://doi.org/10.1016/j.bonr.2024.101767

Whitney, D. G., Alford, A. I., Devlin, M. J., Caird, M. S., Hurvitz, E. A., & Peterson, M. D. (2019). Adults with cerebral palsy have higher prevalence of fracture compared with adults without cerebral palsy independent of osteoporosis and cardiometabolic diseases. *Journal of Bone and Mineral Research*, *34*(7), 1240-1247. https://doi.org/10.1002/jbmr.3694

Wiley, M. E., & Damiano, D. L. (1998). Lower-extremity strength profiles in spastic cerebral palsy. *Developmental Medicine and Child Neurology*, *40*(2), 100-107.

Won, J. H., & Jung, S. H. (2021). Bone mineral density in adults with cerebral palsy. *Frontiers in Neurology*, *12*, 733322. https://doi.org/10.3389/fneur.2021.733322

World Boccia. (2021a). *Boccia classification rules: 5th Edition - September*. Retrieved 20.Sep.2024 from https://www.worldboccia.com/wp-content/uploads/2021/10/Boccia-Classification-Rules-5th-Edition-September-2021287.pdf

World Boccia. (2021b). *Profile description BC5*. Retrieved 16.Jan.2024 from https://www.worldboccia.com/wp-content/uploads/2021/01/PROFILE-description-BC5.pdf

World Boccia. (2024). *About boccia*. Retrieved 2.Jan.2025 from https://www.worldboccia.com/about-boccia/

World Boccia. (n.d.-a). *About World Boccia*. Retrieved 21.Jan.25 from https://www.worldboccia.com/about-world-boccia/#vision

World Boccia. (n.d.-b). *Long-term player development in sport of boccia*. Retrieved 17.Jan.2025 from https://www.worldboccia.com/wp-content/uploads/2021/12/Boccia-Players-Pathway.pdf

Yahagi, K., Masataka, K., Ishiba, T., & Imura, S. (2024). Training effect of repeated rolling motions on boccia players with severe cerebral palsy: Comparison with the effect of conventional upper-limb training using a crossover test. *Journal of Physical Therapy Science*, *36*, 245-251. http://doi.org/ 10.1589/jpts.15.25

Zhou, Z., Li, S., Yang, L., Gao, Z., Lin, Y., Radak, Z., & Gu, Y. (2023). Inter-segmental coordination of the swimming start among Paralympic swimmers: A comparative study between S9, S10, and S12 swimmers. *Applied Sciences*, *13*(16), 1-12. https://doi.org/10.3390/app13169097

Zwierzchowska, A., Gawel, E., Karpinski, J., Maszczyk, A., & Zebrowska, A. (2023). The effect of swimming on the body posture, range of motion and musculoskeletal pain in elite para and able-bodied swimmers. *BMC Sports, Science, Medicine and Rehabilitationl*, *15*(1), 122. https://doi.org/10.1186/s13102-023-00734-z

CHAPTER II

ANTHROPOMETRIC CHARACTERISTICS AND SOMATOTYPE OF WORLD-CLASS PARA SWIMMERS WITH SPASTIC CEREBRAL PALSY

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ABSTRACT

Para swimming is a highly competitive sport in which individual physical characteristics play an important role for sports performance. However, evidence about the physical profile world-class para swimmers with Cerebral Palsy (CP) is scant. Therefore, this study investigated anthropometric characteristics and somatotype of para swimmers with spastic CP, and explored the associations between anthropometric characteristics, training and competition time, locomotion type and sport classification. Detailed measurements included demographics, athletic background, somatotype and anthropometry. Data were evaluated using the linear regression and Pearson correlation. The total sample was classified as "Ectomorph-Endomorph" (3.4 – 1.37 – 2.7), but the most predominant profile was “Endomorph-Ectomorph”. No associations were found between anthropometric variables, training and competition time and sports’ classification. A strong association was reported between the sum of skinfolds and the use of electric wheelchair ($p \leq 0.001$) and sports classification ($p \leq 0.001$). This research offers valuable insights into training and classification of para swimmers with CP.

KEYWORDS: Brain impairment; Body composition; Skinfolds; Perimetry; Bone Breadth; Paralympics

INTRODUCTION

Cerebral Palsy (CP) is a neurodevelopmental disorder resulting from damage to one or several parts of the brain responsible for motor control. This damage often leads to abnormal physical development manifesting as limb asymmetry, shorter stature, or lighter body mass (Runciman et al., 2016). Persons with CP often face specific impairments, such as ataxia, athetosis or hypertonia, which are linked to central nervous system and have a ripple effect in both neural and non-neural aspects (Graham et al., 2016). Ataxia and athetosis are characterized by impaired voluntary control of movement. Ataxia is displayed as loss of movement coordination, which affects force, rhythm and accuracy. On the other hand, athetosis entails in slower, constantly changing, writhing, or contorting movements (Cans et al., 2007). Hypertonia manifests through an abnormal resistance to joint movement, comprising three subtypes. The most prevalent form, spasticity, is characterized by heightened resistance to joint motion as velocity increases. Dystonia involves involuntary muscle activation, leading to abnormal posturing of the extremities, torso, or neck. Rigidity results in resistance to movement regardless of velocity and direction, arising from the simultaneous contraction of agonists and antagonists (Nahm et al., 2018).

While individuals with CP may encounter challenges in daily activities due to issues such as muscle coordination, sensory processing, and functional limitations (Morgan & McGinley, 2018), these factors also impact in sports performance. Specifically, in Paralympic sports, para swimming has become an extremely demanding sport due to the increase participation of para swimmers. The highest participation ever in Paralympic Games was registered in Tokyo 2020, with 606 para swimmers participating across 146 medal events, with a total of 69 World and 124 Paralympic records being broken (International Paralympic Committee, 2021) which clearly demonstrates the sport competitiveness.

Para swimming demands muscular strength endurance, core strength and stability, flexibility, adequate body composition and correct technique (Dummer & Watkinds, 2008) in order to achieve high-performance. The swimmer's performance relies on streamlined body positions, and reduced resistive drag, critical components linked directly to an individual's anthropometric profile combined with technical skills and power production (Dingley et al., 2015). However, for swimmers with CP, optimizing hydrodynamics becomes challenging due to the varied physical profiles associated with different CP types (Dingley et al., 2015). Consequently, motor disorders persistently hinder the ability to perform fundamental swimming skills such as stroke techniques and race starts (Zhou et al., 2023).

Therefore, the study of the anthropometric characteristics of swimmers with CP such as weight and height, limb lengths, breadths and girths that may impact in the critical components of swimming performance is needed. However, there are few studies reporting data on anthropometric characteristics of swimmers with CP (Dingley et al., 2015; Medeiros et al., 2016). Athletes with physical disabilities have been extensively studied in other Paralympic sports such as wheelchair basketball (Goosey-Tolfrey, 2005; e.g. Miguel-Ortega et al., 2023), wheelchair rugby (Gorla et al., 2016), wheelchair tennis (Diaper & Goosey-Tolfrey, 2009). However, these studies rarely include athletes with CP, despite the fact that CP is also classified as a physical impairment. Exceptions are limited to a few studies on CP athletes in football 7-a-side (Gorla et al., 2019; Sarabia et al., 2020) and track and field (Cherif et al., 2022). In research related to para swimming, Medeiros et al. (2016) evaluated antropometric measures of Brazilian swimmers after 6-months of trainning and reported a significant correlation between reduced fat mass percentages and enhanced swimming performance. Similarly, Dingley et al. (2015) highlighted some traits of the physical profile (e.g., low skinfolds) which would be advantageous to swimming propulsion.

The anthropometric measures are also crucial to determine the somatotype of the athletes in a specific sport. The somatotypes are described as a quantifiable representation of an individual's morphological configuration and its distinct characteristics are classified according to the following components: endomorphy, mesomorphy, and ectomorphy (Carter et al., 1983). Although the physical morphology of an athlete with CP is crucial for achieving sport success, studies about the somatotype of swimmers with CP are also scarce. To the best of our knowledge only Kamionka et al. (2020) explored the somatotype of swimmers with physical disabilities. However, the mentioned study was performed with only male and national-level athletes. On the contrary, the specialized literature exploring the somatotype of football players with CP at both national (Gorla et al., 2019; Macedo et al., 2022) and international (Domenech et al., 2023) levels is substantial.

Overall, profiling the anthropometric and somatotype characteristics of world-class athletes with disabilities enables coaches and their multidisciplinary teams (i.e., nutritionists, strength and conditioning staff) to stay updated with the evolving factors affecting sports performance (Goosey-Tolfrey, 2005). Specifically in world-class para swimmers, data about the physical characteristics will provide important information on how to optimize physical fitness levels, including tracking changes over time and comparing individuals, and analysing the impact of different training programs. Moreover, it will allow an individual approach to the swimmers needs according to gender, level of experience (i.e., young and seasoned athletes) and sports classification (Flueck, 2020).

Despite the crucial importance of these data, there is a noticeable gap in the literature concerning the anthropometry and somatotype of international para swimmers with CP. Therefore, the aim of this study was to describe the anthropometric characteristics and somatotype of world-class para swimmers with spastic CP. Specifically, the associations between anthropometric characteristics, training and competition time, walking ability and sports' classification were assessed.

METHODS

Participants

A total of 16 para swimmers with CP from Argentina (n=5), Croatia (n=1), Hungary (n=1), Iceland (n=2), Israel (n=2), Italy (n=3), Portugal (n=1) and South Korea (n=1), participated in the study that took place during the 2022 World Para Swimming Championships (Madeira, Portugal). To be eligible for the study, participants needed to meet the following inclusion criteria: i) having a diagnosis of CP (any type regarding typology and aetiology); ii) being classified between S4 and S8; and iii) participation in international championships for, at least, 2 years. The study excluded swimmers with physical impairments other than spastic hypertonia, motor ataxia, dyskinesia, or intellectual and visual impairments.

The characteristics of the participants including mean, standard-deviation, standard error, minimum and maximum value of age, height, weight and time of practice and competition are presented in Table 1.

Table 1. Demographic characteristics of the participants.

	Mean	**SD**	**Mean SE**	**Minimum**	**Maximum**
Age (years)	25.06	4.88	1.51	17	30
Height (cm)	170.87	11.02	2.96	150	185
Weight (kg)	64.53	10.06	3.23	51	85
Years of practice	17.81	6.88	2.23	9	28
Years of competition	9.37	3.20	0.73	6	13

Notes: SD = Standard-Deviation; SE = Standard Error.

The study included 6 females and 10 males, with mean of age 25.06 years (SD ± 4.88 years). Regarding job occupation, only two participants reported being full dedicated to para swimming. The majority of the participants are students or have other professional activity. The participants were representative of 4 sport classes (S4=3, S5=4, S6=4, S8=5).

Table 2 presents the clinical data of the participants, including type of CP, associated diseases, ambulatory gait and walking aid devices.

Table 2. Clinical data of the participants.

Variable	n	%
Type of CP		
Spastic diplegia	5	31.25
Spastic quadriplegia	5	31.25
Spastic hemiplegia left	4	25.00
Spastic hemiplegia right	2	12.50
Associated diseases		
No	13	81.25
Epilepsy	1	6.25
Neuropathic pain	1	6.25
Hereditary Neuropathy with Liability to Pressure Palsies; Asthma	1	6.25
Ambulatory gait		
Yes	8	50.00
No	8	50.00
Walking aid devices		
No	6	37.50
Manual wheelchair	7	43.75
Electric wheelchair	3	18.75

The majority of the participants had spastic diplegia and quadriplegia, and no associated diseases. Although half of the participants mentioned ambulatory gait, most of them reported using a walking aid device.

Procedures

Before data collection, the local organizing committee authorized the research. Initially, coaches of para swimmers with CP were contacted to inform them about the research study. Special attention was given to the timing of engagement to prevent any potential interference with the athletes' routines. All potential participants, along with their coaches, were provided a comprehensive written and oral presentation detailing the research protocol. This included the purpose of the study, methods employed, potential benefits, and any associated risks. Those who expressed interest in voluntary participation signed the informed consent. For para swimmers below the age of majority, informed consent was duly obtained from both their coaches and the swimmers themselves. The research protocol had been previously approved by the Faculty ethical committee (reference nr. CEFADE 47/2022).

Instruments

All swimmers filled a demographic questionnaire providing personal [age, gender, job occupation, height (m), weight (kg)], sports related (years of practice, years of competition and sports' classification) and clinical variables (type of CP, associated diseases, ambulatory gait and type of assistive device).

The humerus and femur bone breadths were measured using a calliper. Skinfolds (triceps, subscapular, biceps, iliac crest, and medial calf) were measured, on the less affected side, using John Bull skinfold calliper (0.1 cm accuracy, constant 10 g/mm^2 pressure on contact). All procedures were conducted according standardized guidelines by International Society for the Advancement of Kinanthropometry (2001) as well as specific recommendations to people with CP (e.g, when the right side of the body presented morphological limitations, measurements were conducted in the left side) (Crosland & Boyd, 2004). All measurements were collected by the same trained evaluator, ensuring consistency (e.g. three trials per measurement) and minimizing variability**.** The sum of the five skinfolds was calculated. The sum of skinfolds was used as a reliable approach in para swimmers with physical disabilities (Medeiros et al., 2016). Girths (arm tensed, calf) were also measured with a measuring tape. Due to the absence of specific formulas to assess the somatotype of people with physical disabilities, the somatotype of each participant was determined according to the three equations present in Carter (2002), each one related to each component:

Endomorphy = $- 0.7182 + 0.1451 (X) - 0.00068 (X^2) + 0.0000014 (X^3)$
where X = (sum of triceps, subscapular and supraspinale skinfolds) multiplied by (170.18/height in cm).

Mesomorphy = (0.858 x humerus breadth + 0.601 x femur breadth + 0.188 x corrected arm girth + 0.161 x corrected calf girth) – height 0.131 + 4.5.

Three different equations are used to calculate ectomorphy according to the height-weight ratio (HWR):

If HWR 40.75 then ectomorphy = 0.732 HWR - 28.58

If 38.25 < HWR < 40.75, then ectomorphy = 0.463 HWR - 17.63

If HWR 38.25 then ectomorphy = 0.1

Ectomorphy is determined by considering the ponderal index (PI): PI = stretch/ and computed based on these formulas:

If PI > 40.75, then Ectomorphy = (PI x 0.732) - 28.58.

If 38.25 < PI < 40.75, then Ectomorphy = (PI x 0.463) - 17.63.

If PI < 38.25, then Ectomorphy = 0.1.

Statistical analysis

The sample was characterized by mean, standard deviation, standard error of the mean, minimum and maximum values. To assess the normality of data, the Shapiro-Wilk test was used. Linear regressions were performed to identify the relationship between sports class and different anthropometric (height, weight, skinfolds, girths and sports variables (training and competition time), with the sport classes being the dependent variable and the other variables being the predictor variables. Pearson correlations were performed between anthropometric data, type of locomotion and sport class. Cohen's f was calculated to determine the effect size of the results and we determined the power based on our sample size. The significance value adopted was $p < 0.05$ and the statistical package used was R (R Core Team, 2024).

RESULTS

Sixteen para swimmers with CP participated in the study. Anthropometric characteristics and body composition are presented in Table 3.

Table 3. Characterization of the skinfolds, girths and bone breadth of the participants.

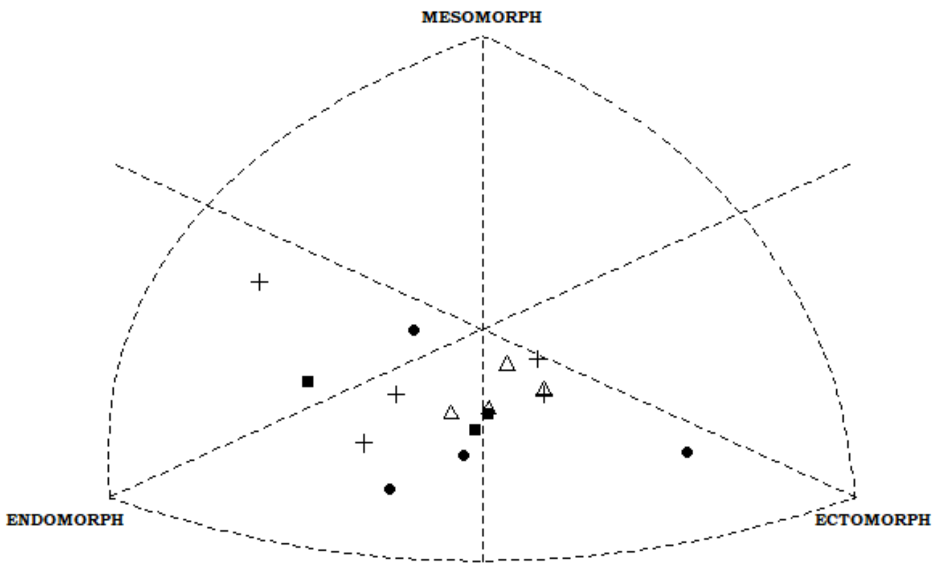
	Mean	Standard deviation	Mean standard error	Minimum value	Maximum value
Skinfolds (mm)					
Triceps right	11.44	3.83	1.38	3.8	17.0
Triceps left	10.72	4.10	2.97	4.4	14.2
Subscapular right	11.6	2.88	1.01	7.6	16.2
Subscapular left	13.08	4.98	1.76	8.0	14.0
Biceps right	6.363	1.98	0.62	4.6	10.0
Biceps left	5.56	2.18	1.51	3.0	7.8
Iliac crest right	10.02	4.55	1.66	4.6	17.0
Iliac crest left	11.24	7.44	1.69	5.2	11.0
Medial calf right	13.05	4.29	1.38	7.4	18.0
Medial calf left	10.96	10.03	2.66	0.0	9.2
∑ Skinfolds	52.19	17.06	4.27	25.4	91.0
Girths (cm)					
Arm tensed right	34.27	3.72	1.36	27.0	41.3
Arm tensed left	34.56	4.99	2.88	31.2	40.0
Calf tensed right	32.44	2.79	0.98	28.8	37.5
Calf tensed left	32.86	3.58	1.45	32.0	37.0
Bone breadth (cm)					
Humerus right	4.54	0.87	0.24	3.5	5.5
Humerus left	4.38	0.96	0.66	3.0	5.3
Femur right	6.72	0.83	0.29	5.3	8.0
Femur left	6.72	0.58	0.40	6.0	7.3

Concerning the somatotype, Table 4 presents the physical morphology of the participants. The "Endomorph-Ectomorph" profile is the most prevalent, with 43.75% of the total participants. The “Ectomorph-endomorph” profile represented 37.50% of the participants. The "Mesomorph-Endomorph" profile represented 18.75% of the participants.

Table 4. Somatotypes of the participants.

Sport class	Average Score Somatotype	Somatotype classification	Frequency distribution
S4 (n = 3)	3.7 – 1.2 – 2.47	Ectomorph-endomorph	33.33% Ectomorph-endomorph 33.33% Endomorph-ectomorph 33.33% Mesomorph-endomorph
S5 (n = 4)	3.88 – 1.35 – 3.68	Endomorph-ectomorph	25% Endomorph-ectomorph 50% Ectomorph-endomorph 25% Mesomorph-endomorph
S6 (n = 4)	3.18 – 1.6 – 3.13	Endomorph-ectomorph	75% Endomorph-ectomorph 25% Ectomorph-endomorph
S8 (n = 5)	3.02 – 1.3 – 1.72	Mesomorph-endomorph	40% Endomorph-ectomorph 40% Ectomorph-endomorph 20% Mesomorph-endomorph
$\bar{x}$ (n = 16)	3.4 – 1.37 – 2.7	Ectomorph-endomorph	

In Figure 1, the graphical representation of the participants' somatotype is presented.



Note: ■ = Class S4; ● = Class S5; Δ = Class S6 and + = Class S8.

Figure 1. Somatochart.

Linear regression demonstrated that none of the anthropometric variables and training and competition time influence the athletes' classification (Table 5).

Table 5. Relation between sports classification and different variables.

Variables	*p*
Height (cm)	0.927
Weight (kg)	0.914
Years of practice	0.663
Years of competition	0.899
Skinfolds (mm)	
Triceps	0.785
Subscapular	0.845
Biceps	0.816
Iliac crest	0.615
Medial calf	0.974
Perimetry (mm)	
Arm tensed right	0.847
Calf tensed right	0.717

When evaluating the relationship between the sum of skinfolds and the athletes' type of locomotion, a strong relationship was identified between the sum of skinfolds and locomotion via electric wheelchair ($p < 0.01$, f de cohen = 0.343, power = 53%) (Figure 2A). Similarly, when evaluating the relationship between the sum of skinfolds and sports classification it was identified a strong relationship between the sum of skinfolds and lower sport classes ($p < 0.01$, f de cohen = 0.337, power = 58%) (Figure 2B).

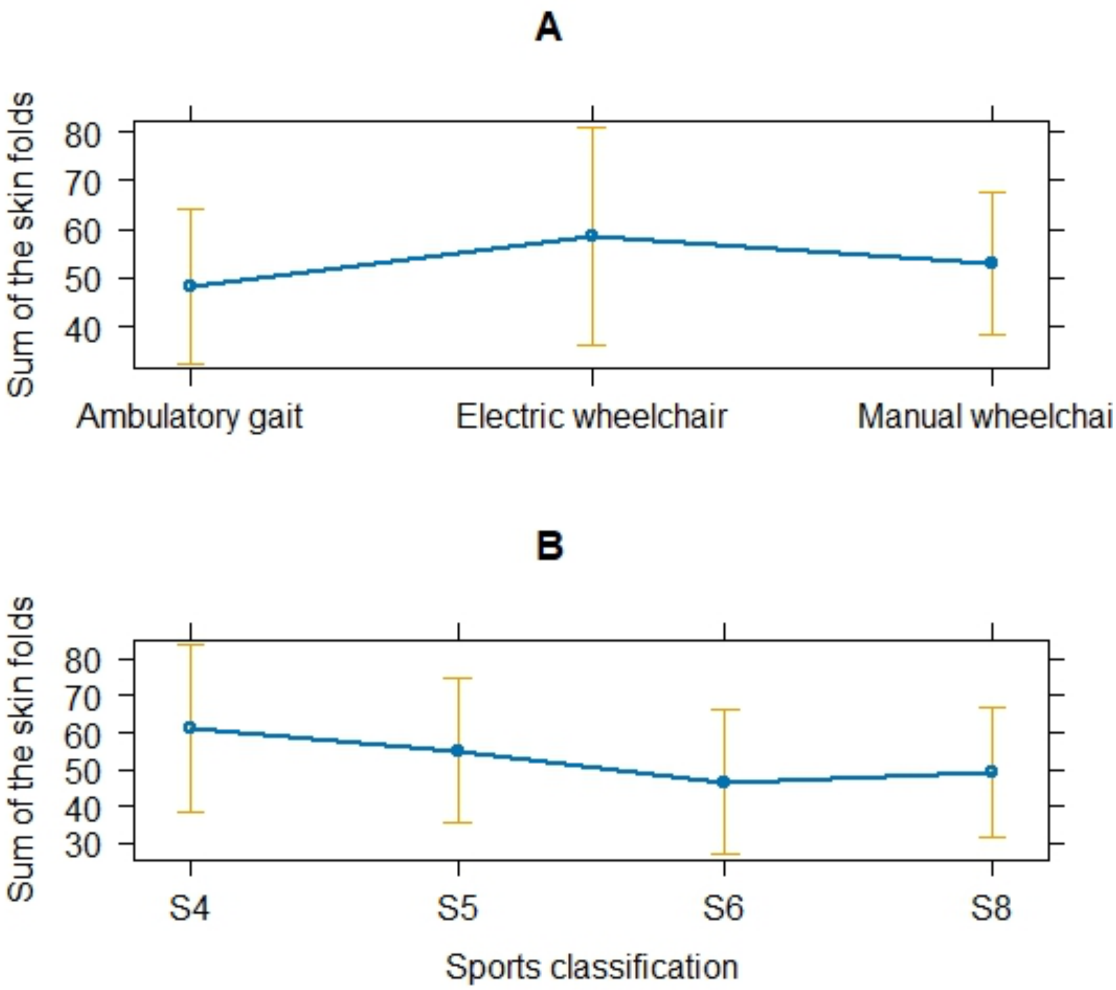


Figure 2. Relationship between sum of skinfolds, locomotion type and sports' classification.

DISCUSSION

The aim of this study was to describe the anthropometric characteristics and somatotype of world-class para swimmers with spastic CP. It was also determined the associations between anthropometrical characteristics, training and competition time, walking ability and sport classification. To best of our knowledge this is the first study to explore the anthropometrical characteristics and somatotype of world-class para swimmers with CP from different countries.

Participants' characteristics

The participants' average age, ranging from late adolescence to early adulthood (17 to 30 years) meet the usual age range for world-class para-sports involvement. Dehghansai et al. (2022) studied the age at which key sport-related developmental and performance milestones were achieved by Canadian and Australian Paralympic athletes and concluded that the group with ataxia, athetosis, and hypertonia including CP had between 18.95 years (± 11.83 years) and 24.04 years (± 11.36 years) between first main sport participation and debut at international level. These findings are in accordance with the participants age range of the present study. Regarding the participant's experience in the sport, with an average of 18 years of practice and 9 years of competition, it is possible to demonstrate the extended engagement in swimming and the athlete's expertise and commitment level. Similarly, Dehghansai et al. (2021) concluded that athletes with earlier onset impairments reached developmental milestones (e.g., national and international debut) at younger ages than athletes with late-onset impairments. Also, athletes with congenital disability accumulated more hours of specific training than athletes that acquired any type of disability in early adulthood.

The participants' average height was found to be 170.87 ± 11.02 cm, taller when compared to track athletes with CP (165.5 ± 8.33) (Cherif et al., 2022), but smaller when compared with football players with CP (176.16 ± 7.17) (Domenech et al., 2023). Medeiros et al. (2016) characterized the Brazilian Paralympic swimming team and reported an average height of 167.6 ± 0.16cm but athletes with CP were not included. Similarly, Durán-Agüero et al. (2016) measured elite athletes from different Paralympic sports, including para swimming and reported an average height of 163.6 ± 16.0cm. However, it was not possible to identify which disabilities featured the para swimming participants. Considering that athletes with CP are generally characterised by body tightness that may shorten the muscles and tendons tight, specially in lower extremities (Moreau & Lieber, 2022), the height of the participants in the present study can be considered relatively high. Height is a morphological indicator that plays a significant role in the swimming performance as taller swimmers are likely to be faster (Dopsaj et al., 2020). Typically, swimmers are tall and lean, which is helpful to keep drag to a minimum, and to produce strength and power, promoting propulsion (Pyne & Sharp, 2014). Therefore, similarly to swimmers without disabilities, height can be considered one important anthropometric characteristic when coaches are selecting swimmers with CP.

Anthropometric characteristics and somatotype

The main contribution of the present study is the description of anthropometric and somatotype profile of world-class swimmers with CP. Determining and understanding the aforementioned characteristics in an important tool for planning high performance swimming training. Regarding the anthropometric characteristics of the para swimmers, skinfolds thickness assessment of lower and upper limbs as well as trunk (i.e., biceps, triceps, subscapular, iliac crest, medial calf) was one of the methods used to explore the body composition of the participants. According to van de Vliet et al. (2011), surface anthropometry is a reliable and valid method to assess para athletes, and the use of non-specific predictive equations should be avoided to determine body fat since normative data are not available for this population. In this sense, the sum of skinfolds remains the appropriate method to assess body composition. Moreover, surface anthropometry can be expanded to include girths and bone breadths which were the assessment methods also used in the present study to explore whole body composition (van de Vliet et al., 2011). Durán-Agüero et al. (2016) also determined the anthropometric profile of Chilean athletes in six Paralympic sports (e.g. table tennis, football, swimming, rugby, powerlifting and wheelchair tennis) using skinfolds, girths and bone breadths. All mean values of skinfolds, girths and bone breadths were substantial higher when comparing with the results of the present study. Several factors such as the diversity of assessed sports and the differences in body segments demands can explain the differences between the studies. Specifically in CP football, Sarabia et al. (2020) studied anthropometric and body composition profiles of international players, and the mean values of the different skinfolds and bone breadths were also higher for all CP types (i.e., spastic, diplegia, athetosis/ataxia, spastic hemiplegia) when compared to the present study. However, differences in the girths were identified in the arm tense and calf leading to the assumption that para swimmers present a physical profile characterized by thicker arms and thinner legs when compared with the football players. Once again, these differences may be related with the different physical demands, more precisely, the use of upper body or lower body of each sport. Typically, para swimmers with CP predominantly use more upper body to generate propulsion in water.

Overall, it is possible to conclude that para swimmers assessed in the present study demonstrated worse scores with higher skinfolds and higher girths, when analysing other world-class athletes in different sports. In line with Sarabia et al. (2020) argumentation, it is suggested that para swimmers are non-professional athletes that may struggle with less availability to engage in extra training (e.g., strength and conditioning training) or nutritional controlled planning when compared with professionals' athletes. In fact, in the present study, only two participants reported being professional swimmers.

Regarding the somatotype profile, three forms of somatotypes were identified among the swimmers with CP with Endomorph-Ectomorph (43.75%) being the most predominant including S5 and S6 swimmers, followed by Ectomorph-Endomorph (37.5%) including S4 swimmers and Mesomorph-Endomorph profile (18.75%) including S8 swimmers. In general, the studied group is homogeneous with a predominance of Endomorphy component in all sport classes which indicates relative adiposity (fat mass). Both S5 and S6 swimmers presented a combination of adiposity and linearity or thinness components. According to Domenech et al. (2023), a balanced endomorph and ectomorph somatotype profile can be an advantage for CP athletes. On the other hand, only the higher functional swimmers (S8) presented a predominant Mesomorphy component, indicating relative muscular-skeletal robustness. Durán-Agüero et al. (2016) classified a subsample of Paralympic male swimmers as Mesomorph-Endomorph which matches the somatotype profile of S8 swimmers in the present study. However, the discussion of the findings is limited because it was not possible to understand whether the Chilean sample of Paralympic swimmers included athletes with CP, or even with physical disabilities. In addition, Kamionka et al. (2020) described the somatotype of 20 male swimmers with physical disabilities, including amputation, musculoskeletal disorders and paraplegia, and identified the prevalence of endomorphic and mesomorphic components. Nevertheless, the assessed swimmers were not engaged in high performance context and CP was not included.

Although, the somatotype profile of elite swimmers is higher in fat mass when compared to other sports, probably due to the effect of flotation when swimmers are inside the water (Durán-Agüero et al., 2016), it is clear that the somatotype of elite swimmers with CP is very different from the somatotype of elite swimmers without physical impairment. Specifically, Stanković et al. (2018) described different somatotype profiles with 46% being classified as Balanced Mesomorphic, 31% as Ecto-Mesomorphic and 23% as Meso-Ectomorphic.

In line with these results, Domenech et al. (2023) reported differences between the somatotype of football players without disabilities and football players with spastic hemiparesis and minimum impairment criteria. The aforementioned authors argued that CP athletes with endomorph profile should periodize their training in order to manage adiposity and enhance lean body mass, ensuring a more precise and effective approach to each individual need. However, in swimmers with CP minimal body fat is not critical in swimming performance (Shreeve et al., 2013). In previous studies with athletes with CP focused on CP football (Domenech et al., 2023; Gorla et al., 2019), mesomorphic component was predominant regardless of the functional profile (hypertonia, athetosis, or ataxia). In CP football, this homogeneity in the somatotype and high stature favours the performance when high neuromuscular efforts combined with speed, endurance, coordination, agility and strength are required (Lameira de-Oliveira et al., 2018). The predominance of muscle mass highlights the need for strength and conditioning programs for football players with CP aiming to develop specific muscle groups to improve performance in specific key performance indicators such as sprinting, changes of direction and jumps (Domenech et al., 2023). Moreover, in five shot put athletes with amputations and spinal cord injuries, the somatotype was characterized by higher skeletal muscle and adipose tissue (Endomorph-Mesomorph), along with considerable stature. These anthropometric and somatotype characteristics favours muscle power and strength which is an advantage in throwing long distances (Garcia-Carrillo et al., 2023).

Overall, the dissimilarities identified in the anthropometric and somatotype characteristics of elite swimmers with CP when compared with previously developed studies with Paralympic athletes may be related with the type of sport and type of disability. Swimmers with CP exhibit a unique body structure and morphological characteristics that are influenced by the water's properties. Muscle and bone are denser than water requiring more energy to stay at the surface. Additionally, low levels of fat mass, which is less dense than water, can impair buoyancy, making it harder to stay in surface and requiring more specialized technique (Troup, 1999). This may represent a potential advantage for the CP swimmers of the present study considering the levels of adipose tissue identified. Moreover, the findings regarding body composition are particularly interesting in the context of para swimming, considering the influence on streamlined body positions and reduce resistive drag (Dingley et al., 2015).

Correlation analysis

To the best of our knowledge, the present study is also the first attempt to identify predictor variables of sport classification in relation to the anthropometric characteristics of para swimmers with CP. Concerning the relation between sports classification and demographic, anthropometric, or training and competition related variables, it remains unclear its contribution to the classification process. Therefore, specific knowledge about these factors could improve the World Para Swimming classification process. According to the International Paralympic Committee (2022), the swimming classification process implies a physical and technical assessment related to the extent of the impairment, to the activity limitation and its effect on the sports performance. The athlete assessment comprises several tests targeting muscle, coordination, joint mobility/range of motion, loss of limb/limb deficiency, body height and leg length difference. Therefore, anthropometric and somatotype related variables are not directly assessed during the classification process. In the present study, linear regressions analysis demonstrated that none of the anthropometric (height, weight, skinfolds and girth) and sports (years of practice and competition) variables influence the swimmers’ classification.

Finally, when evaluating the relationship between the sum of skinfolds and the type of locomotion, it was identified a strong relationship between the sum of skinfolds and locomotion via electric wheelchair. As expected, a strong relationship was also identified between the sum of skinfolds and low functional classification of CP swimmers. Similarly, Dingley et al. (2015) explored anthropometry in para swimmers with different disabilities and reported that para swimmers with higher severity exhibited higher sum of skinfolds. Therefore, para swimmers with high support needs included in low functional sport classes experience less autonomy in daily life activities, relying on different types of assistive devices to aid mobility. Depending on the severity of the condition and symptoms, swimmers may also experience restrictions in sports related activities such as strength and conditioning training that may favour higher levels of body adiposity. In sum, a higher level of locomotor capability might favour the accomplishment of life habits and decrease the occurrence of restrictions to activity in persons with CP. Overall, independent walking facilitates participation in different activities (Lepage et al., 1998).

LIMITATIONS AND SUGGESTIONS FOR FUTURE RESEARCH

There are some limitations that should be considered. The first and main limitation is the sample size, which might not be enough to draw conclusions about this population. The increase of the sample size may allow more detailed analysis such as gender differences concerning anthropometrics. Also, repeated measurements across a sports season would improve the study and the conclusions. However, establishing a representative sample is challenging due to the difficulty in collecting data from different classes and degrees of impairment in para sports involving different types of disabilities, such as para swimming. Other limitation arising from the low sample was the confounding variables such as sport class, type of CP or sex. Second, the present study only included swimmers with spastic CP which may oversimplify the conclusions regarding this disability, given that the different types of CP may have implications in anthropometric variables. In addition, further evaluations including both dominant and non-dominant sides could bring specific insights concerning asymmetries and help coaches to address this issue. Fourth, the present study aimed to address para swimmers ranging from S4 to S8 with CP. Para swimmers from S7 were not included due to unavailability to participate in the research. Moreover, it remains the need to assess swimmers with more severe functional impairment. Finally, although skinfold measurements, girth assessments, and bone breadths are widely used to assess body composition, they come with inherent inaccuracies due to the specificity and heterogeneity of

CP. More advanced techniques, like Dual-energy X-ray Absorptiometry (DXA) are suggested for future studies.

CONCLUSION

The study included world-class para swimmers with CP and provided valuable insights about their anthropometric characteristics and somatotype. The data emphasizes the need for individualized training programs to optimize body composition for peak performance in athletes with CP, especially those who predominantly use upper body to force production.

Concerning somatotype profiles, CP para swimmers exhibited an Ectomorph-Endomorph profile with higher levels of adiposity, in comparison with other para sports. Moreover, no significant correlations were found between anthropometric or sports-related variables and the swimmers' classification, supporting the current classification system which relies on functional and technical assessments. However, a robust association between higher sum of skinfolds and the use of electric wheelchairs and lower functional classification was reported suggesting that higher adiposity is more likely in athletes with lower functional abilities.

Finally, the present findings appear to be relevant for guiding coaches and multidisciplinary teams in defining effective training regimens for world-class para swimmers, emphasizing the need to recognize the influence of CP in athletic development.

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REFERENCES

Cans, C., Dolk, H., Platt, M. J., Colver, A., Prasauskiene, A., & Krägeloh-Mann, I. (2007). Recommendations from the SCPE collaborative group for defining and classifying cerebral palsy. *Developmental Medicine and Child Neurology*, *49*, 35-38. https://doi.org/10.1111/j.1469-8749.2007.tb12626.x

Carter, J. E. L. (2002). *The Heath-Carter antropometric somatotype: Instruction manual*. San Diego State University.

Carter, J. E. L., Ross, W. D., Duquet, W., & Aubry, S. P. (1983). Advances in somatotype methodology and analysis. *American Journal of Physical Anthropology*, *26*, 193-213. https://doi.org/10.1002/ajpa.1330260509

Cherif, M., Said, M. A., Bannour, K., Alhumaid, M. M., Chaifa, M. B., Khammassi, M., & Aouidet, A. (2022). Anthropometry, body composition, and athletic performance in specific field tests in Paralympic athletes with different disabilities. *Heliyon*, *8*(3). https://doi.org/10.1016/j.heliyon.2022.e09023

Crosland, J., & Boyd, C. (2004). Cerebral palsy and acquired brain injuries. In E. Broad (Ed.), *Sports Nutrition for Paralympic Athletes* (pp. 91-105). Taylor & Francis Group.

Dehghansai, N., Allan, V., Pinder, R. A., & Baker, J. (2022). Examining the influence of impairment type on the development of Paralympic sport athletes. *Adapted Physical Activity Quarterly*, *39*(1), 129-138. https://doi.org/10.1123/apaq.2021-0107

Dehghansai, N., Pinder, R. A., & Baker, J. (2021). Pathways in Paralympic sport: An in-depth analysis of athletes' developmental trajectories and training histories. *Adapted Physical Activity Quarterly*, *39*(1), 37-85. https://doi.org/10.1123/apaq.2021-0095

Diaper, N. J., & Goosey-Tolfrey, V. L. (2009). A physiological case study of a Paralympic wheelchair tennis player: Reflective practise. *Journal of Sports Science and Medicine*, *8*, 300-307.

Dingley, A. A., Pyne, D. B., & Burkett, B. (2015). Relationships between propulsion and anthropometry in Paralympic swimmers. *International Journal of Sports Physiology Performance*, *10*(8), 978-985. https://doi.org/10.1123/ijspp.2014-0186

Domenech, C., Roche, E., Reina, R., & Sarabia, J. M. (2023). Somatotype analysis of international football players with cerebral palsy: A comparison with non-disabled football players. *Journal of Functional Morphology and Kinesiology*, *8*(166), 1-11. https://doi.org/10.3390/jfmk8040166

Dopsaj, M., Zuoziene, I. J., Milic, R., Cherepov, E., Erlikh, V., Masiulis, N., di Nino, A., & Vodicar, J. (2020). Body composition in international sprint swimmers: Are there any relations with performance? *International Journal of Environmental Research and Public Health*, *17*, 1-14. https://doi.org/10.3390/ijerph17249464

Dummer, G. M., & Watkinds, D. H. (2008). *Training and conditioning for swimmers with disabilities.* 37th National Adapted Physical Education Conference, Promoting Physical Activity for All, California.

Durán-Agüero, S., Valdés-Badilla, P., Varas-Standen, C., Arroyo-Jofre, P., & Herrera-Valenzuela, T. (2016). Perfil antropométrico de deportistas paralímpicos de élite chilenos. *Revista Española de Nutrición Humana y Dietética*, *20*(4), 307-315. https://doi.org/10.14306/renhyd.20.4.253

Flueck, J. L. (2020). Body composition in Swiss elite wheelchair athletes. *Frontiers in Nutrition*, *7*(1), 1-8. https://doi.org/10.3389/fnut.2020.00001

Garcia-Carrillo, E., Yáñez-Sepúlveda, R., Cortés-Roco, G., Ramirez-Campillo, R., & Izquierdo, M. (2023). Anthropometric characteristics, handgrip strength, and upper limb asymmetries in highly trained Chilean shot put para-athletes. *International Journal of Morphology*, *41*(4), 1123-1127. https://doi.org/10.4067/S0717-95022023000401123

Goosey-Tolfrey, V. (2005). Physiological profiles of elite wheelchair basketball players in preparation for the 2000 Paralympic Games. *Adapted Physical Activity Quarterly*, *22*, 57-66. https://doi.org/https://doi.org/10.1123/apaq.22.1.57

Gorla, J., Nogueira, C., Gonçalves, H., Faria, F., Buratti, J., Nunes, N., Rêgo, J., Borges, M., Vieira, I., & Roca, V. (2019). Composición corporal y perfil somatotípico de jugadores brasileños de fútbol siete con parálisis cerebral de acuerdo con la clasificación funcional. Contribución al deporte Paralímpico. *Retos*, *35*(1), 326-328. https://doi.org/https://doi.org/10.47197/retos.v0i35.58931

Gorla, J. I., Costa e Silva, A., Borges, M., Tanhoffer, R. A., Godoy, P. S., Calegari, D. R., Santos Ade, O., Ramos, C. D., Nadruz Junior, W., & Cliquet Junior, A. (2016). Impact of wheelchair rugby on body composition of subjects with tetraplegia: A pilot study. *Archives of Physical Medicine and Rehabilitation*, *97*(1), 92-96. https://doi.org/10.1016/j.apmr.2015.09.007

Graham, H. K., Rosenbaum, P., Paneth, N., Dan, B., Lin, J. P., Damiano, D. L., Becher, J. G., Gaebler-Spira, D., Colver, A., Reddihough, D. S., Crompton, K. E., & Lieber, R. L. (2016). Cerebral palsy. *Nature Reviews - Disease Primers*, *2*, 15082. https://doi.org/10.1038/nrdp.2015.82

International Paralympic Committee. (2021). *Tokyo 2020: Para swimming in numbers*. Retrieved 14.Jan.2024 from https://www.paralympic.org/news/tokyo-2020-para-swimming-numbers

International Paralympic Committee. (2022). *World para swimming classification: Rules and regulations*. World Para Swimming. Retrieved 12.Out.23 from https://www.paralympic.org/sites/default/files/2024-08/2022%20World%20Para%20Swimming%20Classification%20Rules%20and%20Regulations_FINAL.pdf

International Society for the Advancement of Kinanthropometry (2001). *International standards for anthropometric assessment*. National Library of Australia.

Kamionka, A., Grzywacz, E., & Lipowski, M. (2020). Somatotypes of athletes with physical disabilities and the type of activity they undertake. *Baltic Journal of Health and Physical Activity*, *12*(3), 47-60. https://doi.org/10.29359/bjhpa.12.3.05

Lameira de-Oliveira, G., Soares de Pinho-Gonçalves, P., Perini de-Oliveira, T. A., Valentim-Silva, J. R., Roquetti-Fernandes, P., & Fernandes-Filho, J. (2018). Composição corporal e somatotipo de atletas da seleção brasileira de futebol de 5: Equipe paralímpica Rio 2016. *Revista de la Facultad de Medicina*, *66*(1), 25-29. https://doi.org/10.15446/revfacmed.v66n1.61069

Lepage, C., Noreau, L., & Bernard, P.-M. (1998). Associations between characteristics of locomotion and accomplishment of life habits in children with cerebral palsy. *Physical Therapy*, *78*(5), 458-469. https://doi.org/https://doi.org/10.1093/ptj/78.5.458

Macedo, O. G., Cunha, C. L., Ferreira, V. M., & Soares, M. F. (2022). Differences in body composition between affected and nonaffected sides in cerebral palsy football athletes: Preliminary findings. *Retos*, *44*(2), 416-420. https://doi.org/https://doi.org/10.47197/retos.v44i0.89905

Medeiros, R. M., Alves, E. S., Lemos, V. A., Schwingel, P. A., da Silva, A., Vital, R., Vieira, A. S., Barreto, M. M., Rocha, E. A., Tufik, S., & de Mello, M. T. (2016). Assessment of body composition and sport performance of Brazilian Paralympic swimming team athletes. *Journal of Sports Rehabilitation*, *25*(4), 364-370. https://doi.org/10.1123/jsr.2015-0036

Miguel-Ortega, Á., Calleja-González, J., & Mielgo-Ayuso, J. (2023). Comparison of sports performance and kinanthropometric profiles of elite female basketball and volleyball players over the course of a competitive season. *Applied Sciences*, *13*, 1-19. https://doi.org/10.3390/app13148267

Moreau, N. G., & Lieber, R. L. (2022). Effects of voluntary exercise on muscle structure and function in cerebral palsy. *Developmental Medicine and Child Neurology*, *64*(6), 700-708. https://doi.org/10.1111/dmcn.15173

Morgan, P., & McGinley, J. L. (2018). Cerebral palsy. *Handbook of clinical neurology*, *159*, 323-336. https://doi.org/10.1016/B978-0-444-63916-5.00020-3

Nahm, N. J., Graham, H. K., Gormley, M. E., Jr., & Georgiadis, A. G. (2018). Management of hypertonia in cerebral palsy. *Currently Opinion in Pediatrics*, *30*(1), 57-64. https://doi.org/10.1097/MOP.0000000000000567

Pyne, D. B., & Sharp, R. L. (2014). Physical and energy requirements of competitive swimming events. *International Journal of Sport Nutrition and Exercise Metabolism*, *24*(4), 351-359. https://doi.org/10.1123/ijsnem.2014-0047

R Core Team. (2024). *R: A language and environment for statistical computing.* In R Foundation for Statistical Computing. <https://www.R-project.org/>

Runciman, P., Tucker, R., Ferreira, S., Albertus-Kajee, Y., & Derman, W. (2016). Effects of exercise training on performance and function in individuals with cerebral palsy: A critical review. *South African Journal for Research in Sport, Physical Education and Recreation*, *38*(3), 177-193.

Sarabia, J. M., Domenech, C., Roche, E., Vicente-Salar, N., & Reina, R. (2020). Anthropometrical features of para-footballers according to their cerebral palsy profiles and compared to controls. *International Journal of Environmental Research and Public Health*, *17*(23), 9071. https://doi.org/10.3390/ijerph17239071

Shreeve, S., Rowley, N., Gilby, C., & Mitchell, N. (2013). Changes in body composition and performance of a cerebral palsy Paralympic athlete in preparation for the London Paralympic Games. *British Journal of Sports Medicine*, *47*(17), e4.33-e34. https://doi.org/10.1136/bjsports-2013-093073.39

Stanković, D., Pavlović, R., Petković, E., Raković, A., & Puletić, M. (2018). The somatotypes and body composition of elite track and field athletes and swimmers. *International Journal of Sports Science*, *8*(3), 67-77. https://doi.org/10.5923/j.sports.20180803.01

Troup, J. (1999). The physiology and biomechanics of competitive swimming. *Clinics in Sports Medicine*, *18*(2), 267-285. https://doi.org/10.1016/s0278-5919(05)70143-5

van de Vliet, Broad, E., & Strupler, M. (2011). Nutrition, body composition and pharmacology. In Y. C. Vanlandewijck & W. R. Thomposon (Eds.), *Handbook of sports medicine and science: The Paralympic athlete* (pp. 172-197). Wiley-Blackwell.

Zhou, Z., Li, S., Yang, L., Gao, Z., Lin, Y., Radak, Z., & Gu, Y. (2023). Inter-segmental coordination of the swimming start among Paralympic swimmers: A comparative study between S9, S10, and S12 swimmers. *Applied Sciences*, *13*(16), 1-12. https://doi.org/10.3390/app13169097

CHAPTER III

UPPER BODY STRENGTH AND RANGE OF MOTION OF WORLD-CLASS PARA SWIMMERS WITH SPASTIC CEREBRAL PALSY

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ABSTRACT

This study aims to profile the athletic attributes of world-class para swimmers with Cerebral Palsy, characterizing upper body strength and range of motion (ROM). Specifically, comparations between strength and ROM across different sport classes and associations between strength, ROM and locomotion type were conducted. Sixteen para swimmers with CP (S4=3, S5=4, S6=4, S8=5), competing at the 2022 World Para Swimming Championships, were evaluated. Data included personal, sports-related, clinical variables, anthropometrics, upper body strength and joint range of motion. Descriptive statistics, Spearman test, independent samples t-test and Levene test were conducted ($p \leq 0.05$).

Medicine ball (MB) throwing distance increased with the functional classes. S5 para swimmers presented the worst results in terms of ROM. Shoulder and elbow flexion showed a significant positive correlation ($r = 0.59$, $p = 0.016$) with MB throwing distance. Comparing ROM and MB throwing distance according to locomotion type, significant differences were observed only in MB throwing distance ($p > 0.05$). The present study highlights the importance of high upper body ROM values in high MB throwing distance. Ambulatory gait also appears to be associated to higher force production.

KEY-WORDS: Para swimming, Brain impairment, MB throw, Goniometry, Locomotion type.

INTRODUCTION

Swimming is characterized as a bilateral cyclic sport combining aerobic and anaerobic systems that requires high metabolic, neuromuscular and psychological demands (Clemente-Suarez et al., 2021). Therefore, to achieve elite level, swimmers have to beneficiate from inter and multidisciplinary approaches (Barbosa et al., 2023). Similarly, para swimming has involved into one of the most competitive sports over the edge of the International Paralympic Committee (World Para Swimming, n.d.). It was one of the inaugural sporting events of the history of the Paralympic Games at the 1969 Paralympic Games in Rome (Italy) and is practiced in nearly 100 countries (World Para Swimming, n.d.). Para swimming was the second largest sport at Paris 2024 Paralympic Games in terms of athlete participation counting with 608 para swimmers representing 74 countries (International Paralympic Committee, 2024). A total of 281 women and 327 men (International Paralympic Committee, 2024) with intellectual, visual and physical impairment competed across 14 sport classes (International Paralympic Committee, 2019) and in different competition events such as backstroke, breaststroke, butterfly, freestyle, individual medley and relay (Bush, 2017). Even though para swimmers may have different eligible impairments, the schedule for Paris 2024 comprised 99 medal events distributed over 10 sports class (S1-S10) exclusively for para swimmers with physical impairment (Olympics, 2024) including cerebral palsy (CP), emphasizing the high representation of this area of impairment.

Cerebral palsy refers to a group of permanent disorders related to the development of movement and posture which are linked to non-progressive disruptions that occur during the development of the fetal or infant brain (Graham et al., 2016). Hypertonia, dyskinesia (chorea and dystonia) and motor ataxia are the sub-types of CP that lead to different neuromuscular deficits experienced by people with CP (Claudio Perret & Abel, 2016). Specifically, spasticity is the most common type of hypertonia and is defined as an increase in resistance to movement beyond a certain joint speed. This increased muscle activity is caused by a disruption of descending inhibitory feedback to the spinal cord (Nahm et al., 2018).

In para swimmers with CP, the topography of the impairment interferes in sports performance, due to body asymmetries and atypical movement patterns that affect general coordination or sport-specific tasks (Henriquez et al., 2023). Hogarth et al.

(2020) compared the propulsion of swimmers with physical impairments (classified from S1 to S10) with swimmers without impairments and found that para swimmers had lower capacity to generate propulsion. This disadvantage was even more evident in para swimmers with greater severity of swimming-specific impairment. Therefore, it is suggested that para swimmers' training should focus on the improvement of swimming propulsion ability through force production. Moreover, the authors highlighted the need for future research to focus on para swimmers with hypertonia and impaired muscle power (Hogarth et al., 2020), characteristics typically identified in CP.

Muscular strength and power have been extensively studied in swimmers without impairments (Crowley et al., 2017; Loturco et al., 2016), with upper limbs being identified as the major contributors for swimming propulsion generating 70% of propulsive forces (Morouço et al., 2015). Specifically in front crawl swimming, shoulders muscles act during the early and late underwater pull phases (Amaro et al., 2017; Martens et al., 2015) while agonist antagonist activity of muscles of the elbow and wrist stabilize the forearm and hand to overcome water drag during propulsive actions (Martens et al., 2015). Therefore, Amara et al. (2021) studied the relationship between swimming performance and upper body strength in swimmers without disabilities and highlighted the importance of assessing upper body strength and to maximize it through dry-land training. However, to the best of our knowledge no previous study explored the upper body strength of para swimmers with CP. It is important to keep in mind that swimmers with CP may exhibit great inter-individual variability regarding on how spasticity affects trunk and upper body extremities. Therefore, future research is needed to clarify the contribution of upper body power generation in para swimming performance to inform coaches about training priorities (Dingley et al., 2015).

Another key performance indicator in para swimmers with physical impairments is the range of motion (ROM) of the joints involved in stroke's power (Shimura et al., 2021). According to Flanagan (2012), ROM is defined as the amplitude in which a joint can move passively due to the amount of motion available and is one of the factors that can limit the stroke length and, consequently, the stroke rate. Swimming requires adequate ROM to optimize limb positioning, which enhances force production, reduces drag, maximizes stroke distance, and prevents injury (Dummer & Watkinds, 2008; Shimura et al., 2021). However, para swimmers with physical disabilities often experience limited joint range of motion (Sanchis et al., 2025). For example, swimmers with elbow or shoulder contractures will have restricted movement and may opt to avoid using the affected limb when swimming (Dummer & Watkinds, 2008). Consequently, restricted ROM will diminish force production and, therefore, propulsion capacity in para swimmers.

In this regard, it is important to highlight that strength and mobility training are important for swimming performance but also for para swimmers' rehabilitation. Zwierzchowska et al. (2023) explored the effects of swimming on the body posture, ROM and muscle skeletal pain in a sample of elite Polish swimmers with physical impairments (including CP) and without impairments. In the group of swimmers with physical impairments, an extrinsic compensatory mechanism was identified leading to structural and functional changes in body posture. Both internal compensatory mechanism and continuous overload of the anatomy trains as a result of swimming training were responsible for musculoskeletal complaints. To conclude, the authors advocated the important role of strength and mobility training in injuries prevention allowing to minimize muscular imbalance and disturbances in ROM related to para swimming training (Zwierzchowska et al., 2023). In accordance, Salerno et al. (2022) studied the inclusion of the U.S. Paralympic team in an injury prevention program, and highlighted that para swimmers with physical disability emphasized the value of having individualized support from a well-experienced multidisciplinary team including coaches and different healthcare specialists (e.g., strength and conditioning coaches, sports psychologist, nutritionist, sports medicine physicians and physiotherapists) working all together to support the athlete's pathway.

Therefore, analysing upper limb strength and ROM values from world-class para swimmers and its relationships with sport classification and locomotion type is crucial for coaches and multidisciplinary teams when prescribing individual training programs in order to improve overall para swimming performance. To the best of our knowledge, no previous studies have made this attempt.

Based on the above rationale, the present study aims (1) to characterize upper body strength and ROM of world-class para swimmers with spastic CP; (2) to compare strength and ROM across different sports classes; and (3) to investigate the associations between strength, ROM and locomotion type.

METHODS

Participants

Sixteen para swimmers with CP from several countries in Europe (n=10), South America (n=5) and Asia (n=1) who took part in a World Para Swimming Championships were evaluated. To be included in the study, participants needed to have a confirmed diagnosis of any type of CP regardless of topology (i.e., body distribution) and aetiology of impairment (i.e., congenital vs acquired); to be classified between S4 and S8; and, to have at least 2 years of experience in international championships. Swimmers with other physical impairments than spastic hypertonia, motor ataxia or dyskinesia and intellectual or visual impairments were excluded from the study.

Regarding sport classification, the participants were divided into 4 sport classes (S4=3, S5=4, S6=4, S8=5). No swimmers for the sport class S7 were included in the study. In para swimming, there are ten sport classes named with the prefix "S" for athletes with physical disability, including CP. According to the International Paralympic Committee (2019), S4 swimmers can use their arms and have fair hand function but cannot use their trunk or legs and may also have amputations of three limbs. S5 swimmers have short stature and an additional impairment, such as loss of control on one side of the body (hemiplegia) or paraplegia. S6 swimmers also have short stature, amputations of both arms, or moderate coordination issues on one side of the body S7 with one leg and one arm amputated on opposite sides or paralysis of one arm and one leg on the same side. Those in S8 sport class typically have an amputation of one arm or significant restrictions across the hip, knee, and ankle joints (International Paralympic Committee, 2019).

Regarding locomotion type, half of the participants reported ambulatory gait but two of them mentioned the use of walking aid devices (n=1 manual wheelchair; n=1 electric wheelchair), specifically in competition settings. The other half of participants reported the use of walking devices on a daily basis (n=6 manual wheelchairs; n=2 electric wheelchairs).

Procedures

The organizing committee of the World Para Swimming Championships and the team managers of each participating country authorized the research. Participants voluntarily signed the informed consent after understanding the risks and benefits of participation. For underage participants, consents were also obtained from their coaches. The research was conducted according to the Declaration of Helsinki guidelines and previously approved by the Faculty Ethical Committee (protocol nr CEFADE 47/2022).

Participants were recruited and assessed in a designated schedule, defined by the head coaches to minimize the interference with sport's performance. Specifically, participants were approached during rest periods between the training and adaptation phase or upon concluding individual events. This organization ensured minimal interference in the participants competition routines. Data collection occurred in each accommodation site and did not exceed a duration of 35 minutes to optimize participants comfort.

Instruments

Swimmers were asked to complete a sociodemographic questionnaire with personal, sports and clinical information. Height (m) and weight (kg) were also reported.

To assess functional upper limb strength, a seated throw was performed. Athletes sited on a chair (or daily living wheelchair) and throwed a 2kg medicine ball (MB throw), using a chest pass movement, as far as possible. The distance (in centimetres) where the ball first landed was registered. The mean value of three throws trials was taken as the final measurement. This protocol was adapted from Gomes Costa et al. (2021) who conducted a similar research with wheelchair basketball athletes and used a 5kg MB throw. The authors argued that MB throw is a fast, feasible and inexpensive assessment tool to be used in Paralympic sports. Also, Oliveira et al. (2023) highlighted the potential of using the 2kg MB throw test as a parameter for assessing strength in throwing athletes with physical disabilities. Range of motion (º) was determined in the less affected side with goniometry at shoulder (flexion/extension, adduction/abduction and internal/external rotation), elbow (flexion/extension and supination/pronation) and wrist (flexion/extension) joints using International Society of Biomechanics guidelines (Wu et al., 2005) as suggested by Francisco-Martinez et al. (2021) for athletes with CP from different sports. Similarly, Suarez-Iglesias et al. (2020) used goniometry to successfully assess ROM with boccia players with CP.

Statistical analysis

The sample was characterized by mean, standard deviation, standard error of the mean, minimum and maximum values. To test the normality of the data, the Shapiro-Wilk test was used. The significance value adopted was $p \leq 0.05$ and the statistical software used was (R Core Team, 2024). ANOVA analysis of variance was carried out between the type of locomotion and classification and throwing distance. When significant differences were identified, a post-hoc Tukey test was used. Furthermore, correlations were carried out between sport class and the other variables. A correlation was made between the variables of ROM and throwing distance.

RESULTS

Sixteen para swimmers with CP (females=6; males=10) participated in the study. Demographic, strength and ROM variables are presented in Table 1.

Table 1. Participants' characteristics regarding demographic, strength and ROM variables

	Mean	SD	Mean SE	Minimum	Maximum
Age (years)	25	4.88	1.51	17	30
Height (cm)	171	11.02	2.96	150	185
Weight (kg)	64	10.06	3.23	51	85
Years of practice	17.5	6.88	2.23	9	28
Years of competition	9.5	3.20	0.73	6	13
Strength (cm)	386.67	185.24	53.38	145	690
Shoulder flexion	172.94	14.81	3.70	135	180
Shoulder abduction	159.50	45.27	11.32	20	180
Shoulder internal rotation	38.33	23.98	6.00	0	70
Shoulder external rotation	57.44	30.36	7.59	10	90
Elbow flexion	126.44	21.91	5.48	75	150
Elbow supination	71.44	22.97	5.74	20	90
Elbow pronation	70.63	25.85	6.46	5	90
Wrist flexion	55.50	14.04	3.51	20	75
Wrist extension	51.47	20.39	5.10	0	70

Note: SD = Standard Deviation; SE = Standard Error; ROM (range of motion).

Concerning types of CP, all participants had spastic hypertonia. with different body distribution (n=5 diplegia; n=5 quadriplegia; and n=6 hemiplegia). On average, participants practised swimming for 17.5 years (± 6.88) and competed for 9.5 years (±3.20). Strength measurements varied from 145 to 690 cm. Regarding ROM, shoulder flexion exhibited a mean value of 172.94º (±14.81), while shoulder abduction showed a mean of 159.50º (± 45.27). Internal and external shoulder rotations averaged 38.33º (± 23.98) and 57.44º (± 30.36), respectively. Elbow flexion had a mean of 126.44º (± 21.91) and wrist flexion and extension with means of 55.50º (±14.04) and 51.47º (± 20.39).

When performing the ANOVA and comparing the results found between the sport classification groups, a significant difference was found only when compared with age ($p = 0.007$). The older athletes were part of the S8 class while the younger athletes were part of the S4 class (Figure 1).

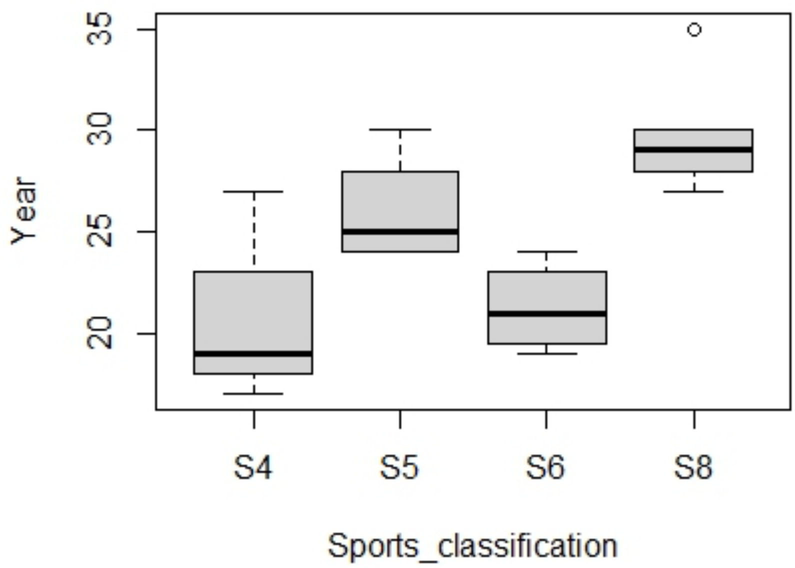

Figure 1. Comparison between sport classes.

When comparing the locomotion data with the other variables, we found a significant difference between the locomotion of participants with the sport class (p = 0.014, mainly between manual wheelchair and ambulatory gait (p = 0.012), in which athletes with ambulatory gait presented higher sport classes, which was already expected, since higher the class, the greater the functionality (Figure 2).

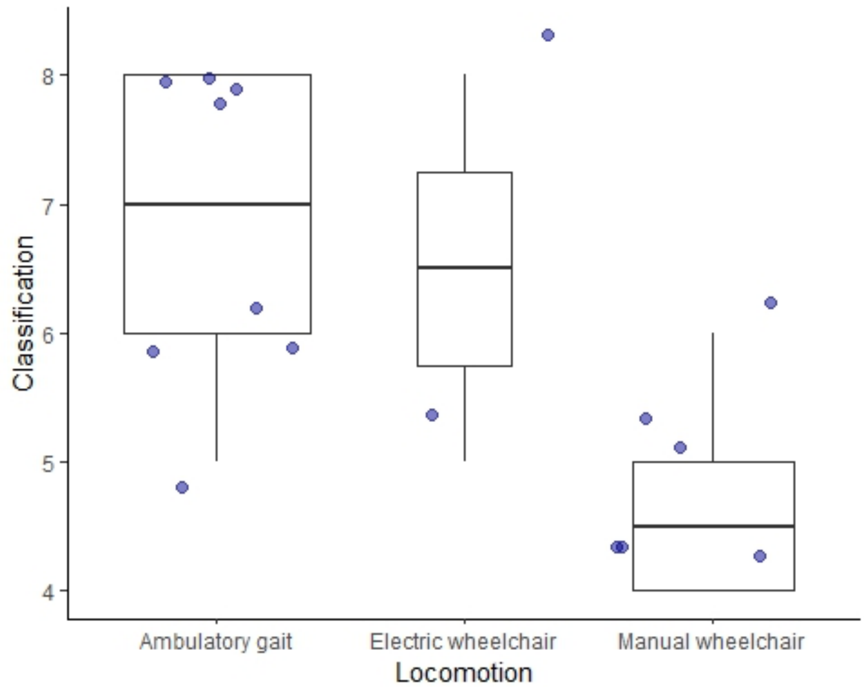

Figure 2. Comparation between classification and locomotion.

There was also a significant difference between locomotion and the distance between throwing the ball (p = 0.0358) in which athletes with ambulatory gait achieved greater throwing distances (Figure 3).

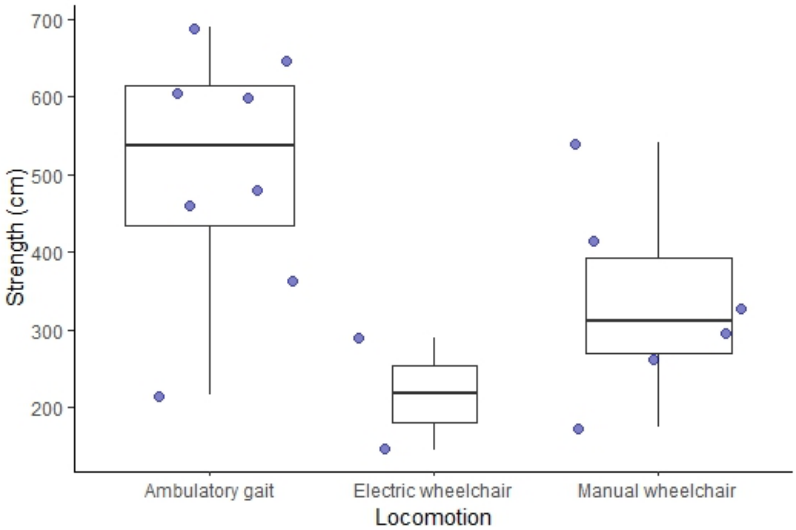

Figure 3. Comparation between locomotion and throwing distance.

When performing the correlations, only age showed a moderate and significant correlation (Table 2), demonstrating a directly proportional relationship (Figure 4), in which the older the age, the higher the sport class.

Table 2. Correlation between sport classes and other variables.

Variables	r	P - Value
Age (years)	0.60	0.014
Height (cm)	0.10	0.719
Weight (kg)	0.37	0.156
Years of practice	0.31	0.248
Years of competition	0.11	0.692
Strength (cm)	0.44	0.090

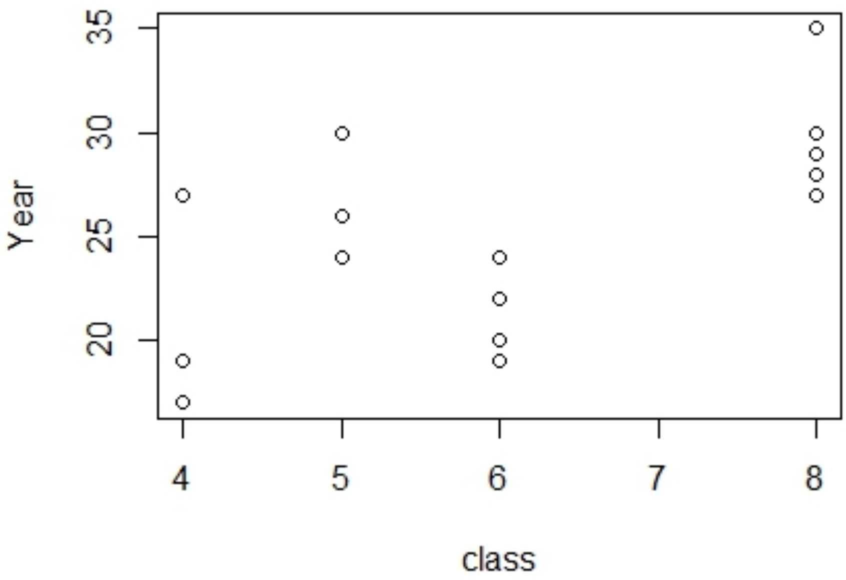

Figure 4. Relation between sport classes and age.

Correlations between throwing distance and range of motion demonstrated moderate and significant correlations between distance and shoulder flexion (p = 0.016) and between distance and elbow flexion (p = 0.006). The correlations demonstrate a directly proportional relationship between the ranges of movement and the throwing distance, the greater the angle, the greater the distance values (Table 3).

Table 3. Correlation between ball throwing and goniometry.

Movement	R^2	P - value
shoulder flexion	0.59	0.016
shoulder abduction	0.33	0.206
shoulder internal rotation	0.16	0.544
shoulder external rotation	0.35	0.179
elbow flexion	0.65	0.006
elbow supination	0.21	0.430
elbow pronation	0.21	0.434
wrist flexion	0.39	0.134
wrist extension	0.37	0.162

DISCUSSION

This study aimed (1) to characterize upper body strength and ROM of world-class para swimmers with spastic CP; (2) to compare strength and ROM across different sports classes; and (3) to investigate the associations between strength, ROM and locomotion type.

In relation to the first goal, concerning strength values, the minimum vale of the MB throw was 145cm and the maximum was 690cm. Longer MB throwing distance means more upper body strength. To the best of the author's knowledge, this test hasn't been used yet with para swimmers with CP. Marszalek et al. (2019) created a calculator to predict mean power or peak power on the basis of the selected field-based test (namely 3kg MB chest pass test) results for two functional categories of wheelchair basketball players, where one player with CP was included. The participants were divided in two groups accordingly to their functional classification (players with lower classification belonged to group A and higher classes were attributed to group B), so it is unclear to which group the player with CP belongs to. However, the results indicated that the group B had a higher mean throwing distance (7.08 ± 1.27m) that group A (5.90 ± 0.93m). These results support the ones in the present study in so far as the higher classes present longer throwing distances that the lower classes. Strength and employing effective training methods are essential aspects of enhancing performance in both swimming and para swimming. Gola et al. (2014) studied the relationship between the strength of upper extremity muscle groups and freestyle swimming velocity in competitive swimmers without disabilities and found that the participants who achieved some of the fastest swimming velocities featured greater upper extremity strength. However, the used tests were not the MB throwing. Garrido et al. (2010) used ball throwing performance (1 and 3kg) to examine the effects of eight weeks of combined dry land strength and aerobic swimming training for increasing upper and lower body strength, power and swimming performance in young competitive swimmers and to assess the effects of a detraining period (strength training cessation) on strength and swimming performance. Once performance in both tests increased after the strength training in the experimental group whereas in the control group the values remained similar results indicated a tendency to improve sprint performance due to strength training. Similarly, but in para swimming, Dingley et al. (2015) studied the effectiveness of a dry-land program that focuses on improving measures of power and strength in Paralympic swimmers and whether these improvements transfer to swimming performance in Paralympic swimmers (3 with CP), but used other test (swim bench). The results also indicated that despite the inherent diversity in disabilities among Paralympic swimmers, generalized programs can lead to measurable improvements that translate to enhanced swimming performance. In addition, tailoring a dry-land resistance training regimen with exercises specifically adapted to each swimmer's unique disability might result in even more significant performance gains concerning strength. Also, Cavaggioni et al. (2024) conducted a study to examine the relationship between strength and power in dryland upper body exercises and swimming performance among elite Paralympic swimmers, finding a strong correlation between the studied variables. Even though there were no para swimmers with CP, there were participants from S5 class (n=2), S6 class (n=1) and S8 class (n=1), the same classes assessed in the present study.

Concerning ROM values, it is important to highlight that shoulder ROM is influenced by age, sex and hand dominance (Barnes et al., 2001), so it affects the ability to establish normative values, especially for para swimmers with CP.

Cejudo et al. (2019) did a study to determine the profile of shoulder flexibility in young competitive swimmers without disability and found that pain-free swimmers had 180.8 ± 8.7º of shoulder flexion, 176.9 ± 8.1º of shoulder abduction, internal rotation of 75.0 ± 12.6º and external rotation of 132.8 ± 11.9º. Shimura et al. (2021) studied if hemiplegic swimmers (S7) had restricted ROM on the non-paretic limb comparing to other para swimmers without physical disabilities and found that there were no differences between groups. For shoulder flexion, the dominant side showed a range of 189.7°, while the non-dominant or paretic side had a reduced range of 165.0°. In terms of external rotation, the dominant side achieved 102.0°, but the paretic side showed a much lower range of 45.7°. For internal rotation, the dominant side reached 54.0°, whereas the non-dominant side displayed a reduced range of 34.3°. Elbow range of motion also demonstrated asymmetry. In flexion, the dominant side achieved 150.7°, and the non-dominant or paretic side was similar at 151°. In the present study, the assessed side was the (less affected side) dominant one, so the values found are lower than Shimura et al. (2021). This might be due to the difference in the functional classes of each study’s participants – the present study comprised S4, S5, S6 and S8 whereas Shimura et al. (2021) only assessed para swimmers S7. Other reason might be the difference in CP type, given that the present study had participants not only with hemiplegia, but also with diplegia and quadriplegia. CP presents with a wide range of clinical symptoms, with severity and distribution of impairments across the trunk and extremities varying significantly between individuals. Para swimmers with this condition often face challenges such as reduced strength, limited motor coordination, and restricted range of motion, which hinder their ability to generate propulsion and reduce resistance in the water (Burkett et al., 2018). This highlights the importance of assessing these physical variables and find effective methodologies to improve them and, consequently, improve swimming performance.

When comparing strength and range of motion across different sports classes, results obtained showed that MB throwing distance increases with the increase of the functional class. Para swimmers classified as S8 presented longer MB throwing distance, (507.07 ± 220.20cm) than the S4 (323.00 ± 80.09cm). Nicholson et al. (2018) established the reliability and preliminary normative values for a battery of swimming-specific range of motion tests and found that athletes in lowest functional class, typically characterized by more severe physical disabilities, often face challenges associated with reduced muscle function, which can directly impact their capacity to generate the necessary propulsion and power required for optimal performance. This is in concordance with the values found in the present study. Nicholson et al. (2018) also reported that a higher degree of disability may lead to a limited range of motion. However, S5 swimmers presented the lowest values in all joints evaluated. Nevertheless, the assess S5 were not the para swimmers with higher degree of disability, since the present study also includes S4 para swimmers, therefore, presenting more limitations.

Regarding the relation between MB throwing distance and ROM, there is a significant positive correlation with shoulder flexion and elbow flexion. This may suggest that para swimmers with more ROM on these joints can produce more strength with their upper extremities. Greater values in strength and ROM may indicate that the swimming performance will be better. These findings are in line with the findings of Gola et al. (2014), in which swimmers registered best results in elbow flexors and shoulder flexors and extensors.

When comparing joint range of motion and MB throwing distance based on locomotion type, significant differences were observed in MB throwing distance between ambulatory and non-ambulatory para swimmers. The non-ambulatory group exhibits significantly different throwing distances compared to the ambulatory group. This may suggest that para swimmers that are able to walk can produce more upper body strength than para swimmers who use any type of wheelchair (electric or manual). Hemiplegics who are unable to walk independently show less muscle mass on both paretic and nonparetic sides (Shimura et al., 2021), hence, displaying less force production ability. It is anticipated that ambulatory athletes are classified in higher classes, since they usually present less severe physical disabilities that lower classes. This leads to more muscle function and, consequently, greater capacity of producing more strength and power (Zhou et al., 2023) than lower classes, therefore, non-ambulatory para swimmers.

LIMITATIONS AND SUGGESTIONS FOR FUTURE RESEARCH

This study has several limitations. The reduced number of participants do not allow to generalize the findings, even though some of the best para swimmers of the world with CP were included in the study. Concerning methodology, both upper body extremities should have been assessed for ROM, enabling the comparison between sides. Also, future research assessing ROM should consider the use of an inclinometer, as suggested by Nicholson et al. (2018). The relationship between sports performance (i.e., times and rankings) strength and ROM values of each functional class should also be explored in further studies. It is also noteworthy that fatigue alters ROM and the training/competition volume that para swimmers had at the time of the measurements, could have influenced the results. Other timings in-season should be considered for future research. Lastly, longitudinal approaches can be interesting approaches to characterize the development of world-class para swimmers with CP thought the Paralympic cycle. Adding physiological variables such as heart-rate variability or lactate levels could also help coaches and multidisciplinary staff tailoring individualized training prescription in the future.

CONCLUSION

The present study presents world-class reference values from para swimmers with CP, that can be used as key-performance indicators for coaches and youth talent programs. Also, it introduces the relationship between upper extremities force production and functional classification, which increase proportionally. Force production represented as the throwing distance of the medicine ball also relates to the range of motion of the upper body joints, more precisely, with the shoulder and elbow joints. Para swimmers with higher MB throwing distance have greater shoulder and elbow flexion. At last, when comparing ambulatory and non-ambulatory athletes, in seems that using a wheelchair, manual or electric, compromises the force production, since throwing distance decreased. In conclusion, this study gives valuable insights for coaches concerning several physical variables that should be addressed when prescribing training programs with the aim of reaching world-class level.

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REFERENCES

Amara, S., Chortane, O. G., Negra, Y., Hammami, R., Khalifa, R., Chortane, S. G., & van den Tillaar, R. (2021). Relationship between swimming performance, biomechanical variables and the calculated predicted 1-RM push-up in competitive swimmers. *International Journal of Environmental Research and Public Health*, *18*(21). https://doi.org/10.3390/ijerph182111395

Amaro, N., Marinho, D. A., Marques, M. C., Batalha, N. P., & Morouço, P. (2017). Effects of dry-land strength and conditioning programs in age group swimmers. *Journal of Strength and Conditioning Research*, *31*(9), 2447-2454.

Barbosa, T. M., Barbosa, A. C., Simbana Escobar, D., Mullen, G. J., Cossor, J. M., Hodierne, R., Arellano, R., & Mason, B. R. (2023). The role of the biomechanics analyst in swimming training and competition analysis. *Sports Biomechics*, *22*(12), 1734-1751. https://doi.org/10.1080/14763141.2021.1960417

Barnes, C. J., Van Steyn, S. J., & Fischer, R. A. (2001). The effects of age, sex, and shoulder dominance on range of motion of the shoulder. *Journal of Shoulder and Elbow Surgery*, *10*(3), 242-246. https://doi.org/10.1067/mse.2001.115270

Burkett, B., Hogarth, L., Vliet, P. V. d., & Payton, C. (2018). *Using underwater 3D kinematics to improve the Paralympic Swimming* 36th Conference of the International Society of Biomechanics in Sports, Auckland, New Zealand.

Bush, A. J. (2017). From Melksham to Rio: A coach's 20-year journey in para-swimming. In Geoffery Z. Kohe & D. M. Peters (Eds.), *High performance disability sport coaching* (pp. 163-185). Routledge.

Cavaggioni, L., Scurati, R., Tosin, M., Vernole, R., Bonfanti, L., Trecroci, A., & Formenti, D. (2024). Are dryland strength and power measurements associated with swimming performance? Preliminary results on elite paralympic swimmers. *Sports*, *12*(4). https://doi.org/10.3390/sports12040094

Cejudo, A., Sanchez-Castillo, S., Sainz de Baranda, P., Gamez, J. C., & Santonja-Medina, F. (2019). Low range of shoulders horizontal abduction predisposes for shoulder pain in competitive young swimmers. *Frontiers in Psychology*, *10*, 478. https://doi.org/10.3389/fpsyg.2019.00478

Claudio Perret, & Abel, T. (2016). Physiology. In Yves C. Vanlandewijck & W. R. Thompson (Eds.), *Training and coaching the Paralympic athlete* (Vol. 2016, pp. 53-74). International Olympic Committee.

Clemente-Suarez, V. J., Fuentes-Garcia, J. P., Fernandes, R. J., & Vilas-Boas, J. P. (2021). Psychological and physiological features associated with swimming performance. *International Journal of Environmental Research and Public Health*, *18*(9). https://doi.org/10.3390/ijerph18094561

Crowley, E., Harrison, A. J., & Lyons, M. (2017). The impact of resistance training on swimming performance: A systematic review. *Sports Medicine*, *47*(11), 2285-2307. https://doi.org/10.1007/s40279-017-0730-2

Dingley, A. A., Pyne, D. B., Youngson, J., & Burkett, B. (2015). Effectiveness of a dry-land resistance training. *Journal of Strength and Conditioning Research*, *29*(3), 619-626.

Dummer, G. M., & Watkinds, D. H. (2008). *Training and conditioning for swimmers with disabilities.* 37th National Adapted Physical Education Conference, Promoting Physical Activity for All, California.

Flanagan, S. P. (2012). Mobility. In T. Miller (Ed.), *NSCA's guide to tests and assessments* (pp. 275-294). Human Kinetics.

Francisco-Martinez, C., Prado-Olivarez, J., Padilla-Medina, J. A., Diaz-Carmona, J., Perez-Pinal, F. J., Barranco-Gutierrez, A. I., & Martinez-Nolasco, J. J. (2021). Upper limb movement measurement systems for cerebral palsy: A systematic literature review. *Sensors (Basel)*, *21*(23). https://doi.org/10.3390/s21237884

Garrido, N., Marinho, D. A., Reis, V. M., Tillaar, R. v. d., Costa, A. M., Silva, A. J., & Marques, M. C. (2010). Does combined dry-land strength and aerobic training inhibit performance of young competitive swimmers? *Journal of Sports Science and Medicine*, *9*, 300-310.

Gola, R., Urbanik, C., Iwańska, D., & Madej, A. (2014). Relationship between muscle strength and front crawl swimming velocity. *Human Movement*, *15*(2). https://doi.org/10.2478/humo-2014-0011

Gomes Costa, R. R., Dorneles, J. R., Lopes, G. H., Gorla, J. I., & Ribeiro Neto, F. (2021). Medicine ball throw responsiveness to measure wheelchair basketball mobility in male players. *Journal of Sport Rehabilitation*, *30*(8), 1230-1232. https://doi.org/10.1123/jsr.2020-0222

Graham, H. K., Rosenbaum, P., Paneth, N., Dan, B., Lin, J. P., Damiano, D. L., Becher, J. G., Gaebler-Spira, D., Colver, A., Reddihough, D. S., Crompton, K. E., & Lieber, R. L. (2016). Cerebral palsy. *Nature Reviews - Disease Primers*, *2*, 15082. https://doi.org/10.1038/nrdp.2015.82

Henriquez, M., Pena-Gonzalez, I., Albaladejo-Garcia, C., Sadarangani, K. P., & Reina, R. (2023). Sex differences in change of direction deficit and asymmetries in footballers with cerebral palsy. *Scandinavian Journal of Medicine & Science in Sports*, *33*(8), 1519-1530. https://doi.org/10.1111/sms.14383

Hogarth, L., Burkett, B., Van de Vliet, P., & Payton, C. (2020). Maximal fully tethered swim performance in para swimmers with physical impairment. *International Journal of Sports Physiology and Performance*, *15*(6), 816-824. https://doi.org/10.1123/ijspp.2019-0515

International Paralympic Committee. (2019). *Explanatory guide to classification: Paralympic summer sports*. Retrieved 1.Nov.2020 from https://gtimg.tokyo2020.org/image/upload/production/n4fd9qx81mgkd9hjllgd.pdf

International Paralympic Committee. (2024). *Paris 2024: Introduction to Para swimming*. Retrieved 01.Aug.2024 from https://www.paralympic.org/feature/paris-2024-introduction-para-swimming

Loturco, I., Barbosa, A. C., Nocentini, R. K., Pereira, L. A., Kobal, R., Kitamura, K., Abad, C. C., Figueiredo, P., & Nakamura, F. Y. (2016). A correlational analysis of tethered swimming, swim sprint performance and dry-land power assessments. *International Journal of Sports Medicine*, *37*(3), 211-218. https://doi.org/10.1055/s-0035-1559694

Marszalek, J., Kosmol, A., Morgulec-Adamowicz, N., Mroz, A., Gryko, K., Klavina, A., Skucas, K., Navia, J. A., & Molik, B. (2019). Laboratory and non-laboratory assessment of anaerobic performance of elite male wheelchair basketball athletes. *Frontiers in Psychology*, *10*, 514. https://doi.org/10.3389/fpsyg.2019.00514

Martens, J., Figueiredo, P., & Daly, D. (2015). Electromyography in the four competitive swimming strokes: A systematic review. *Journal of Electromyography and Kinesiology*, *25*(2), 273-291. https://doi.org/10.1016/j.jelekin.2014.12.003

Morouço, P. G., Marinho, D. A., Izquierdo, M., Neiva, H., & Marques, M. C. (2015). Relative contribution of arms and legs in 30s fully tethered front crawl swimming. *BioMed Research International*, *2015*, 563206. https://doi.org/10.1155/2015/563206

Nahm, N. J., Graham, H. K., Gormley, M. E., Jr., & Georgiadis, A. G. (2018). Management of hypertonia in cerebral palsy. *Currently Opinion in Pediatrics*, *30*(1), 57-64. https://doi.org/10.1097/MOP.0000000000000567

Nicholson, V. P., Spathis, J. G., Hogarth, L. W., Connick, M. J., Beckman, E. M., Tweedy, S. M., Payton, C. J., & Burkett, B. J. (2018). Establishing the reliability of a novel battery of range of motion tests to enable evidence-based classification in Para Swimming. *Physical Therapy in Sport*, *32*, 34-41. https://doi.org/10.1016/j.ptsp.2018.04.021

Oliveira, J. I. V. d., Silva, L. R. d., Gomes, L. P. A., Alves, J. F. V. V., Dantas, M. J. B., Arruda, S. F., & Oliveira, S. F. M. d. (2023). A adiposidade corporal e a amplitude articular de ombro podem influencer no desempenho da força explosiva dos membros superiores em lançadores paralímpicos? *Revista da Associação Brasileira de Atividade Motor Adaptada*, *24*(2), 188-201.

R Core Team. (2024). *R: A language and environment for statistical computing.* in R foundation for statistical computing. <https://www.R-project.org/>

Salerno, J., Tow, S., Regan, E., Bendziewicz, S., McMillan, M., & Harrington, S. (2022). Injury and injury prevention in United States para swimming: A mixed-methods approach. *International Journal of Sports Physical Therapy*, *17*(2), 293-306. https://doi.org/10.26603/001c.31173

Sanchis, G. J. B., Resende, R. A., Martins, P. F. F., Silva, S., Mello, M. T., Mohmara, Y. A., & Silva, A. (2025). Season changes in performance of upper limbs and trunk in para swimmers. *Physical Therapy in Sport*, *71*, 31-35. https://doi.org/10.1016/j.ptsp.2024.11.007

Shimura, K., Koizumi, K., Yoshizawa, T., & Aoki, T. (2021). Physique, range of motion, and gross muscle strength in hemiplegic para swimmers: A cross-sectional case series. *The Journal of Physical Therapy Science*, *33*, 832-837.

Suarez-Iglesias, D., Ayan Perez, C., Mendoza-Laiz, N., & Villa-Vicente, J. G. (2020). Boccia as a rehabilitation intervention for adults with severe mobility limitations due to neuromuscular and other neurological disorders:

Feasibility and effects on upper limb impairments. *Frontiers in Psychology*, *11*, 581. https://doi.org/10.3389/fpsyg.2020.00581

World Para Swimming. (n.d.). *History of Para Swimming*. Retrieved 1.Aug.2024 from https://www.paralympic.org/swimming/about

Wu, G., van der Helm, F. C., Veeger, H. E., Makhsous, M., Van Roy, P., Anglin, C., Nagels, J., Karduna, A. R., McQuade, K., Wang, X., Werner, F. W., Buchholz, B., & International Society of, B. (2005). ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion-Part II: Shoulder, elbow, wrist and hand. *Journal of Biomechanics*, *38*(5), 981-992. https://doi.org/10.1016/j.jbiomech.2004.05.042

Zhou, Z., Li, S., Yang, L., Gao, Z., Lin, Y., Radak, Z., & Gu, Y. (2023). Inter-segmental coordination of the swimming start among Paralympic swimmers: A comparative study between S9, S10, and S12 swimmers. *Applied Sciences*, *13*(16), 1-12. https://doi.org/10.3390/app13169097

Zwierzchowska, A., Gawel, E., Karpinski, J., Maszczyk, A., & Zebrowska, A. (2023). The effect of swimming on the body posture, range of motion and musculoskeletal pain in elite para and able-bodied swimmers. *BMC Sports Science, Medicine and Rehabilitation*, *15*(1), 122. https://doi.org/10.1186/s13102-023-00734-z

CHAPTER IV

ASSESSMENT OF HEALTH-RELATED PARAMETERS IN WORLD-CLASS BOCCIA PLAYERS USING DXA

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ABSTRACT
Sport plays an important role in health promotion of people with Cerebral Palsy (CP). However, risk factors as obesity, sarcopenia and osteoporosis may impair sports performance and health in non-ambulatory athletes. Therefore, the aim of the present study was to characterize body composition and bone mineral density (BMD) parameters in world-class boccia players with CP. Five BC2-class players with CP, aged 15-42 years old, were assessed using Dual-Energy X-Ray Absorptiometry (DXA) for body composition (total fat mass, total body% fat, total lean mass, appendicular lean mass), BMD and content (BMC) for radius, lumbar spine and whole body. Fat mass index (kg/m^2) was used to define obesity class 1 between 9-12 kg/m^2 (men) and 13-17 kg/m^2 (women). BMD Z-score ≤ - 2.0 was considered "below the expected range for age", while a Z-score > -2.0 was "within the expected range for age". Sarcopenia was defined as ≤ 7.0 kg/m^2 (men) and ≤ 5.5 kg/m^2 (women). Results indicated that 60% of the players were categorized in obesity class I and 40% presented normal fat levels. Sixty percent players exhibited BMD levels below the expected range for age. Also, 40% players may be at risk for sarcopenia. Therefore, due to boccia's specific characteristics players may experience limited physiological health benefits and additional strategies are required (e.g., cross-training, nutritional education) to avoid premature mortality and impaired quality of life. To conclude, overweight, low BMD and generalized loss of muscle mass are emerging health issues in players with severe CP that should be closely monitored by multidisciplinary teams.

KEYWORDS: Paralympic Sports, Cerebral Palsy, Body Composition, Obesity, Sarcopenia, Bone Health, Osteoporosis, Diagnostic Imaging.

INTRODUCTION

Cerebral Palsy (CP) is a clinical description for a set of permanent developmental disorders affecting posture and movement, leading to activity limitations. CP is a non-progressive injury that occurs in the developing brain of a fetus or child. It is typically accompanied by sensory, cognitive, communication, perception, and behavioural disorders, as well as epilepsy and secondary musculoskeletal issues (Rosenbaum et al., 2006). CP types can be categorized into three primary syndromes: spastic, dyskinetic, and motor ataxia (Paul et al., 2022). Spastic CP, resulting from cortical damage, is characterized by spasticity, hyperreflexia, slow and effortful voluntary movements. Dyskinetic CP, involving basal ganglia damage, is characterized by involuntary movements without contractures, subdivided into choreo-athetoid CP (with rapid, unpredictable muscle contractions and oropharyngeal difficulties) and dystonic CP (marked by co-contraction of muscles and dysarthria). Finally, motor ataxia is a rarer form associated with cerebellum damage, characterized by loss of muscle coordination leading to irregular force, disrupted rhythm, and reduced movements precision (O'Shea, 2008). The motor abilities of people with CP are assessed by the Gross Motor Function Classification Scale (GMFCS) according to five distinct levels. At Level I, people are able to walk unassisted in all environments, while those categorized at Level V rely on wheelchair assistance for mobility (Palisano et al., 1997). Therefore, people with CP exhibit a wide range of clinical symptoms.

Participation in sports has been identified as a key factor influencing overall health and quality of life for people with CP. It is crucial that people with CP engage in sports or any physical activity as a health-promoting measure. In this sense, Groff et al. (2009) emphasizes the importance of inclusive practices as para sports to support the well-being and social inclusion of this population. In addition, Shapiro and Malone (2016) argued that para sports may be prescribed in a rehabilitation setting for people with disability due to its contribution to physical function. Specifically, boccia is a Paralympic sport originally developed for people with CP (Ferreira et al., 2022) and is described as a highly strategical and precision game that consists of placing red or blue balls as close to the target (white ball) as possible (World Boccia, 2024a). Even though it is currently being played by athletes with different physical disabilities (e.g., spinal cord injuries or muscular dystrophy), CP players with severe quadriplegic represent the majority of the boccia players (Kataoka et al., 2020). Boccia improves life satisfaction, transforms exercise into an enjoyable activity and gives players a sense of purpose and self-worth (Boccia England, 2024). However, many people with CP report a diminished quality of life due to limited inclusion in health and community activities (Rimmer et al., 2004).

As people with CP transition into adulthood, they often face significant secondary health conditions due to physical inactivity, which leads to decreased physical fitness levels. This lack of physical activity not only reduces overall functional capacity but also raises the risk of obesity, further complicating health outcomes for adults with CP (Shin & Jung, 2021). Overall, people with CP are at risk for different health parameters due to the neurological disorder itself, physical inactive lifestyles, medication and lack of mobility when compared with the general population.

Specifically, one of the most concerning health issues is the extreme variation in body composition among people with CP. People with physical impairments, including CP, usually present differences in body composition patterns that may be characterized by increased fat mass or loss of lean mass (Dionyssiotis et al., 2008; Sherk et al., 2010). Cavedon et al. (2021) demonstrated that the type of physical impairment and its severity may also impact on whole-body and regional body composition with people with spinal cord injury having multiple body regions affected (i.e., trunk, android, gynoid and leg regions) when compared with people with amputations (i.e., only impaired leg). Moreover, people with tetraplegia develop an increased deposition of subcutaneous and visceral fat and reduction of lean mass in upper and lower limbs (Spungen et al., 2003). On the other hand, the risk of malnutrition in people with CP may increase due to gastroesophageal reflux, often resulting from oral-motor dysfunction. This dysfunction can lead to complications such as hypoxemia, temporomandibular joint contractures, vomiting, and aspiration pneumonia (Krigger, 2006). This situation is more evident in people with severe forms of CP. For example, Shin and Jung (2021) found that an ambulatory group of adults with CP had more people with a normal fat mass index (FMI) while a non-ambulatory group had more people considered fat-deficit and obese. Regarding children with CP, research about body composition is limited and inconsistent being difficulty to characterize the prevalence of overweight or underweight among this age group. For example, Sung et al. (2017) reported that children with higher GMFCS levels had significantly reduced measures in lean mass index, fat-free mass index, skeletal muscle mass index, when compared to children at GMFCS levels I to III. Similarly, children with CP present significantly lower values for fat free mass and skeletal muscle mass when compared with typically developing children (Szkoda et al., 2023). In contrast, Whitney, Miller, et al. (2019) compared the FMI of children with CP with typically developing peers and reported significantly higher FMI in children with CP. Moreover, non-ambulatory children with CP exhibited significantly higher FMI in comparation with an ambulatory group (Whitney, Miller, et al., 2019). Therefore, more research is needed to characterize body composition variables in both adults and children with CP, specifically those engaged in a sports setting.

It is important to highlight that, even though there are no studies analysing the relation between body composition and performance of boccia players, in other Paralympic sports such as para swimming (Dingley et al., 2015; Medeiros et al., 2016) and track and field (Cherif et al., 2022) this analyze was already conducted. Medeiros et al. (2016) observed a significant relationship between reduced fat mass percentages and improved performance among Brazilian swimmers after six months of training. Additionally, Dingley et al. (2015) emphasized that specific physical attributes, such as lower skinfold thickness, contributed positively to swimming propulsion and efficiency. On the other hand, Cherif et al. (2022) demonstrated a negative correlation between physical performance (e.g., performance of the drop-jump, repeated sprints ability) and body composition measures among track and field athletes with CP. Overall, it is suggested that physical fitness and consequently sports performance are affected by body composition in athletes with CP.

A conceptual model about the cyclical nature of health and functional decline of people with CP identifies muscle weakness and fatigue as main features leading to the development of premature sarcopenia (Peterson et al., 2015). Sarcopenia is a progressive skeletal muscle disease characterized by reduced muscle quantity or quality, and it’s diagnosed when at least two of the following criteria are meet, namely reduced muscle strength, diminished muscle quality or quantity, and/or compromised physical performance (Cruz-Jentoft et al., 2019). According to Su et al. (2023), the previously mentioned criteria often occur simultaneously in people with CP, with adults presenting a higher prevalence of sarcopenia when compared to the general population (Jeon et al., 2019). Consequently, sarcopenia heightens cardiometabolic risk and accelerates functional decline of people with CP (Peterson et al., 2015). However, to the best of our knowledge, no previous studies characterized sarcopenia among players with CP.

Another important health-related parameter in people with CP is bone health. People with neurological disorders that cause quadriplegia face a significant risk of developing osteopenia or osteoporosis, due to reduced bone density (King et al., 2003). In accordance, a recent systematic review on bone mineral density (BMD) in ambulatory people with CP (Mus-Peters et al., 2019), indicated that children classified at GMFCS as levels II (walks independently but with limitations) and III (walks with adaptive equipment assistance) are at increased risk for low BMD. Although there is little evidence for BMD in adults, a similar trend was described by Won and Jung (2021) with decreased BMD being associated with male sex, age, decreased motor function, loss of ambulatory function and low BMI. Specifically in young adults with CP, ambulatory status (Marciniak et al., 2016), type of CP (Kim et al., 2015) and GMFCS scores (Fowler et al., 2015) were associated with BMD. Also, relatively low bone mass in lumbar spine, hip and femur were identified in this group (King et al., 2003). Overall, low BMD represents a common health issue in people with CP regardless of age which leads to a high prevalence of fracture (Whitney, Alford, et al., 2019), increased risk of fracture with minor stress and, consequently, decreased ambulation (Sheung-Tung, 2012). People with CP have an annual fracture rate of around 5%, which is twice higher when compared with an age-matched general population (Su et al., 2023). Therefore, it is crucial to characterize bone mass in athletes with CP due to the impact that training and competition loads can have on athletes' bone health.

Overall, underweight or obesity, sarcopenia and osteoporosis comprise a triad of health issues that affect people with CP. From a health perspective, physical activity and sport may have an important preventive contribution on the above-described triad of comorbidities and their interactions throughout the lifespan of people with CP. However, there are limited insights into critical aspects of body composition and bone health in athletes with physical disability (Cavedon et al., 2021), specifically with CP. Consequently, a better understanding of body composition of world-class boccia players is needed not only for sports performance requirements, but also for athletes’ long-term health.

Therefore, this study aimed to provide a descriptive analysis of body composition and bone health, including fat mass, lean mass and BMD among a group of world-class boccia players with CP using DXA. Specifically, health-related risk factors such as underweight or obesity, sarcopenia and osteoporosis were identified and strategies to optimize sports participation and health maintenance in players with CP were explored.

MATERIALS AND METHODS

Participants

A total of five BC2 boccia players, aged between 15 and 42 years old, and a diagnose of CP were recruited to participate in the present study. Inclusion criteria encompassed: i) a confirmed diagnosis of CP, regardless of its subtype; ii) classification as BC2; iii) participation in the national boccia team during the preceding season; and iv) participation in training sessions during the current season. Exclusion criterion was related with participants who had never received a call-up to the national boccia team. BC2 class was chosen because it represents the sports class with a greater number of players with CP in the Portuguese national team. All participants were European or World medallists. Regarding locomotion type, all were non-ambulatory and used electric wheelchair.

Table 1 presents an overview of the participants' personal and clinical-related characteristics including gender, type of CP and presence of associated diseases.

Table 1. Personal and clinical characterization of the participants.

VARIABLE	n (%)
Gender	
F	2 (40)
M	3 (60)
Type of CP	
Spastic quadriplegia	5 (100)
Associated diseases	
No	4 (80)
Arrhythmia	1 (20)

Note: F = Female; M = Male; CP = Cerebral Palsy.

Procedures

Data collection took place in the Research Centre for Physical Activity, Health and Leisure (CIAFEL) laboratory located at the Faculty of Sport, University of Porto. All participants received a comprehensive verbal explanation of the protocol details. Upon voluntarily agreement to participate, the participants signed a consent form containing a written explanation of the protocol. Informed consent was obtained from the underage participants' tutors as well as from the participants themselves. The research protocol received approval from the faculty Ethical Committee, under the reference number CEFADE 47/2022.

Instruments

Participants filled a sociodemographic questionnaire including personal information such as age, gender, height (m), weight (kg) and sports-related information such as years of training and competition, training frequency per week and duration (min) per session for both specific and strength and conditioning (S&C) training. Additionally, clinical information was collected, including the type of CP, walking capability, type of walking assistive device used and associated diseases.

Dual-Energy X-Ray Scan (Explorer QDR 4500, Hologic, Bedford, MA) was used to assess total fat mass (FM), total body% fat, total lean mass and appendicular lean mass. Also, to assess BMD and BMC, whole body, radius and lumbar spine scans were used.

Body mass index (BMI) was calculated as body mass (kg) divided by height squared (m^2). Fat mass index (FMI) was calculated as FM (kg) divided by height squared (m^2). FMI categories were defined as follows: severe fat deficit in men with < 2 kg/m^2 and women with < 3.5 kg/m^2; moderate fat deficit in men with 2 kg/m^2 to less than 2.3 kg/m^2 and women with 3.5 kg/m^2 to less than 4 kg/m2; mild fat deficit in men with 2.3 kg/m^2 to less than 3 kg/m^2 and women with 4 kg/m^2 to less than 5 kg/m^2; normal fat levels in men with 3 kg/m^2 to 6 kg/m^2 and women with 5 kg/m^2 to 9 kg/m^2; excess fat levels in men with more than 6 kg/m^2 up to 9 kg/m^2 and women with more than 9 kg/m^2 up to 13 kg/m^2; obesity class 1 in men with more than 9 kg/m^2 up to 12 kg/m2 and women with more than 13 kg/m^2 up to 17 kg/m^2; obesity class 2 in men with more than 12 kg/m^2 up to 15 kg/m^2 and women with more than

17 kg/m^2 up to 21 kg/m2; and obesity class 3 in men with more than 15 kg/m2 and women with more than 21 kg/m^2 (Kelly et al., 2009).Total body %FM was calculated as FM divided by the total body mass (kg). Appendicular lean mass index (kg/m2) was calculated as appendicular lean mass (kg) divided by height squared (m^2) and used to establish sarcopenia risk. The cut-off points for sarcopenia risk according to gender were ≤ to 7.0 kg/m2 (men) and ≤ 5.5 kg/m2 (women) (Cruz-Jentoft et al., 2019).

BMD (g/cm2) and osteoporosis were defined using the Binkley et al. (2006) cut-off points where Z-scores (age, gender, and ethnicity-matched) are used for females prior to menopause and males younger than age 50. Z-score of -2.0 or lower is defined as "below the expected range for age", while a Z-score above -2.0 is considered "within the expected range for age".

Regarding DXA measurement procedures, the same trained operator performed all scans and analyses to ensure consistency. Participants were placed in a supine position with arms in extension near the trunk and lower limbs in extension, with a slight abduction of the feet. Some participants needed foam pads to enable consistent positioning and separation of limbs. The foam was used because it is not detectable by the DXA scanner. Due to difficulties with positioning on the DXA and post-analysis of the scans, only full body values were used for body composition. Participants' clothing was kept to a minimum and all metallic objects (e.g., earrings, watches) as well as shoes were removed.

Statistical analysis

Descriptive statistics including mean, standard deviation, minimum and maximum values were calculated using the statistical package R (R Core Team, 2024).

RESULTS

Table 2 presents a detail description of sociodemographic variables, body composition, BMD and BMC parameters for whole body, radius and lumbar spine regions.

Table 2. Sociodemographic variables, body composition, BMD and BMC parameters for whole body, radius and lumbar spine regions of the players.

	Mean	SD	Player 1	Player 2	Player 3	Player 4	Player 5
Sex	-	-	Male	Male	Male	Female	Female
Age	29	13.06	42	15	41	16	31
Height (cm)	157.4	10.06	152.0	165.0	170.0	145.0	155.0
Weight (kg)	58.4	19.53	75.0	42.0	74.0	33.0	68.0
Years of practice	13.80	8.11	15	10	25	3	16
Years of competition	11.20	9.58	10	3	25	2	16
Specific training sessions: duration per session (min)	183.00	65.73	300	150	150	150	165*
Specific training sessions: frequency per week	4.40	1.14	5	4	6	3	4
S&C training sessions: duration per session (min)	43.00	14.40	20	45*	45	45	60
S&C training sessions: frequency per week	3.25	1.50	5	2	4	2	2.5*
BMI (kg/m^2)	23.50	7.65	32.5	15.4	25.6	15.7	28.3

Note: SD = Standard deviation; S&C = Strength & Conditioning; BMI = Body Mass Index; FMI = Fat Mass Index; ALM = Appendicular Lean Mass; ALMI = Appendicular Lean Mass Index; BMD = Bone Mineral Density; BMC = Bone Mineral Content; * mean of the reported intervals.

Table 2 continued.

		Mean	SD	Player 1	Player 2	Player 3	Player 4	Player 5
Whole body	Fat mass (kg)	22.31	11.17	27.169	9.598	29.874	11.127	33.798
	FMI (kg/m²)	9.00	4.44	11.76	3.52	10.34	5.29	14.07
	% Fat	37.82	10.63	38.60	22.50	42.90	34.00	51.10
	Lean Mass (kg)	32.53	7.98	41.398	31.897	37.844	20.484	31.016
	ALM (kg)	12.80	3.87	16.63	12.80	16.21	7.27	11.08
	ALMI (kg/m²)	5.12	1.39	7.20	4.70	5.61	3.46	4.61
	BMD (g/cm²)	0.941	0.065	0.966	0.907	1.036	0.865	0.929
	BMD Z-score	- 2.1	0.3	-2.4	-2.0	-1.6	-2.4	-2.3
	BMC (g)	1463.27	345.27	1811.21	1225.16	1858.47	1123.09	1298.43
Radius 1/3	BMC (g)	1.57	0.31	2.05	1.32	1.7	1.43	1.35
	BMD (g/cm²)	0.66	0.07	0.763	0.636	0.713	0.601	0.599
	BMD Z-score	-1.30	0.35	-0.8	-1.1	-1.7	-1.5	-1.4
Lumbar Spine	BMC (g)	44.31	12.69	40.54	50.1	63.03	30.03	37.83
	BMD (g/cm²)	0.85	0.16	0.779	0.906	1.089	0.672	0.818
	BMD Z-score	-1.70	1.50	-2.7	-0.4	0.1	-3.4	-2.1

Note: SD = Standard deviation; S&C = Strength & Conditioning; BMI = Body Mass Index; FMI = Fat Mass Index; ALM = Appendicular Lean Mass; ALMI = Appendicular Lean Mass Index; BMD = Bone Mineral Density; BMC = Bone Mineral Content; * mean of the reported intervals.

In relation to sociodemographic parameters, participants included both female (n=2) and male (n=3) players as well as adults (n=3) and young players (n=2). There was a wide interval of sports experience with years of boccia practice ranging from 3 to 25 years and years of boccia competition ranging from 2 to 25 years. The frequency of boccia training ranged from 2 to 6 sessions per week (including specific and S&C training).

Regarding body composition, Player 3 (male, 41 years) and Player 5 (female, 31 years old) exhibited the highest total fat mass and FMI scores categorizing on obesity class I (Kelly et al., 2009). Overall, based on FMI classifications, 60% of the players (n=3) are categorized in obesity class I and 40% (n=2) are categorized with normal fat levels. It is important to highlight that none of the Player exhibited fat deficit. Specifically in the adults' group, Player 1 (male, 42 years old) exhibited the highest ALM and ALMI. In contrast, Player 5 (female, 31 years old) exhibited the lowest ALM and ALMI scores. Considering that low muscle mass is suggested when ALMI is ≤ 7.0 kg/m^2 for men and ≤ 5.5 kg/m^2 for women (Cruz-Jentoft et al., 2019), 66.7% (n=2) of the adults' players are at risk of sarcopenia. Among the youth group, both Player 2 (male, 15 years old) and Player 4 (female, 16 years old) exhibited lower ALM and ALMI scores when comparing with the adult's cut-off suggesting muscle atrophy (Cruz-Jentoft et al., 2019).

Regarding bone health, Player 1 (male, 42 years old), Player 4 (female, 16 years old) and Player 5 (female, 31 years old) exhibited the lowest BMD Z-scores. Overall, 60% (n=3) of the athletes were classified as "below the expected range for age", (Z-score < -2.0) and 40% (n=2) as "within the expected range for age" (Z-score > -2) (Binkley et al., 2006).

A detailed analysis of each player demonstrated that 60% of the players exhibited multiple health-related risk factors. Specifically, Player 1 (male) was the oldest participant, reported the higher volume of training per week (duration x frequency of specific training per week) and exhibited obesity class I and BMD Z-score below the expected range for age. Player 3 (male) reported the highest number of years of practice and competition as well the highest volume of S&C training (duration x frequency of S&C training per week) and exhibited obesity class I and sarcopenia risk. Player 5 is the oldest female participant and exhibited obesity class I, sarcopenia risk and BMD Z-score below the expected range for age. It is also important to highlight that a young player (Player 4) also exhibited BMD Z-score below the expected range for age.

DISCUSSION

This study aimed to provide a descriptive analysis of body composition and bone health among a group of world-class boccia players with CP using DXA. Specifically, health-related risk factors were identified and strategies to optimize sports performance and health maintenance in players with CP were explored. The present study includes many positive aspects due to the original and innovative nature of its findings when addressing the specific needs and characteristics of boccia players.

First, boccia is a Paralympic sport included in the Summer Paralympic Games since 1984. Due to its specific nature, boccia is the only sport for persons with physical disability without an Olympic counterpart. Recently, in Paris 2024 Paralympic Games, a total of 124 athletes representing 35 nations (World Boccia, 2024b), competed across 11 medal events (International Paralympic Committee, 2024) which demonstrates the strength of the sport around the world.

Despite the relevance of boccia in the context of sport for persons with disabilities, there is a scarcity of studies that provide scientific-based evidence about this Paralympic sport. In accordance, Ferreira et al. (2023) developed an up-to-date systematic review about the status of boccia research. The previous mentioned authors only identified 9 studies and concluded that boccia has been consistently neglected in research when compared with other Paralympic sports. Moreover, the analyzed studies mainly focus on factors influencing the technique of boccia throwing (Ferreira et al., 2023).

Second, boccia is one of the few Paralympic sports for athletes with severe physical disability. Boccia players, including those with severe CP, are part of a minority group with great inter-individual variability, difficult access to the study participants (Ferreira et al., 2022) and important methodological limitations when accessing non-ambulatory athletes. Overall, this may explain the lack of opportunity and interest of the scientific community in studying boccia players.

Third, to the best of our knowledge, this is the first study to use DXA in boccia world-class players with CP to assess body composition. Moreover, few studies have analysed the prevalence of BMD among athletes from different Paralympic sports (Koivisto-Mork et al., 2023; Weijer et al., 2024) using DXA and Boccia players with CP were not included. DXA is a sophisticated method to assess body composition and bone health with several advantages for research because it is a fast, accurate and easy-to-use methodology that allows regional measurements and less radiation when compared with Computed Tomography scans, chest and lumbar spine X-rays, although it is not recommended for regular assessments (van de Vliet et al., 2011). Moreover, the use of DXA allows to overcome the limitations of BMI assessment. BMI is a frequently used method, but it is not accurate to assess overall adiposity for adults with CP given the diversity of body morphology and lifestyles (Shin & Jung, 2021). Therefore, assessing boccia players with DXA provide unique findings with great importance for multidisciplinary teams working with high-performance players. The results of the present study may support the development of specific strategies and recommendations for health-promotion and training periodization.

Lastly, to the best of our knowledge this is the first study to highlight the importance of high-performance boccia in promoting health-related parameters. While the latest research in the field only focus on boccia sports' performance factors (Ferreira et al., 2023; Hendarto, 2023; Rezavandzayeri et al., 2024; Yahagi et al., 2024), the assessment of health-related parameters enhances the need for health monitoring in an understudied population of Paralympic athletes (Fagher et al., 2022). Consequently, it is not known if sport-specific movements planned during boccia training sessions may have a positive contribution in the prevention of CP associated comorbidities such as obesity, sarcopenia and osteoporosis.

In relation to body composition analysis, 60% of the players were categorized in obesity class I and included all adults' players while 40% were categorized with normal fat levels and included all youth players. Similarly, Cavedon et al. (2021)

assessed the body composition of SCI athletes competing in different Paralympic sports (e.g., handbike, wheelchair rugby and wheelchair basketball) and reported that 58.3% were classified as obese. McPhee et al. (2018) argued that obesity is an important risk factor for higher prevalence of cardiovascular disease (CVD) in people with CP. Adults with severe CP present several risk factors such as obesity and overweight, hypertension, low-density lipoprotein cholesterol and higher risk of atherosclerosis due to the increase of the carotid artery intima media thickness (McPhee et al., 2018; Peterson et al., 2015). Consequently, there is an increase CVD-related mortality (Strauss et al., 1999). Therefore, monitoring and managing common risk factors is essential to prevent the onset of CVD in adults with CP (McPhee et al., 2018).

Although it is difficult to determine if adults with CP face a higher prevalence of overweight or obesity when compared to the general population (McPhee et al., 2018), the findings of the present study suggest a similar unfavourable trend among a group of world-class players with CP. All boccia players reported extensive volume of training per week, including technical, tactical boccia training and S&C training. Boccia S&C training should include skills acquisition and basic body maintenance to promote players' health and wellness (Boccia Canada, n.d.). Moreover, stretching and mobility training should be included to maintain postural control and flexibility and strength training to improve strength and power levels (Boccia Canada, n.d.). Boccia players should also be exposed to high-intensity interval training as a strategy to improve aerobic capacity and increase energy reserves (Lauglo et al., 2016), crucial to perform a full schedule in a world-class competition. For example, at Paris 2024 Paralympic Games (Olympics, 2024), a male BC2 player reaching the final in the individual competition played a total of seven games over a four day period. Additionally, participation in the BC1/BC2 team events would add five games over three days competition. This demanding schedule requires energy reserves and aerobic capacity to sustain high performance levels across multiple games, recover between games, and minimize the risk of fatigue-related errors that may compromise the player's ability to compete successfully. High-intensity interval training is also an important strategy to maintain a balanced body composition (Runciman et al., 2016) and avoid the development of multiple metabolic and cardiovascular risk factors. Therefore, boccia preparation should include additional physical activities (e.g., swimming) as cross-training strategy (Boccia Canada, n.d.) to manage weight and ensure proper cardiovascular capacity for sports performance.

Furthermore, it is important to consider that players of the present study are in a highly vulnerable condition due to the severity of CP when compared to players with CP who participate in other Paralympic sports such as swimming, athletics or para equestrian (Koivisto-Mork et al., 2023). Usually, boccia players are non-ambulatory and wheelchair users (relying on manual or electric wheelchairs) for both sports practice and daily life activities. Therefore, they are included in the group of players with high support needs (AHSN) or severe disabilities. AHSN players' are described as requiring assistance during competition, based on the rules of the sport and/or requiring support staff in the sport environment and daily living functions, including players with a greater degree of physical impairment resulting in more extensive disability (i.e., athletes with tetraplegia or CP) (Slocum et al., 2018).

As previously stated, it was not possible to identify in the literature normative or comparative values for fat mass among boccia players with CP. However, the findings of the present study can be discussed according to evidence related with AHSN athletes. In this context, Gorla et al. (2016) assessed the longitudinal effects of Wheelchair Rugby (WR) training on the body composition of players with tetraplegia and found that WR training increases lean mass in the arms and decreases FM in the trunk and legs demonstrating that WR can have a positive effect on the weight management of the players. Similarly to WR, boccia primarily involves upper-body movements to perform (Hendarto, 2023) but both sports are very different in terms of intensity of the effort and, consequently, cardiovascular capacity performance. Boccia training requires limited aerobic or anaerobic intensity and may not generate enough metabolic demand to efficiently manage adiposity or fat mass.

Once again, considering that the players of the present study were expose to boccia training over a long period of time (average 13.8 years), it seems that boccia training per si was not enough to promote a positive long-term effect on body composition parameters and additional strategies are required. In accordance, it is important to highlight the need for regular assessment of boccia players, as part of health monitoring provided by the multidisciplinary teams to improve knowledge about the athletes' health and to reduce the risk of injuries and illnesses (Fagher et al., 2022). For example, Kataoka et al. (2021) described the efforts made by the Japanese Paralympic Committee in the field of nutrition to support athletes included in the boccia national team. As result, the awareness of the players and staff regarding diet and nutrition improved, and behavioural change was promoted. Similarly, the players of the present study were supported by a nutritionist when call-up to the national boccia team. However, information about daily nutritional guidance offered to athletes, families and clubs was not collected.

Regarding body composition parameters related with sarcopenia analysis, 66.7% of the adults' participating in the present study are at risk of sarcopenia. Although literature emphasises the importance of exercise and physical activity to improve muscle health in people with CP (Verschuren et al., 2016), the group of world-class boccia players exhibited a similar muscle loss pattern when comparing with non-athletes with CP. For example, Kim et al. (2023) assessed sarcopenia in patients with neuromuscular disorders, including CP and found that sarcopenia was more severe in non-ambulatory participants with severe scoliosis. Specifically, spinal deformities such as scoliosis, hyperkyphosis, hyperlordosis and spondylolysis and/or spondylolisthesis are common in people with CP (Britz et al., 2020). This indicates that while neurological impairments contribute to muscle loss, secondary factors such as scoliosis and gait dysfunction can exacerbate sarcopenia and, consequently, decline gross motor function (Kim et al., 2023). Therefore, it is suggested that sarcopenia in CP is influenced by both neurological and musculoskeletal factors (Kim et al., 2023). The central inhibition of muscle recruitment prevents the activation of available motor units in the affected muscles—along with the typical neuromuscular deficits seen in CP, may contribute to significantly impact muscle size, function, and physiology (Stackhouse et al., 2005).

Overall, strength training is of crucial importance for boccia players not only because of performance factors related with the ability to throw at longer distance (Kataoka et al., 2020) but also for prevent muscle loss. Consequently, S&C coaches responsible to provide strength training for boccia players must be knowledgeable about exercise guidelines and recommendations for athletes with CP. For example, exercises should progress from primarily single-joint, machine-based resistance exercises to a combination of machine and free-weight, multi-joint, closed-kinetic chain exercises. Single-joint training is particularly beneficial for people with very weak muscles or those who compensate excessively during multi-joint movements, specifically at the beginning of a training program (Verschuren et al., 2016).
Moreover, it is also important to analyse the low ALM and ALMI scores of youth players considering that both Player 2 and Player 4 seem to exhibit muscle atrophy. In children with spastic CP, the loss of muscle mass and function is caused by the neurological disorder itself or by other factors such as malnutrition, disuse or cachexia but it is not age-related sarcopenia (Aksakal et al., 2024). Although in general population sarcopenia is described as an age-related loss of both muscle mass and muscle function being diagnosed in adulthood due to the decline of alpha motor neurons and insufficient reinnervation of muscle fibbers (Clark, 2023; Larsson et al., 2019), the premature onset of muscle atrophy among children and youth with CP (Kim et al., 2023; Multani et al., 2019) is a concerning health issue. Therefore, youth players with CP engaged in boccia training should be closely monitorized and offered a tailored S&C training design to increase skeletal muscle mass, reserves and strength since yearly ages.
Finally, regarding bone health parameters, the present study revealed very concerning evidence with all boccia players exhibiting poor bone health. Specifically, 60% of the players were classified as having BMD levels below the expected range for age. Again, the group of world-class boccia players exhibited an unfavourable pattern characterized by low BMD and BMC which was already reported in studies with non-athletes with CP. For example, Won and Jung (2021) assessed BMD in adults with CP and reported that 25% had osteoporosis, with

prevalence rising to 65% in persons over 50 years old. Moreover, men, non-ambulatory and those with bilateral CP were at higher risk of lower BMD.

When analysing previous literature about the assessment of BMD in athletes with disabilities, Koivisto-Mork et al. (2023) also found that 50% of Norwegian Paralympic athletes had low BMD, with 29% exhibiting osteoporotic BMD levels and non-ambulatory athletes with congenital conditions, being at a higher risk for low BMD compared to other para-athletes. Although the previously mentioned study encompassed elite athletes from different sports and types of disabilities, boccia was not included and only 5 ambulatory athletes with CP were assessed. Ambulatory status is an important factor when analysing the contribution of sports in preventing osteoporosis in athletes with disabilities. Miyahara et al. (2008) explored the effects of sports activity and found that wheelchair-dependent athletes had significantly lower BMD Z-scores in the whole body than non-wheelchair dependent athletes. Similarly, Cavedon et al. (2021) reported significantly lower BMD in athletes with SCI with 45.8% reporting osteopenia and 12.5% osteoporosis. However, the two previously mentioned studies only included athletes with SCI. In the only study found with boccia players, Weijer et al. (2024) also concluded that wheelchair-dependent athletes exhibited significantly lower BMD Z-scores and higher prevalence of osteoporosis when compared to non-wheelchair-dependent athletes at whole-body level. Mechanical loading patterns, including wheelchair use, the type of sport, and body mass were identified as primary risk factors. However, Weijer et al. (2024) study only included one boccia player and specific information about this participant was not available.

Lastly, an individual analysis showed that some players are in a vulnerable health status exhibiting multiple health-related risk factors. Specifically, Player 3 exhibited obesity class I and sarcopenia risk. In cases where sarcopenia overlaps with obesity, the term "sarcopenic obesity" is used to describe the condition which, like obesity, is a risk factor for metabolic diseases (Cruz-Jentoft et al., 2019). Also, Player 5 presented concurrent obesity class I, sarcopenia risk and BMD levels below the expected range for age. According to Kelly et al. (2019), the coexistence of sarcopenia, obesity, and osteoporosis is called osteosarcopenic obesity (OSO) and refers to a triad of obesity and impaired bone and muscle health. OSO represents higher risk and mortality when compared to each condition independently (Fan et al., 2024). Although there is no evidence about OSO in people with CP, the present findings suggest very poor health status with possible impact on the players life expectancy, quality of life and ability to maintain high-level boccia performance over time. Therefore, world-class boccia players should be monitored by a multidisciplinary team involving health staff (e.g., physicians) (Fagher et al., 2022), to facilitate an early detection and diagnosis of the above-mentioned health-related parameters.

LIMITATIONS AND SUGGESTIONS FOR FUTURE RESEARCH

The present findings should be interpreted with caution due to some methodological considerations. First, the small sample size limits the ability to draw broad conclusions about boccia players with CP. Expanding the sample would allow comparisons between genders, age groups and other variables with impact in body composition and bone health measures. However, gathering a representative sample of boccia players with CP is very challenging due to its reduced number as well as the severity of the disability and complexity of daily life activities. For example, the majority of the players rely on others to ensure transportation and functional mobility for daily living. This makes it difficult to collect data without interfering in daily life activities as well as training routines, limiting the opportunities for larger samples. To overcome these barriers, the establishment of international collaborations could improve the studies' representativeness. Partnerships between boccia clubs and national teams within World Boccia organization could facilitate multi-site research aggregating data from different countries.

Second, issues related with body alignment and spasticity of the players hindered data collection procedures, reducing the number of reliable data available from DXA. Therefore, it is crucial to develop more tailored and specific methods to assess body composition of people with CP. The use of portable DXA technology combined with protocols designed to address the unique challenges of players with severe CP, could enhance the accuracy and reliability of the data. For example, specific protocols could include customized positioning aids and adjustments to account for postural asymmetries, allowing a successful evaluation of players with spasticity or movement limitations. Additionally, it is important to highlight that no normative or specific cut-off values to analyze body composition of people with CP are available in the literature. Therefore, in the present study normative values used for the general population were applied which limits the interpretation and generalization of the findings in people with CP. Additionally, dietary and hydration status should have been monitored prior to the scan to minimize their influence. Third, the use of self-reported measures to determine height and weight could also be considered a limitation.

Fourth, important variables associated to body composition were not formally assessed. For example, future studies should explore the relationship between body composition and blood biomarkers (e.g., markers of inflammation, lipid profiles, and glucose metabolism) to provide a more accurate approach to health-related parameters in boccia players with CP. Similarly, further research should include information about anticonvulsant medication due to its influence on BMD. Fifth, the lack of information about the nutritional status of boccia players is also a limitation. Nutrition plays a crucial role in managing weight and reducing the risk of obesity, in contributing to hypertrophy combining specific S&C programs with proper protein and carbs ingestion and in reducing the risk of osteoporosis by providing adequate vitamin D and calcium intake. Considering that the majority of participants were categorized as obesity class I, future studies should offer a behavioural lifestyle intervention that combines structured S&C boccia programs with a healthy diet. A practical intervention could include nutrition education programs (e.g., workshops) developed by sports nutritionists specifically for boccia players, sports assistants and families. This would provide evidence-based recommendations for a balanced nutrition to enhance athletic performance and overall health in people with CP.

Lastly, this is a cross-sectional study, consequently the effect of boccia practice over time could be analysed. In this sense, longitudinal studies about the impact of specific boccia programs on different health-related parameters might contribute to the identification of the causal pathways between boccia and the prevention of obesity, sarcopenia and osteoporosis in players with CP.

Despite the current limitations, the present findings could help to understand the importance of body composition and bone health on the long-term health of Boccia players with CP as well as their ability to keep competing at world-class level over time.

CONCLUSIONS

The present study represents a novel approach to the assessment of health-related parameters in world-class boccia players with CP. Despite extensive boccia training, the results demonstrated that 60% of the players were classified as obesity class I, 66.7% of the adults were at risk for sarcopenia and youth players showed premature signs of muscle atrophy. Poor bone health was common to all players with 60% presenting BMD levels below the expected range for age. The present findings suggest that boccia has limited weight management, muscle mass and osteogenic benefits.

The specific characteristics of boccia game may limit physiological health benefits commonly associated with other Paralympic sports. Contrarily to wheelchair rugby or wheelchair basketball (Gorla et al., 2016; Miyahara et al., 2008), boccia training does not typically involve sustained aerobic or anaerobic effort. Boccia is mainly a skill-based sport that involves precise throwing actions with minimal physical exertion or high-intensity movements. Overall, the low mechanical loading associated with limited exercise intensity may limit boccia physiological health benefits hindering improvements in cardiovascular fitness, muscle hypertrophy, or bone mass. Consequently, high-performance boccia training is unlikely to counteract health risks such as obesity, sarcopenia, or osteoporosis, emphasizing the need for supplementary S&C programs.

Specific S&C programs combined with cross-training and nutritional support are essential to improve body composition, physical fitness, and bone health in this population. Moreover, a closely multidisciplinary monitoring is crucial for players with multiple risk factors, such as Athlete 5, who presented the triad used to diagnose OSO. The combination of obesity, sarcopenia, and osteoporosis increases the risk of complications like cardiovascular diseases, bone fractures, and extended training absences, ultimately impairing high-performance.

The present findings highlight the need to use tailored interventions to address individual health needs, optimize training protocols, and prevent the progression of health risks. Overall, this research highlights boccia players' unique challenges and opportunities, emphasizing the importance of integrating health promotion strategies into boccia training regardless of the competitive level. Such efforts can optimize sport performance, enhance quality of life, and highlight the important role of Paralympic sports in promoting health and inclusion for people with CP.

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REFERENCES

Aksakal, M. F., Abdulsalam, A. J., Kara, M., & Ozcakar, L. (2024). Grip strength and sarcopenia in children with cerebral palsy: A level playing field? *Pediatric Neurology*, *161*, 84. https://doi.org/10.1016/j.pediatrneurol.2024.09.002

Binkley, N., Bilezikian, J. P., Kendler, D. L., Leib, E. S., Lewiecki, E. M., Petak, S. M., & International Society for Clinical, D. (2006). Official positions of the International Society for Clinical Densitometry and Executive Summary of the 2005 Position Development Conference. *Journal of Clinical Densitometry*, *9*(1), 4-14. https://doi.org/10.1016/j.jocd.2006.05.002

Boccia Canada. (n.d.). *Long-term athlete development model*. Retrieved 21.Dec.2024 from https://bocciacanada.ca/wp-content/uploads/2021/08/Long-Term-Athlete-Development-Model-en.pdf

Boccia England. (2024). *Big boccia survey 2024 results*. Retrieved 10.December from https://www.bocciaengland.org.uk/news/big-boccia-survey-2024-results

Britz, E., Langerak, N. G., & Lamberts, R. P. (2020). A narrative review on spinal deformities in people with cerebral palsy: Measurement, norm values, incidence, risk factors and treatment. *South African Medical Journal*, *110*(8), 767-776. https://doi.org/10.7196/SAMJ.2020.v110i6.14472

Cavedon, V., Sandri, M., Peluso, I., Zancanaro, C., & Milanese, C. (2021). Body composition and bone mineral density in athletes with a physical impairment. *PeerJ*, *9*, e11296. https://doi.org/10.7717/peerj.11296

Cherif, M., Said, M. A., Bannour, K., Alhumaid, M. M., Chaifa, M. B., Khammassi, M., & Aouidet, A. (2022). Anthropometry, body composition, and athletic performance in specific field tests in Paralympic athletes with different disabilities. *Heliyon*, *8*(3). https://doi.org/10.1016/j.heliyon.2022.e09023

Clark, B. C. (2023). Neural mechanisms of age-related loss of muscle performance and physical function. *Journals of Gerontology. Series A, Biological sciences and medical sciences*, *78*(Suppl 1), 8-13. https://doi.org/10.1093/gerona/glad029

Cruz-Jentoft, A. J., Bahat, G., Bauer, J., Boirie, Y., Bruyere, O., Cederholm, T., Cooper, C., Landi, F., Rolland, Y., Sayer, A. A., Schneider, S. M., Sieber, C. C., Topinkova, E., Vandewoude, M., Visser, M., Zamboni, M., Writing Group for the European Working Group on Sarcopenia in Older, P., & the Extended Group for, E. (2019). Sarcopenia: Revised European consensus on definition and diagnosis. *Age Ageing*, *48*(1), 16-31. https://doi.org/10.1093/ageing/afy169

Dingley, A. A., Pyne, D. B., & Burkett, B. (2015). Relationships between propulsion and anthropometry in Paralympic swimmers. *International Journal of Sports Physiology Performance*, *10*(8), 978-985. https://doi.org/10.1123/ijspp.2014-0186

Dionyssiotis, Y., Petropoulou, K., Rapidi, C. A., Papagelopoulos, P., Papaioannou, N., Galanos, A., Papadaki, P., & Lyritis, G. P. (2008). Body composition in paraplegic men. *Journal of Clinical Densitometry*, *11*(3), 437-443. https://doi.org/10.1016/j.jocd.2008.04.006

Fagher, K., Badenhorst, M., Kunorozva, L., Derman, W., & Lexell, J. (2022). "It gives me a wake-up call"-It is time to implement athlete health monitoring within the Para sport context. *Scandinavian Journal of Medicine & Science in Sports*, *33*(5), 776-786. https://doi.org/10.1111/sms.14281

Fan, S., Cai, Y., Wei, Y., Yang, J., Gao, J., & Yang, Y. (2024). Sarcopenic obesity and osteoporosis: Research progress and hot spots. *Experimental Gerontology*, *195*, 112544. https://doi.org/10.1016/j.exger.2024.112544

Ferreira, C. C., Espada, M. C., Gamonales, J. M., & Muñoz-Jiménez, J. (2023). Current status of sport performance in Boccia: Systematic review of the literature. *Retos*, *48*, 1070-1077. https://doi.org/10.47197/retos.v48.95110

Ferreira, C. C., Gamonales, J. M., Santos, F. J., Espada, M. C., & Muñoz-Jiménez, J. (2022). Boccia in Paralympic Games: The evolution from 1984 to 2016 and future perspectives. *Cuadernos de Psicología del Deporte*, *22*(1), 205-214. https://doi.org/10.6018/cpd.492031

Fowler, E. G., Rao, S., Nattiv, A., Heberer, K., & Oppenheim, W. L. (2015). Bone density in premenopausal women and men under 50 years of age with cerebral palsy. *Archives of Physical Medicine and Rehabilitation*, *96*(7), 1304-1309. https://doi.org/10.1016/j.apmr.2015.03.012

Gorla, J. I., Costa e Silva, A., Borges, M., Tanhoffer, R. A., Godoy, P. S., Calegari, D. R., Santos Ade, O., Ramos, C. D., Nadruz Junior, W., & Cliquet Junior, A. (2016). Impact of wheelchair rugby on body composition of subjects with tetraplegia: A pilot study. *Archives of Physical Medicine and Rehabilitation*, *97*(1), 92-96. https://doi.org/10.1016/j.apmr.2015.09.007

Groff, D. G., Lundberg, N. R., & Zabriskie, R. B. (2009). Influence of adapted sport on quality of life: Perceptions of athletes with cerebral palsy. *Disability and Rehabilitation*, *31*(4), 318-326. https://doi.org/10.1080/09638280801976233

Hendarto, S. (2023). Gender differences in boccia underhand throw biomechanics. *Revista Iberoamericana de Psícologia del Ejercicio y el Deporte*, *18*(2), 228-234.

International Paralympic Committee. (2024). *Paris 2024 Paralympic Games Sports: Boccia*. Retrieved 21.Dec.2024 from https://www.paralympic.org/paris-2024/sports#boccia

Jeon, I., Bang, M. S., Lim, J. Y., Shin, H. I., Leigh, J. H., Kim, K., Kwon, B. S., Jang, S. N., & Jung, S. H. (2019). Sarcopenia among adults with cerebral palsy in South Korea. *Physical Medicine & Rehabilitation Journal*, *11*(12), 1296-1301. https://doi.org/10.1002/pmrj.12134

Kataoka, M., Okuda, K., Iwata, A., Imura, S., Yahagi, K., & Matsuo, Y. (2020). Throwing distance and competitive performance of Boccia players. *Journal of Physical Therapy Science*, *32*, 574–577. https://doi.org/https://doi.org/10.55860/BOUA9793

Kataoka, S., Yahagi, K., & Murakami, M. (2021). Nutritional support for the Japanese national paralympic boccia team. *Journal of High Performance Sport*, *7*, 98-106.

Kelly, O. J., Gilman, J. C., Boschiero, D., & Ilich, J. Z. (2019). Osteosarcopenic obesity: Current knowledge, revised identification criteria and treatment principles. *Nutrients*, *11*(4). https://doi.org/10.3390/nu11040747

Kelly, T. L., Wilson, K. E., & Heymsfield, S. B. (2009). Dual energy X-Ray absorptiometry body composition reference values from NHANES. *Plos One*, *4*(9), e7038. https://doi.org/10.1371/journal.pone.0007038

Kim, J., Yoon, H., Lim, H. J., Kim, H. W., Suk, Y. J., Park, K. B., & Lee, M. J. (2023). Decrease of muscle mass in young patients with neuromuscular disease: Assessment of sarcopenia. *Journal of Korean Medical Science*, *38*(21), e187. https://doi.org/10.3346/jkms.2023.38.e187

Kim, W., Lee, S. J., Yoon, Y. K., Shin, Y. K., Cho, S. R., & Rhee, Y. (2015). Adults with spastic cerebral palsy have lower bone mass than those with dyskinetic cerebral palsy. *Bone*, *71*, 89-93. https://doi.org/10.1016/j.bone.2014.10.003

King, W., Levin, R., Schmidt, R., Oestreich, A., & Heubi, J. E. (2003). Prevalence of reduced bone mass in children and adults with spastic quadriplegia. *Developmental Medicine and Child Neurology*, *45*(1), 12-16. https://doi.org/10.1111/j.1469-8749.2003.tb00853.x

Koivisto-Mork, A. E., Steffen, K., Finnes, T. E., Pretorius, M., & Berge, H. M. (2023). High prevalence of low bone mineral density but normal trabecular bone score in Norwegian elite Para athletes. *Frontiers in Sports and Active Living*, *5*, 1246828. https://doi.org/10.3389/fspor.2023.1246828

Krigger, K. W. (2006). Cerebral palsy: An overview. *American Academy of Family Physicians*, *73*, 91-100.

Larsson, L., Degens, H., Li, M., Salviati, L., Lee, Y. I., Thompson, W., Kirkland, J. L., & Sandri, M. (2019). Sarcopenia: Aging-related loss of muscle mass and function. *Physiological Reviews*, *99*(1), 427-511. https://doi.org/10.1152/physrev.00061.2017

Lauglo, R., Vik, T., Lamvik, T., Stensvold, D., Finbraten, A. K., & Moholdt, T. (2016). High-intensity interval training to improve fitness in children with cerebral palsy. *BMJ Open Sport & Exercise Medicine*, *2*(1), e000111. https://doi.org/10.1136/bmjsem-2016-000111

Marciniak, C., Gabet, J., Lee, J., Ma, M., Brander, K., & Wysocki, N. (2016). Osteoporosis in adults with cerebral palsy: Feasibility of DXA screening and risk factors for low bone density. *Osteoporosis International*, *27*(4), 1477-1484. https://doi.org/10.1007/s00198-015-3393-6

McPhee, P. G., Claridge, E. A., Noorduyn, S. G., & Gorter, J. W. (2018). Cardiovascular disease and related risk factors in adults with cerebral palsy: A systematic review. *Developmental Medicine & Child Neurology*, *61*(8), 915-923. https://doi.org/10.1111/dmcn.14028

Medeiros, R. M., Alves, E. S., Lemos, V. A., Schwingel, P. A., da Silva, A., Vital, R., Vieira, A. S., Barreto, M. M., Rocha, E. A., Tufik, S., & de Mello, M. T. (2016). Assessment of body composition and sport performance of Brazilian Paralympic swim team athletes. *Journal of Sports Rehabilitation*, *25*(4), 364-370. https://doi.org/10.1123/jsr.2015-0036

Miyahara, K., Wang, D. H., Mori, K., Takahashi, K., Miyatake, N., Wang, B. L., Takigawa, T., Takaki, J., & Ogino, K. (2008). Effect of sports activity on bone mineral density in wheelchair athletes. *Journal of Bone and Mineral Metabolism*, *26*(1), 101-106. https://doi.org/10.1007/s00774-007-0789-1

Multani, I., Manji, J., Tang, M. J., Herzog, W., Howard, J. J., & Graham, H. K. (2019). Sarcopenia, cerebral palsy, and botulinum toxin type A. *Journal of Bone & Joint Surgery*, *7*(8), e4. https://doi.org/10.2106/JBJS.RVW.18.00153

Mus-Peters, C. T. R., Huisstede, B. M. A., Noten, S., Hitters, M., van der Slot, W. M. A., & van den Berg-Emons, R. J. G. (2019). Low bone mineral density in ambulatory persons with cerebral palsy? A systematic review. *Disability and Rehabilitation*, *41*(20), 2392-2402. https://doi.org/10.1080/09638288.2018.1470261

O'Shea, T. (2008). Diagnosis, treatment, and prevention of cerebral palsy. *Clinical Obstetrics and Gynecology*, *51*(4), 816-828.

Olympics. (2024). *Paralympic Schedule & Results: Boccia*. Retrieved 13.Jan.25 from https://olympics.com/en/paris-2024/paralympic-games/schedule/boccia?day=29-august

Palisano, R., Rosenbaum, P., Walter, S., Russell, D., Wood, E., & Galuppi, B. (1997). Development and reliability of a system to classify gross motor function in children with cerebral palsy. *Developmental Medicine & Child*

Neurology, *39*(4), 214-223. https://doi.org/10.1111/j.1469-8749.1997.tb07414.x

Paul, S., Nahar, A., Bhagawati, M., & Kunwar, A. J. (2022). A Review on recent advances of cerebral palsy. *Oxidative Medicine and Cellular Longevity*, *2022*, 2622310. https://doi.org/10.1155/2022/2622310

Peterson, M. D., Zhang, P., Haapala, H. J., Wang, S. C., & Hurvitz, E. A. (2015). Greater adipose tissue distribution and diminished spinal musculoskeletal density in adults with cerebral palsy. *Archives of Physical Medicine and Rehabilitation*, *96*(10), 1828-1833. https://doi.org/10.1016/j.apmr.2015.06.007

R Core Team. (2024). *R: A language and environment for statistical computing.* in R foundation for statistical computing. <https://www.R-project.org/>

Rezavandzayeri, F., Suarez, H., Khortabi, A., & Carral, J. (2024). The effects of Boccia training load on emotional intelligence and quality of life in individuals with cerebral palsy. *Retos*, *54*, 381-388.

Rimmer, J. H., Riley, B., Wang, E., Rauworth, A., & Jurkowski, J. (2004). Physical activity participation among persons with disabilities: Barriers and facilitators. *American Journal of Preventive Medicine*, *26*(5), 419-425. https://doi.org/10.1016/j.amepre.2004.02.002

Rosenbaum, P. L., Jacobsson, B., & Damiano, D. (2006). A report: The definition and classification of cerebral palsy April 2006. *Developmental Medicine and Child Neurology*, *49*, 8-14. https://doi.org/10.1111/j.1469-8749.2007.tb12610.x

Runciman, P., Tucker, R., Ferreira, S., Albertus-Kajee, Y., Micklesfield, L., & Derman, W. (2016). Site-specific bone mineral density is unaltered despite differences in fat-free soft tissue mass between affected and nonaffected sides in hemiplegic paralympic athletes with cerebral palsy: Preliminary findings. *American Journal of Physical Medicine & Rehabilitation*, *95*(10), 771-778. https://doi.org/10.1097/PHM.0000000000000532

Shapiro, D. R., & Malone, L. A. (2016). Quality of life and psychological affect related to sport participation in children and youth athletes with physical disabilities: A parent and athlete perspective. *Disability and Health Journal*, *9*(3), 385-391. https://doi.org/10.1016/j.dhjo.2015.11.007

Sherk, V. D., Bemben, M. G., & Bemben, D. A. (2010). Interlimb muscle and fat comparisons in persons with lower-limb amputation. *Archives of Physical Medicine and Rehabilitation*, *91*(7), 1077-1081. https://doi.org/10.1016/j.apmr.2010.04.008

Sheung-Tung, H. (2012). Review of fractures and low bone mass in children with cerebral palsy. *Journal of Orthopaedics, Trauma and Rehabilitation*, *16*(2), 45-50. https://doi.org/10.1016/j.jotr.2012.09.001

Shin, H. I., & Jung, S. H. (2021). Body fat distribution and associated risk of cardiovascular disease in adults with cerebral palsy. *Frontiers in Neurology*, *12*, 733294. https://doi.org/10.3389/fneur.2021.733294

Slocum, C., Kim, S., & Blauwet, C. (2018). Women and athletes with high support needs in paralympic sport: Progress and further opportunities for underrepresented populations. In *The Palgrave Handbook of Paralympic Studies* (pp. 371-388). https://doi.org/10.1057/978-1-137-47901-3_17

Spungen, A. M., Adkins, R. H., Stewart, C. A., Wang, J., Richard N. Pierson, J., Waters, R. L., & Bauman, W. A. (2003). Factors influencing body composition in persons with spinal cord injury: A cross-sectional study. *Journal of Applied Physiology*, *95*, 2398–2407.

Stackhouse, S. K., Binder-Macleod, S. A., & Lee, S. C. (2005). Voluntary muscle activation, contractile properties, and fatigability in children with and without cerebral palsy. *Muscle Nerve*, *31*(5), 594-601. https://doi.org/10.1002/mus.20302

Strauss, D., Cable, W., & Shavelle, R. (1999). Causes of excess mortality in cerebral palsy. *Developmental Medicine and Child Neurology*, *41*(9), 580-585. https://doi.org/10.1111/j.1469-8749.1999.tb00660.x

Su, Y. C., Tsai, M. C., Lin, C. Y., Yang, J., Wu, P. S., Yang, H. C., & Lin, Y. C. (2023). Does botulinum toxin injection exacerbate sarcopenia and bone mass in individuals with cerebral palsy? *Pediatric Neurology*, *149*, 32-38. https://doi.org/10.1016/j.pediatrneurol.2023.09.002

Sung, K. H., Chung, C. Y., Lee, K. M., Cho, B. C., Moon, S. J., Kim, J., & Park, M. S. (2017). Differences in body composition according to gross motor function in children with cerebral palsy. *Archive of Physical Medicine and Rehabilitation*, *98*(11), 2295-2300. https://doi.org/10.1016/j.apmr.2017.04.005

Szkoda, L., Szopa, A., Kwiecien-Czerwieniec, I., Siwiec, A., & Domagalska-Szopa, M. (2023). Body composition in outpatient children with cerebral palsy: A case-control study. *International Journal of General Medicine*, *16*, 281-291. https://doi.org/10.2147/IJGM.S393484

van de Vliet, Broad, E., & Strupler, M. (2011). Nutrition, body composition and pharmacology. In Y. C. Vanlandewijck & W. R. Thompson (Eds.), *Handbook of Sports Medicine and Science: The Paralympic Athlete* (pp. 172-197). Wiley-Blackwell.

Verschuren, O., Peterson, M. D., Balemans, A. C., & Hurvitz, E. A. (2016). Exercise and physical activity recommendations for people with cerebral palsy. *Developmental Medicine & Child Neurology*, *58*(8), 798-808. https://doi.org/10.1111/dmcn.13053

Weijer, V. C. R., van Dijk, J. W., van Dam, L., Risvang, L., Bons, J., Raastad, T., van Loon, L. J. C., & Jonvik, K. L. (2024). Do Paralympic athletes suffer from brittle bones? Prevalence and risk factors of low bone mineral density in Paralympic athletes. *Bone Reports*, *21*, 101767. https://doi.org/10.1016/j.bonr.2024.101767

Whitney, D. G., Alford, A. I., Devlin, M. J., Caird, M. S., Hurvitz, E. A., & Peterson, M. D. (2019). Adults with cerebral palsy have higher prevalence of fracture compared with adults without cerebral palsy independent of osteoporosis and cardiometabolic diseases. *Journal of Bone and Mineral Research*, *34*(7), 1240-1247. https://doi.org/10.1002/jbmr.3694

Whitney, D. G., Miller, F., Pohlig, R. T., & Modlesky, C. M. (2019). BMI does not capture the high fat mass index and low fat-free mass index in children with cerebral palsy and proposed statistical models that improve this accuracy. *International Journal of Obesity*, *43*(1), 82-90. https://doi.org/10.1038/s41366-018-0183-1

Won, J. H., & Jung, S. H. (2021). Bone mineral density in adults with cerebral palsy. *Frontiers in Neurology*, *12*, 733322. https://doi.org/10.3389/fneur.2021.733322

World Boccia. (2024a). *About boccia*. Retrieved 2.Jan.2025 from https://www.worldboccia.com/about-boccia/

World Boccia. (2024b). *New heroes, fresh stories and bright future for boccia after individual events at Paris 2024 Paralympics*. Retrieved 21.Dec.2024 from https://www.worldboccia.com/2024/09/03/new-heroes-fresh-stories-and-bright-future-for-boccia-after-individual-events-at-paris-2024-paralympics/

Yahagi, K., Masataka, K., Ishiba, T., & Imura, S. (2024). Training effect of repeated rolling motions on boccia players with severe cerebral palsy: Comparison with the effect of conventional upper-limb training using a crossover test. *Journal of Physical Therapy Science*, *36*, 245-251.

CHAPTER V

KINEMATICAL ANALYSIS OF DIFFERENT TYPES OF BOCCIA THROWS IN BC2 WORLD-CLASS PLAYERS WITH SPASTIC CEREBRAL PALSY

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ABSTRACT

Kinematic analyses in boccia might play an important role in improving throwing technique. This study aimed to characterize the kinematic parameters involved in the throwing motion, such as upper body angles, angular velocity and throwing velocity, for different types of boccia throws performed by world-class players with Cerebral Palsy. Associations between the different kinematic parameters and sports-related variables were assessed. Five BC2 players performed underarm throws (UA) and three of them performed also overarm throws (OA). Kinematic analyses were made at ball release through angles and angular velocity of each joint and the velocity of the throw. UA presented higher flexion in the thorax, lower flexion, abduction and internal rotation of the shoulder and lower elbow extension than OA. UA showed higher angular velocities. The release velocity of the UA was higher than OA. A higher frequency of Strength & Conditioning (S&C) training was associated to a higher magnitude of the throwing velocity for the UA. Also, a higher frequency of both specific and S&C training was associated to a higher magnitude of the throwing velocity and higher shoulder angle on the Y axis of the OA. The findings may help multidisciplinary teams optimizing throwing performance as well as injury risk reduction.

KEY-WORDS: Paralympic Sport, Spastic hypertonia, Markerless, Underarm throw, Overarm throw.

INTRODUCTION

Boccia is a paralympic sport that requires high precision skills to place the coloured balls (i.e., red or blue) as close as possible to a target white ball, also named jack. This sport can be played individually (divided by gender), in pairs or teams with all players being required to play seated in manual or powered wheelchairs (World Boccia, 2024a). The goal of the game is to have the highest number of balls closer to the jack than the opponent's closest ball, with the winner of the game being the player, pair, or team achieving the higher sum of points. Therefore, boccia is mainly described as a target sport being the precision of the throw a crucial competitive element (Kataoka et al., 2020).

Players with different physical impairments including impaired muscle power, impaired passive range of movement, limb deficiency, involuntary movements, muscle tension and uncoordinated movements affecting sports performance are eligible to compete and are categorized in 4 sport classes namely BC1, BC2, BC3 and BC4 (International Paralympic Committee, 2019). Overall, the players in the different classes are subject to different game regulations with implication to the type of sports equipment used, type of game assistance, and specific ways of throwing, among others rules. For example, BC3 players who have the most severe functional limitations, rely on assistive devices (e.g., ramps) to propel the ball. With the exception of BC3 players, all players use the hand or foot to propel the ball. Specifically in BC1 and BC4 classes, players are allowed to use the foot but there is a reduced number of foot players at both national and international levels. Also, BC1 and BC3 players can be supported by a sport assistant and ramp operator respectively, during the game while BC2 and BC4 players (with the exception of foot players) and are not eligible for assistance. Sport assistants and ramp operators are needed to stabilize the player's chair or handling the balls and ramps (World Boccia, 2024b).

According to the International Paralympic Committee (2019), BC2 players have neurological impairments that affect all four limbs, caused by conditions such as cerebral palsy (CP), stroke, or acquired brain injury. Players of this class usually exhibit spasticity hypertonia that may be accompanied by dyskinesia. BC2 players experience a moderate level of impairment that limits the ability to move effectively, with reduced muscle control or spasticity affecting upper limbs and trunk, leading to difficulties in performing coordinated movements or maintaining an active functional range of motion. Some players are able to walk for short to moderate distances independently or with the assistance of walking aids. When compared to BC1 class which also includes players with brain impairment, BC2 players typically have better functional abilities allowing for greater independence during the game.

Cerebral palsy is defined as a group of permanent disorders affecting movement and posture causing activity limitation. It is described as a nonprogressive disorder occurring in the developing fetal or infant brain until 5 years of age (Paul et al., 2022). Boccia players with CP experience impaired neuromuscular functions such as abnormal muscle tone, imbalances in agonist-antagonist muscle coordination, and reduced range of motion in the affected limbs (Reina et al., 2018) impairing upper limb (Van Thiel et al., 2000) and hand function (Braendvik et al., 2010). Consequently, the severity of CP limits the trunk, shoulder and wrist movements needed to perform precise and controlled throws (Reina et al., 2018). Boccia throwing technique requires control of wrist, elbow, and shoulder movements, as well as the actions of grasping, gripping, and releasing with the hands, which are crucial for determining the landing point, trajectory, and rolling speed of the ball in the court. Furthermore, players must stabilize trunk, control the limbs' movement, and coordinate hand-eye actions (Huang et al., 2014).

Boccia players may perform different throwing techniques, such as underarm, overarm, dart, chest, and pendulum (Sportability, n.d.), that should be examined to identify key-performance indicators that may influence successful execution, not only in terms of precision, but also in terms of strength and velocity of throwing. The players choice regarding the type of throwing technique to apply during the game depends on the player's functional abilities and tactical decisions.

Considering that throwing is the predominant movement during boccia game, conducting a kinematic analysis to describe the throwing technique is important to understand movement patterns and possible oscillations due to neural components of CP. This knowledge would assist coaches and multidisciplinary teams (e.g., physiotherapists), on how to enhance throwing performance and reduce the risk of injury, caused by repetitive strain, compensatory movements, and/or excessive stress on muscles and joints involved in the throwing technique.

Kinematic analysis is described as the study of motion without considering the forces that cause it (Grimshaw et al., 2007), being therefore a tool to assess how athletes with physical impairments move and how that impairment compromise the efficiency of those motions in the context of para sports. Kinematics analysis is a common method used to characterize the throwing techniques in different sports such as baseball, basketball or handball (e.g. Okubo & Hubbard, 2015; Oyama, 2012; Skejo et al., 2019). There are also some studies approaching throwing techniques in para-athletics, specifically in Paralympic seated throwing (e.g. Hyde et al., 2017), and in wheelchair basketball (e.g. Goosey-Tolfrey et al., 2002; Prvulovic et al., 2022).

However, in boccia research, the application of kinematic analysis is almost inexistent. Hendarto (2023) studied 6 players (3 males and 3 females) who competed in the Asian Paragames and determined gender differences in boccia UA throw biomechanics. In addition, Reina et al. (2018) analyzed the impact of different throwing distances on the kinematics and precision across repeated throws in 5 players (BC1=2; BC2=3) from the Spanish national team. Romero and Hernández (2000) also studied Spanish boccia players, and the types of throwing techniques more frequently used during different championships. The authors concluded that UA throw was used by half of the players in national competitions, regardless of impairment level. However, even though the previously mentioned studies have addressed kinematic aspects of throwing technique, to the best of the author’s knowledge, no studies focused on comparing different throwing techniques.

The abovementioned rationale highlights the need for providing more tools to improve training methods and technical feedback concerning the different throwing techniques trained by boccia coaches as well as specific training staff [e.g., biomechanists, strength and conditioning (S&C) coaches]. Although Keogh

(2011) emphasized the critical role of sports biomechanics in enhancing performance across different summer Paralympic sports, boccia continuous to be a neglected sport in terms of research and consultancy. Given this gap, understanding the biomechanical aspects of throwing performance becomes even more important for multidisciplinary teams working with world-class boccia players.

Therefore, the aim of the present study was to characterize the kinematic parameters involved in the throwing motion, such as upper body angles, angular velocity of joint movements and throwing velocity in two different types of boccia throws performed by world-class boccia players with CP. Moreover, the associations between the different kinematic parameters and sports-related variables were assessed.

METHODS

Participants

Five boccia players (3 males and 2 females), with spastic quadriplegia CP aged between 15 and 42 years old, were recruited to participate in this study. The inclusion criteria encompassed participants with a confirmed diagnosis of CP, regardless of subtype and topology, and classified as BC2. The players needed to be part of the Portuguese national team during the previous season and to train regularly in the current season. The BC2 class was selected because it includes the highest number of players with CP within the Portuguese national team. Participants who did not have international competitive experience representing the national boccia team were excluded from the study. A sociodemographic questionnaire collecting personal (e.g., age, gender, height, weight) and clinical information (e.g., type of CP) was completed by the participants. Sports-related information, such as number of years of training, years of competition, frequency of training sessions per week, and duration of both sport-specific and S&C training was also collected.

Regarding data collection procedures, all participants received a comprehensive verbal explanation of the study's protocol describing the study's goals, methodology, potential advantages, and associated risks. Subsequently, those who voluntarily chose to participate formally signed a consent form, which included a written explanation of the protocol. For underage participants, informed consent was signed by the players and also by their tutors. The research was approved by the local ethical committee, with the approval identification CEFADE 47/2022.

Instruments

Data for motion capture was recorded with a set of 8 Miqus Video Cameras (Miqus, Qualysis AB, Sweden) placed around the player, recording at 1080p resolution with a sampling frequency of 85 Hz. Two cameras were positioned behind the player at equal distances to ensure a symmetrical view. The remaining cameras were distributed along the sides, also equidistant from the player, to provide optimal coverage of both the player’s movements and the initial trajectory of the ball, ensuring the best possible perspective for analysis (Figure 1).

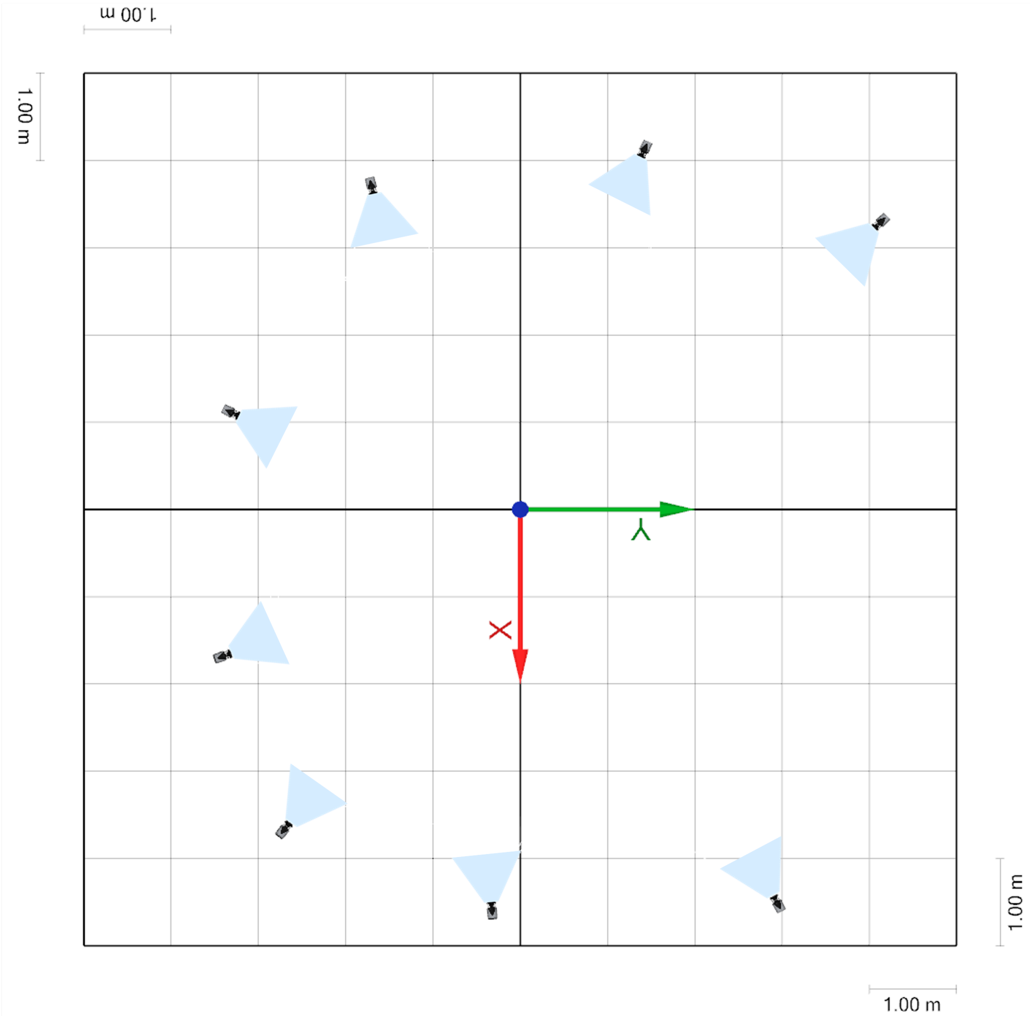

Figure 1. Set-up of the data collection.

A performance volume of approximately 2m x 1.5m x 2m and was calibrated with an error of 0.70 mm. A global coordinate system was established, where the X-axis corresponded to the anterior-posterior direction, the Y-axis corresponded to the medial-lateral direction and the Z-axis corresponded to the vertical direction. Markerless kinematics were obtained using Theia Markerless (Theia Markerless, Kingston, ON, Canada) software and analyzed in Visual 3D software (HAS-Motion, Kingston, ON, Canada). Data was exported to MS Excel (Microsoft, USA) for visualization. The markerless system, a non-invasive and fully automated system overcomes the difficulties tied to marker placement while reducing errors caused by soft tissue movement (Das et al., 2023).

Data collection took place in the sports hall of the faculty and players were instructed to wear tight-fitting clothing, preferably sleeveless t-shirts, to ensure that the movements of all the joints involved in the throw could be clearly observed. Male players performed the throws without wearing a t-shirt to further enhance the visibility of joint movements for analysis.

Regarding assessment conditions, players used their competition wheelchair and stood behind a line that simulated the throwing line (World Boccia, 2024b). The target ball was placed at 10 meters to serve as visual feedback, simulating the longest valid distance to throw the ball, as suggested by Kataoka et al. (2020). Players received the instruction to throw with the maximum velocity possible. Before testing, players performed individual warm-up and 3 consecutive throws (UA and OA techniques, if possible). The OA and UA throwing techniques are depicted in Figures 2 and 3, respectively.

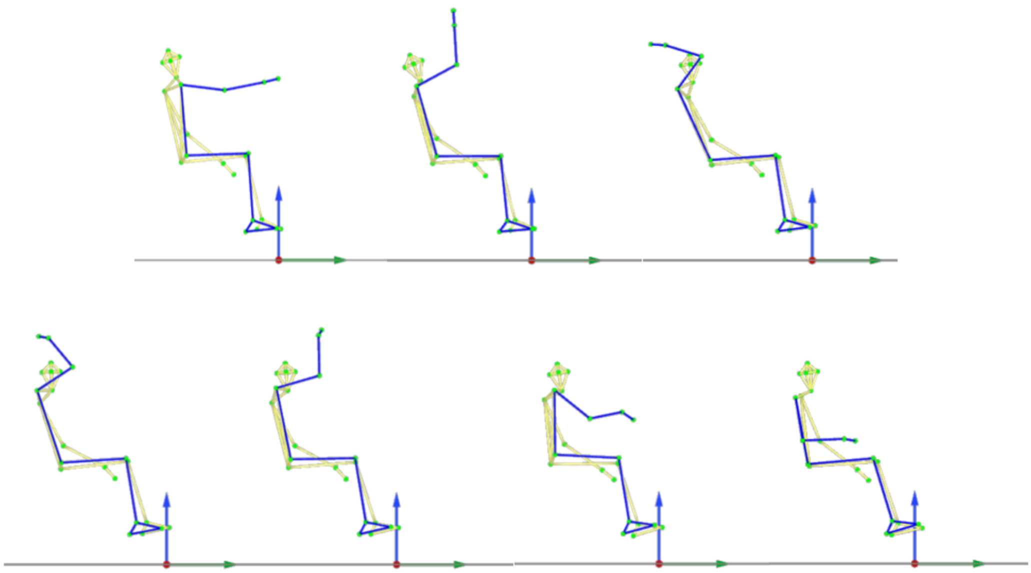

Figure 2. Schematic representation of the overarm through in boccia. The throwing (right) side is highlighted in blue thicker lines. The wheelchair is not shown for clarity

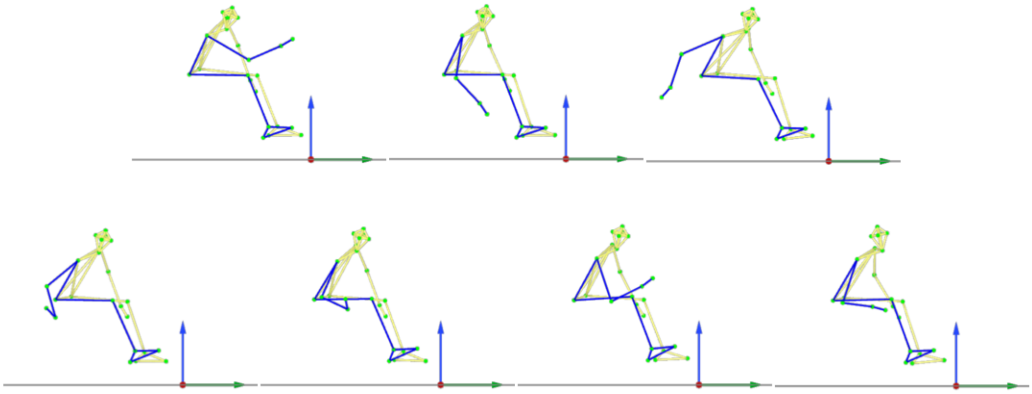

Figure 3. Schematic representation of the underarm through in boccia. The throwing (right) side is highlighted in blue heavier lines. The wheelchair is not shown for clarity.

During testing, players performed 6 throws using official boccia balls (weight: 275 ± 12 g) from a standard kit (Boccas Soft Brazil) during 4 minutes, for each type of throw (UA and OA techniques, if possible).

Kinematic analyses were made at ball release (BR) through angles and angular velocity of each joint and velocity of the hand, from this point forward referred to as velocity of the throw. The BR was considered the last moment before the fingers lose contact with the ball and was identified by visual inspection of the video recordings. Assessment of upper body angular position and velocity included thorax lateral flexion and rotation, shoulder flexion/extension, adduction/abduction, internal/external rotation, elbow flexion/extension, internal/external rotation and wrist flexion/extension, adduction/abduction. All joint angles and velocities were calculated in relation to the proximal limb. The shoulder variables were computed in relation to the thorax, in turn related to the pelvis. Through the position of the centre of mass for the hand, the velocity of the throws was calculated using the numerical derivative in the global referential.

Statistical analysis

Descriptive statistics were performed using mean and standard deviation. For data normality, the Shapiro Wilk test was performed, and the kinematic values were correlated using the Pearson correlation test with the other variables using using R Core Team (2024).

RESULTS

Wrist data was excluded due to the image acquisition rate being low for this motion, causing the results to be unreliable. Concerning elbow, only flexion/extension data were included due to the same reason. Descriptive data is presented in Table 1.

Table 1. Sex and sports-related parameters of each player.

	Player 1	**Player 2**	**Player 3**	**Player 4**	**Player 5**
Sex	Male	Male	Male	Female	Female
Throwing hand	Right	Right	Left	Left	Left
Years of practice	15	10	25	3	16
Years of competition	10	3	25	2	16
Specific training sessions: duration per session (min)	300	150	150	150	165*
Specific training sessions: frequency per week	5	4	6	3	4
S&C training sessions: duration per session (min)	20	45*	45	45	60
S&C training sessions: frequency per week	5	2	4	2	2.5*
UA throw	Yes	Yes	Yes	Yes	Yes
OA throw	Yes	Yes	No	Yes	No

Notes: S&C = Strength & Conditioning; UA throw = Underarm throw; OA throw = Overarm throw;
* mean of the reported intervals.

The participants presented a broad range of experience in boccia, with 3 to 25 years of practice and 2 to 25 years of competition. The volume and frequency of specific training sessions were 150–300 minutes and 3–6 times per week, respectively. Concerning S&C training sessions, the volume ranged from 20 to 60 minutes and the frequency from 2 to 5 times per week. All players perform UA throws but only three players were able to perform OA.

Table 2 displays the mean joint angles calculated individually for each player, as well as the group mean and standard deviation for both UA and OA throws at BR.

Table 2. Mean and standard deviation of each angle for each player for the UA and OA throw at BR.

Joint	Player	X (°)		Y (°)		Z (°)	
		UA	OA	UA	OA	UA	OA
Thorax	Player 1	-37.6	-12.3	18.9	12.0	14.4	4.5
	Player 2	-49.8	13.4	34.1	4.7	8.3	17.6
	Player 3	-49.6	—	13.6	—	16.1	—
	Player 4	-34.4	-22.9	25.3	9.0	1.7	12.4
	Player 5	-44.4	—	14.5	—	5.3	—
	Group mean ± SD	-43.1 ± 7.0	-7.3 ± 18.7	21.3 ± 8.5	8.6 ± 3.7	9.2 ± 6.0	11.5 ± 6.6
Shoulder	Player 1	34.0	115.5	-41.3	-22.6	21.4	9.6
	Player 2	49.2	104.2	-57.4	-29.1	59.3	33.7
	Player 3	35.2	—	-21.2	—	-7.6	—
	Player 4	30.2	110.4	-32.3	-37.5	1.0	24.5
	Player 5	21.3	—	-28.7	—	22.8	—
	Group mean ± SD	34.0 ± 10.1	110.0 ± 5.7	-36.2 ± 13.9	-29.8 ± 7.5	19.4 ± 25.9	22.6 ± 12.2
Elbow	Player 1	47.6	90.4				
	Player 2	109.3	130.3				
	Player 3	30.3	—				
	Player 4	32.3	118.2				
	Player 5	43.4	—				
	Group mean ± SD	52.6 ± 32.6	113.0 ± 20.5				

Note: For the thorax: X = extension (+) / flexion (-); Y = lateral flexion to throwing side; Z = rotation towards throwing side. For the shoulder: X = flexion (+) / extension (-); Y = adduction (+) / abduction (-); Z = internal rotation (+) / external rotation (-); For the elbow: X = flexion (+) / extension (-). — = players who were not able to perform the OA throw.

During the UA throw at BR, the thorax flexion/extension showed a mean of -43.1° ± 7.0°, while the other angles depended on the player's preferences to the left or right turns. Shoulder motion demonstrated a wider range, specifically in internal/external rotation (19.4° ± 25.9°), while the mean elbow flexion was 52.6° ± 32.6°. During the OA throw at BR, the thorax flexion/extension showed a mean of -7.3° ± 18.7°, and a rotation mean -11.5° ± 6.6°. Shoulder motion exhibited a narrower range compared to the thorax, with in-ternal/external rotation averaging 22.6° ± 12.2°, while the mean elbow flexion was 113.0° ±20.5°.
Results of the angular velocity for each joint of both UA and OA throws are displayed in Table 3.

Table 3. Mean and standard deviation of the angular velocity components for both UA and OA throws at BR.

Throw	Joint	X (°/s)	Y (°/s)	Z (°/s)
UA	**Thorax**	26.8 ± 24.1	23.5 ± 11.3	19.8 ± 9.8
	Shoulder	455.8 ± 113.2	-7.2 ± 133.2	125.9 ± 59.3
	Elbow	120.4 ± 88.0		
OA	**Thorax**	-9.3 ± 29.5	15.5 ± 5.9	22.0 ± 10.7
	Shoulder	-238.5 ± 180.8	-188.1 ± 179.1	10.8 ± 132.8
	Elbow	-241.9 ± 273.8		

Note: For the thorax: X = extension (+) / flexion (-); Y = lateral flexion to throwing side; Z = rotation towards throwing side. For the shoulder: X = flexion (+) / extension (-); Y = adduction (+) / abduction (-); Z = internal rotation (+) / external rotation (-); For the elbow: X = flexion (+) / extension (-). — = players who were not able to perform the OA throw.

Angular velocity of the UA shower higher values for the all the components except for the shoulder internal/external rotation (-7.2± 133.2°/s).

Table 4 presents data concerning the velocity components and magnitude for each type of throw at BR.

Table 4. Mean and standard deviation of the velocity components in the global frame and magnitude for each type of throw at BR.

Throw	Medial (-) / Lateral (+) (m/s)	Anterior (+) / Posterior (-) (m/s)	Upwards (+) / Downwards (-) (m/s)	Magnitude (m/s)
UA	-0.06 ± 0.60	4.43 ± 0.89	1.04 ± 0.94	4.74 ± 0.89
OA	-0.12 ± 0.45	3.37 ± 0.91	-0.26 ± 0.79	3.50 ± 0.84

Note: UA = underarm throw; OA = overarm throw.

The magnitude of the velocity was higher for the UA (4.74 ± 0.89 m/s). Concerning the components, UA was higher for all except for the medial/lateral, where OA presented -0.12 ± 0.45 m/s.

Regarding the correlation analysis, when considering the UA throw, only one variable showed a statistically significant correlation, namely, for the magnitude of the hand velocity and frequency of S&C training sessions ($r = 0.925$, $p = 0.004$). A higher frequency of S&C training was associated to a higher magnitude of the ball throw velocity.

Regarding OA throws, statistically significant correlations were found between the shoulder adduction / abduction angle and the frequency of specific training ($r = 0.997$, $p = 0.046$), as well as for the total magnitude of the hand velocity on the anterior-posterior axis and the frequency of S&C training ($r = 1.000$, $p = 0.004$). It is possible to conclude that a higher frequency of both specific and S&C training was associated to a higher magnitude of the hand velocity and a higher shoulder angle on the Y axis. For the other variables no statistically significant correlations were found.

DISCUSSION

The aim of the present study was to characterize the kinematic parameters involved in the throwing motion, including upper body angles and angular velocities as well as throwing velocity in different types of boccia throws performed by world-class players with CP. Additionally, the study explored the relationships between different kinematic parameters and sports-related factors. The present study provides original and innovative data describing the kinematics characteristics of boccia UA and OA in BR events. In general, boccia throwing technique requires four implementation stages: set-up, preparation, delivery and follow-through (World Boccia, n.d.). The delivery is the phase including ball release. The BR is the most important event of the delivery stage because it is when the joint angles define the direction of the ball and consequently the precision of the throw. Therefore, analyzing the angular velocity and velocity of the BR can offer valuable insights for coaches, enabling them to provide targeted feedback during training sessions. Moreover, the associations between kinematic parameters of the throws and sports-related parameters may help to support changes to the periodization developed by the coaching staff, namely concerning frequency, duration and volume of training sessions.

Although boccia is considered one of the most inclusive and unique sports of the Summer Paralympic programme, being the only sport for persons with physical impairment without an Olympic counterpart (Brittain, 2017), there is a lack of research focusing on boccia. Recently, Ferreira et al. (2023) conducted a systematic review about the current status of boccia performance. From the final pool of 9 studies, the authors concluded that the majority focused on the boccia throwing technique (Hendarto, 2023; Kataoka et al., 2020; Reina et al., 2018). However, a detail analysis of the previously mentioned studies demonstrates that values of the angles at BR were not reported, hindering the detailed characterization of the throwing technique with precise values or range of values. Also, in the literature it was not possible to identify studies exploring the associations between training-related variables (e.g., frequency of specific and S&C training) and throwing techniques. Therefore, the present findings hold particular value for multidisciplinary teams aiming to refine training strategies and methods to enhance throwing performance. The results may support the development of tailored interventions, specific technical feedback, and evidence-based training approaches, further contributing for high-performance boccia

First, it is important to highlight that all players were able to perform the UA throw. Considering that all participants were world-class players and therefore playing at high-level in the national and international championships, the present findings are in accordance with Romero and Hernández (2000) study. The authors reported that at national level, the UA throw was used by half of the players, confirming UA as the most used throw. The authors reported that at national level, the UA throw was used by half of the players, suggesting UA as the most used throw. In the present study, only 3 players were able to perform the OA throw. In this context, it is important to mention that the UA technique is easier to perform because it requires less range of motion in the involved joints, specifically in the shoulder flexion. In accordance, in the present study the UA shoulder flexion exhibited a mean of 34° while OA shoulder flexion exhibited a mean of 110°. Also, UA apparently requires less strength and coordination of the body parts involved in the throwing and less stability of the core than OA.
Concerning joint angles, the UA throws presented a higher flexion in the thorax, a lower flexion of the shoulder and a lower elbow extension than OA throws, suggesting less complexity of the throwing technique, as previously mentioned. Considering that people with spastic quadriplegia typical present permanent shoulder internal rotation and elbow flexion (Gharbaoui et al., 2016), motions requiring higher ranges of motion of these joints are also limited in this group of players. Overall, UA requires lower ranges of motion in shoulder and elbow joints and, consequently, requires less functional abilities when compared to OA.

Reina et al. (2018) also accessed kinematics of Boccia throws but the results reported in the study do not allow to objectively quantify the angles of the measured motions (e.g., elbow extension and flexion, trunk inclination). However, it was possible to observe that, for the maximum speed throws, which was the same instruction given to the players of the present study, the BC2 players presented an elbow flexion between 120-140º, showing a substantial difference when compared with the values of the present study (53±33°). Although Reina et al. (2018) stated that the throw type used by the players was the most suitable one according to the distance, it was not clear if UA throw was the only type of throw assessed in the study. Furthermore, it was not explicit how were the angles measured, but we may speculate that the Reina et al. (2018) elbow flexion angle (around 130°) plus the present work angles (around 50°) sum 180°, which may hint on Reina et al. (2018) definition of the angle. On the other hand, Hendarto (2023) analysed kinematic parameters of UA throws related with specific movements of throwing preparation (e.g., backswing, frontswing, follow-through) but not with the BR event as explored in the present study. Once again, the lack of studies with a clear definition of angles in boccia throws limits the comparation with the values obtained in the present study in order to characterize the UA and the OA throws.

Boccia is a Paralympic sport where throwing techniques are specific and unique, but some parameters could be similar to other Paralympic sports for athletes with physical impairment. For example, OA throws may present some similarities to the free throw in wheelchair basketball, even considering that one is done with one hand, while the other is usually performed with both hands. Goosey-Tolfrey et al. (2002) examined the differences in free throw technique among wheelchair basketball players of lower classes (Group 1, with higher impairment) and higher classes (Group 2, with lower impairment) using kinematic parameters. In regard of joint angles at BR, shoulder flexion/extension values ranged from 104 ± 36° to 123 ± 13° whereas elbow flexion/extension ranged from 138 ± 11° to 141 ± 10° for GL and GH, respectively (Goosey-Tolfrey et al., 2002). Therefore, considering that the mean shoulder flexion/extension of the present study was 110 ± 6°, and the mean elbow flexion/extension was 113 ± 21° it is possible to confirm that OA presents very similar patterns with the free throw of wheelchair basketball. However, in a similar study from Prvulovic et al. (2022), that analyzed the kinematic elements of the free throw shooting technique among wheelchair basketball players from different sport classes, the angles of flexion/extension of the elbow ranged from 51° to 89°, showing lower joint angles at BR in shoulder and elbow flexion/extension. Nevertheless, these differences may be due to the level of the athletes' performance from each study, since Goosey-Tolfrey et al. (2002) assessed players from the Great Britain training squad preparing for the Paralympic Games in Sydney, while Prvulovic et al. (2022) assessed players from a local club in Serbia. The present findings can also be discussed in the light of evidence related to sport for people without disability. For example, UA throw resembles pitching in softball. Scarborough et al. (2019) analyzed the relationships between the kinematics of the elbow and forearm and alignment of the elbow (carrying angle and elbow extension) in the softball pitch of female players and found an average elbow flexion of 35 ± 9.6º. In our sample, with the exception of player 2, all players exhibited values for elbow flexion similar to softball (48°, 30°, 32° and 43°, with a mean of 38 ± 8°) in the UA throw at BR. We may speculate that boccia coaches might consider incorporating insights from softball techniques when addressing UA throwing.

In terms of angular velocity, the OA throws showed higher angular velocities, the shoulder reaching 188 °/s of abduction and 239 °/s of extension, and the elbow 241 °/s of extension, revealing that OA throw is a faster throw than the UA. Considering that it was not possible to identify studies determining the angular velocities in UA or OA boccia techniques, the similarities of angular velocity of free throws in wheelchair basketball were considered. In this sense, Goosey-Tolfrey et al. (2002) indicated a shoulder angular velocity between 4.9 ± 2.2 rad/s and 6.5 ± 1.3 rad/s (281 ± 126°/s and 372 ± 74°/s), for Group 1 (lower sport classes) and Group 2 (higher sport classes), respectively. In the present study, the shoulder adduction and extension angular velocities for the OA were lower than those of the free throw, possibly since in the Goosey-Tolfrey et al. (2002) sample none of the athletes had CP. Another important difference between OA throws and free throws is that boccia throws are done with one hand holding the ball, while in wheelchair basketball throws are usually done with both hands holding the ball (i.e., higher sport classes). Nevertheless, there are some similarities between boccia OA and wheelchair basketball free throwing technique, suggesting that boccia coaches may expand their feedback options and also use wheelchair basketball free throw technique as a partial model to adjust the OA technique.

Concerning the velocity of the throws, OA were performed at lower velocity (3.5 ± 0.8 m/s) when compared to UA throws (4.7 ± 0.9 m/s) suggestion that UA throws may be more efficient when throwing longer distances in boccia field. Reina et al. (2018) also analysed the maximum speed throws and reported speeds throws between 5 and 6 m/s. However, possible comparisons are hindered by the lack of information about the type of throw used in Reina et al. (2018) research. When analyzing the values from Goosey-Tolfrey et al. (2002) study, the wheelchair basketball free throws presented higher velocities (ranging from 7.2 ± 0.2 m/s to 7.6 ± 0.4 m/s for Group 1 and Group 2, respectively) when compared to the present study. This is an expected result because in wheelchair basketball the target is at 3.05 m height.

Although boccia is considered a target sport, the ability to execute long-distance throws is also essential. Overall, players have to be able to successfully throw at short (1.5-3 m), middle (5-6 m) and long distances (8-10 m) applying proper velocity and strength needed to execute the best tactical decisions for the game (Kataoka et al., 2020). Therefore, being able to produce more strength during the throws allows to achieve longer distances and increased velocity. Reina et al. (2018) also demonstrated that higher velocities are present in long-distance throws in boccia, reinforcing the idea that increased throwing strength and velocity can expand tactical options and player’s effectiveness. Similarly, van den Tillaar and Ettema (2003) conducted a study focusing on handball and revealed that experienced players could achieve accurate throws even at relatively high speeds. However, the combination of fast and high precision throws was only possible up to a limited distance, afterwards with increasing velocity the precision decreases.

Regarding the results about the correlation analysis between the kinematic variables and the sports-related parameters, when considering the UA throw it was possible to observe that the higher the frequency of S&C training, the greater the magnitude of the ball throw velocity. Also for the OA, the higher the frequency of specific and S&C training, the greater the velocity and the greater the shoulder adduction/abduction angle. Therefore, the present findings suggest that a higher training frequency, including both S&C and specific training, is associated to a better throwing performance, particularly in terms of velocity, but also range of motion. It is important to highlight that all boccia players participating in the present study reported substantial amounts of training per week, including technical and tactical boccia training but also S&C work. In this sense, S&C

training for boccia should focus on skill development and essential body maintenance, incorporating stretching and mobility exercises for maintaining thorax control, and strength training to enhance muscle power (Boccia Canada, n.d.). Therefore, an adjusted periodization may lead to higher throwing velocities in both UA and OA, as well as wider angles for the shoulder adduction/abduction.
Finally, it is important to highlight the main methodological limitations of the present study. First, the small sample size limits the ability to draw broad conclusions about the UA and OA throwing techniques. A larger sample would allow gender or sport classes comparisons helping to establish reference values for joint angles crucial for both UA and OA performance. Therefore, further studies should include other topologies of CP (e.g., dyskinesia) and, eventually, other sports classes where players with CP are eligible to compete to enable comparations and increase the spectrum of normative data.

Second, the image acquisition rate used was 85 Hz, which hindered and compromised some analyses, particularly those related to wrist data. Future research should use higher acquisition rates to ensure detailed tracking of fine motor actions needed in boccia throwing techniques.

Third, the precision of the throws or variations in throwing distances were not considered. Assessing precision is essential to understanding the effectiveness of different throwing techniques. Also, analyzing throws with different target distances would provide more evidence about throwing performance demands. Incorporating these factors in future research could offer valuable insights into the relationship between technique, accuracy, and distance in throws performed by BC2 players. Additionally, only the BR event was analysed. Other critical phases of the throws, such as the set-up and follow-through should be analysed in future studies to provide a complete characterization and description of the throws' motion. Also, the fatigue during the data collection was not addressed, which could have influenced the values of the last throws. Finally, concerning that there are other techniques to propel the ball (e.g., chest throw, or foot players), a broader kinematic analysis is needed to provide a comprehensive understanding about all the throwing techniques specific of the boccia game.

CONCLUSION

The present study analyzed the kinematic parameters of the UA and OA throws in world-class boccia players with CP, revealing different characteristics of motion in joint angles and angular velocities. The UA technique was characterized by faster movements and lower range of motions compared to OA technique. Also, UA throws reached higher velocities than OA's. Training frequency emerged as an important variable related to throw performance, with higher training frequency associated to increased throwing velocities and wider shoulder adduction/abduction angles. These findings emphasized the importance of combining S&C with technical training to enhance both throwing power and range of motion.

The hinted similarities between the UA and OA throwing techniques with other sports (e.g., wheelchair basketball and softball) may bring new insights to boccia training, specifically, to improve throwing techniques, mainly, due to the lack of research concerning the specificities of boccia technique.

AUTHOR CONTRIBUTIONS

Conceptualization, B.V., L.M., J.G., J.P.V.B., and T.B.; methodology, B.V., L.M., P.F., J.P.V.B., K.S., and T.B.; software B.V., P.F., L.M., and K.S.; validation, L.M., J.G., R.C. and T.B.; formal analysis, B.V., P.F., L.M. K.S., and T.B.; investigation, B.V., L.M., J.G., R.C. and T.B.; resources, B.V., L.M., and J.P.V.B.; data curation, B.V., P.F., and K.S.; writing—original draft preparation, B.V.; writing—review and editing, B.V., P.F., L.M., J.P.V.B., J.G., K.S., R.C. and T.B.; visualization, B.V., P.F., L.M., J.G., K.S., R.C. and T.B.; supervision, J.G., R.C. and T.B.

FUNDING

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INSTITUTIONAL REVIEW BOARD STATEMENT

The study was conducted in accordance with the Declaration of Helsinki and approved by the Faculty of Sport Ethics Committee (protocol code 47/2022 and date of approval: 18 January 2023 Committee).

INFORMED CONSENT STATEMENT

Informed consent was obtained from all subjects involved in the study as abovementioned.

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CONFLICTS OF INTEREST

The authors report no conflicts of interest.

ABBREVIATIONS

The following abbreviations are used in this manuscript:

BR	Ball release
CP	Cerebral Palsy
Hz	Hertz
OA	Overarm
S&C	Strength & Conditioning
UA	Underarm

REFERENCES

Boccia Canada. Long-term athlete development model. n.d. https://bocciacanada.ca/wp-content/uploads/2021/08/Long-Term-Athlete-Development-Model-en.pdf (accessed 21.Dec.2024).

Braendvik, S. M.; Elvrum, A. K.; Vereijken, B.; Roeleveld, K. Relationship between neuromuscular body functions and upper extremity activity in children with cerebral palsy. Developmental Medicine & Child Neurology 2010, 52 (2), e29-34. http://doi.org/10.1111/j.1469-8749.2009.03490.x

Brittain, I. Glynn Tromans: In search of “fearless” boccia and the “big hairy audacious goal”. In High performance disability sport coaching, Kohe, G. Z., Peters, D. M. Eds.; Routledge, 2017; pp 145-162.

Das, K.; de Paula Oliveira, T.; Newell, J. Comparison of markerless and marker-based motion capture systems using 95% functional limits of agreement in a linear mixed-effects modelling framework. Scientific Reports 2023, 13 (1), 22880. http://doi.org/10.1038/s41598-023-49360-2

Ferreira, C. C.; Espada, M. C.; Gamonales, J. M.; Muñoz-Jiménez, J. Current status of sport performance in boccia: Systematic review of the literature. Retos 2023, 48, 1070-1077. http://doi.org/10.47197/retos.v48.95110.

Gharbaoui, I.; Kania, K.; Cole, P. Spastic paralysis of the elbow and forearm. Seminars in Plastic Surgery 2016, 30 (1), 39-44. http://doi.org/10.1055/s-0035-1571255

Goosey-Tolfrey, V.; Butterworth, D.; Morriss, C. Free throw shooting technique of male wheelchair basketball players. Adapted Physical Activity Quarterly 2002, 19, 238-250. http://doi.org/10.1123/apaq.19.2.238.

Grimshaw, P.; Lees, A.; Fowler, N.; Burden, A. *Sport & Exercise Biomechanics*; Taylor & Francis, 2007.

Hendarto, S. Gender differences in boccia underhand throw biomechanics. Revista Iberoamericana de Psícologia del Ejercicio y el Deporte 2023, 18 (2), 228-234.

Huang, P. C.; Pan, P. J.; Ou, Y. C.; Yu, Y. C.; Tsai, Y. S. Motion analysis of throwing boccia balls in children with cerebral palsy. Research in

Developmental Disabilities 2014, 35 (2), 393-399. http://doi.org/10.1016/j.ridd.2013.11.017

Hyde, A.; Hogarth, L.; Sayers, M.; Beckman, E.; Connick, M. J.; Tweedy, S.; Burkett, B. The impact of an assistive pole, seat configuration, and strength in Paralympic seated throwing. International Journal of Sports Physiology and Performance 2017, 12 (7), 977-983. http://doi.org/10.1123/ijspp.2016-0340

International Paralympic Committee. Explanatory guide to classification: Paralympic summer sports. 2019. https://gtimg.tokyo2020.org/image/upload/production/n4fd9qx81mgkd9hjllgd.pdf (accessed 1.Nov.2020).

Kataoka, M.; Okuda, K.; Iwata, A.; Imura, S.; Yahagi, K.; Matsuo, Y. Throwing distance and competitive performance of boccia players. Journal of Physical Therapy Science 2020, 32, 574–577. http://doi.org/10.55860/BOUA9793.

Keogh, J. W. Paralympic sport: An emerging area for research and consultancy in sports biomechanics. Sports Biomechanics 2011, 10 (3), 234-253. http://doi.org/10.1080/14763141.2011.592341

Okubo, H.; Hubbard, M. Kinematics of arm joint motions in basketball shooting. Procedia Engineering 2015, 112, 443-448. http://doi.org/10.1016/j.proeng.2015.07.222.

Oyama, S. Baseball pitching kinematics, joint loads, and injury prevention. Journal of Sport and Health Science 2012, 1 (2), 80-91. http://doi.org/10.1016/j.jshs.2012.06.004.

Paul, S.; Nahar, A.; Bhagawati, M.; Kunwar, A. J. A review on recent advances of cerebral palsy. Oxidative Medicine and Cellular Longevity, 2022, 2622310. http://doi.org/10.1155/2022/2622310

Prvulovic, N.; Hadzovic, M.; Lilic, A. A biomechanical analysis of the free throw shooting technique in wheelchair basketball: A pilot study. Journal of Anthropology of Sport and Physical Education 2022, 6 (1), 3-6. http://doi.org/10.26773/jaspe.220101.

R Core Team (2024). R: A language and environment for statistical computing. In R foundation for statistical computing. <https://www.R-project.org/>

Reina, R.; Domínguez-Díez, M.; Urbán, T.; Roldán, A. Throwing distance constraints regarding kinematics and accuracy in high-level boccia players. Science & Sports 2018, 33 (5), 299-306. http://doi.org/10.1016/j.scispo.2018.03.078.

Romero, F. Á.; Hernández, F. J. M. The perception and neuromuscular activity in individuals with cerebral palsy playing boccia: Methodological evalutation. Apunts: Educación física y deportes. 2000, (60), 59-65.

Scarborough, D. M.; McCunney, R. C.; Berkson, E. M.; Oh, L. S. The relationship of elbow alignment and kinematics on shoulder torque during the softball pitch: A biomechanical analysis of female softball pitchers. Journal of Shoulder and Elbow Surgery 2019, 28 (2), 357-364. http://doi.org/10.1016/j.jse.2018.07.021

Skejo, S. D.; Moller, M.; Bencke, J.; Sorensen, H. Shoulder kinematics and kinetics of team handball throwing: A scoping review. Human Movement Science 2019, 64, 203-212. http://doi.org/10.1016/j.humov.2019.02.006

Sportability. Sportability's boccia coaching resource. n.d. https://sportabilitybc.ca/boccia-resource/ (accessed 27.Dec.2024).

van den Tillaar, R.; Ettema, G. Influence of instruction on velocity and accuracy of overarm throwing. Perceptual and Motor Skills 2003, 96 (2), 355-702. http://doi.org/10.2466/pms.2003.96.2.423.

Van Thiel, E.; Meulenbroek, R. G.; Hulstijn, W.; Steenbergen, B. Kinematics of fast hemiparetic aiming movements toward stationary and moving targets. Experimental Brain Research 2000, 132 (2), 230-242. http://doi.org/10.1007/s002219900331

World Boccia. About boccia. 2024. https://www.worldboccia.com/about-boccia/ (accessed 2.Jan.2025).

World Boccia. Long-term player development in sport of boccia. n.d. https://www.worldboccia.com/wp-content/uploads/2021/12/Boccia-Players-Pathway.pdf (accessed 17.Jan.2025).

World Boccia. World boccia international rules. v2.2. 2024. https://www.worldboccia.com/wp-content/uploads/2024/04/World-Boccia-International-Rules-v2.2.pdf (accessed 3.Jan.2025).

CHAPTER VI

GENERAL CONCLUSION, LIMITATIONS AND FUTURE DIRECTIONS

The present thesis focused on drawing the physical profile of world-class athletes with Cerebral Palsy, characterizing health and performance related-variables interfering in sports performance and providing scientific knowledge that may be relevant for multidisciplinary teams working with both para swimmers and boccia players. The study contributed with the following conclusions:

Study 1: Anthropometric characteristics and somatotype of world-class para swimmers with spastic Cerebral Palsy.

- Para swimmers exhibited an Ectomorph-Endomorph somatotype profile with higher levels of adiposity, in comparison with other para sports;
- No significant correlations were found between anthropometric or sports-related variables and the swimmers' classification, supporting the current classification system which relies on functional and technical assessments;
- A higher adiposity is more likely in para swimmers with lower functional abilities.

Study 2: Upper body strength and range of motion of world-class para swimmers with spastic Cerebral Palsy.

- In para swimmers, strength relates with range of motion of upper body joints, namely shoulder and elbow;
- Para swimmers with greater levels of strength have greater shoulder and elbow flexion;
- Para swimmers that use manual or electric wheelchair have lower strength levels.

Study 3: Assessment of health-related parameters in world-class boccia players using DXA.

- Boccia players showed an obesity class I prevalence of 60%, with the remaining 40% presenting normal fat level;
- Sarcopenia risk was presented in 66.7% of the adults.
- BMD levels where below the expected range for age in 60% of the boccia players.

Study 4: Kinematical analysis of different types of boccia throws in BC2 world-class players with spastic Cerebral Palsy.

- UA presented a higher flexion in the thorax, a lower flexion, abduction and internal rotation of the shoulder and a lower elbow extension than OA;
- UA showed higher angular velocities and velocity than OA;
- Higher frequency of S&C training was associated to a higher magnitude of the ball throw velocity of the UA and a higher frequency of specific and S&C training was associated to a higher magnitude of the velocity and higher shoulder angle on the Y axis of the OA.

The findings revealed that world-class para swimmers with CP present an anthropometric and somatotype profile characterized by higher adiposity and somatotypes with endomorphic components being predominant. Strength and ROM assessments confirmed that upper-body force production and joint mobility vary according to functional classification and ambulatory locomotion, with ambulatory athletes demonstrating greater strength and ROM, particularly in shoulder and elbow flexion.

In boccia, athletes—who typically have more severe physical impairments—demonstrated significant health risks despite high-performance involvement. The use of DXA revealed concerning levels of adiposity, sarcopenia risk, and reduced BMD, particularly in adult players. These findings underline the limited health benefits of boccia alone and point to the need for extra interventions, including S&C training and tailored health monitoring.

Lastly, the kinematic analysis of boccia throws provided novel insights into the technical aspects of the sport. The study distinguished between UA and OA techniques, with UA requiring lower joint ranges and contributing to higher ball velocities. Higher frequencies of both strength and sport-specific training were associated with improved throwing performance, reinforcing the importance of well-structured periodization and technical refinement.

As a whole, this thesis highlights the importance of an individualized, evidence-based approach to training and health management in para sports, especially in athletes with CP. The integration of morphological, physiological, and biomechanical data is essential to optimizing performance while safeguarding athlete well-being.

However, while the studies provide valuable contributions, some limitations must be acknowledged. The primary limitation across all studies was the small sample size, which is a persistent challenge in Paralympic research due to the heterogeneity of impairments and logistical barriers in accessing elite athletes with CP. Consequently, the generalizability of the findings is limited.

Additionally, variations in CP types (e.g., spasticity, ataxia), sex, and sport classification may have introduced confounding effects that were not fully controlled. In the kinematic analysis, low frame acquisition rates and the exclusion of key throw phases (e.g., follow-through) limited the granularity of motion analysis. Similarly, DXA assessments in non-ambulatory athletes were challenged by issues such as spasticity and postural asymmetries, which could compromise measurement accuracy.

Furthermore, all studies employed cross-sectional designs, which limit the ability to assess long-term variations. The absence of performance outcome measures (e.g., swim times or competition results) in correlation analyses also restricted the ability to directly link physical assessments with real-world sport success.

In this sense, to advance research in this field, several avenues must be established. Conducting larger, collaborative, and international studies is essential to overcome the limitations of small, homogeneous samples and to better reflect the diversity in CP types, functional classifications, and training backgrounds. Longitudinal research that monitors athletes across training seasons or entire Paralympic cycles would provide valuable insights into developmental trends, the efficacy of training interventions, and key predictors of elite performance.

Future studies should seek to strengthen the relationship between physical and biomechanical assessments and actual competitive outcomes, enhancing the value of such evaluations for talent identification and individualized training planning. Health promotion should also be prioritized, particularly in sports such as boccia, where the current findings highlight risks of obesity, sarcopenia, and osteoporosis. Structured S&C programs and nutritional interventions should be considered essential elements of athlete support.

More especifically, in para swimming, future research should pay closer attention to potential asymmetries by assessing and comparing, not only, anthropometric characteristics but also joint range of motion, on both sides of the body. Bilateral evaluations may offer valuable insights into how asymmetries impact stroke technique, propulsion efficiency, and injury risk. Such findings could contribute to the development of more individualized training strategies aimed at optimizing performance while minimizing overuse injuries. Moreover, analyzing these variables across different functional classifications may help clarify the influence of impairment severity on biomechanical adaptations and performance profiles, thereby contributing to both training and classification processes.

In the context of boccia, further investigation into ball-handling strategies is warranted. Comparing different grip techniques and their effects on throwing performance—particularly in athletes with varying degrees of motor control—may help to identify biomechanical adaptations that enhance precision and consistency. Analyzing these variables across throwing styles could also reveal meaningful patterns with implications for evidence-based training and performance development.

This thesis contributes significantly to the limited knowledge on high-performance athletes with CP, particularly in para swimming and boccia. By addressing physical, functional, and health-related parameters, it offers practical implications for coaches, classifiers, and multidisciplinary teams. Above all, it emphasizes the need for a multidimensional, athlete-centred approach that not only enhances sport performance but also promotes long-term health.

APPENDIX I

FREE AND INFORMED CONSENT (ADULT): MADEIRA

U.PORTO UNIVERSIDADE DO PORTO FACULDADE DE DESPORTO

CENTRO DE INVESTIGAÇÃO FORMAÇÃO INOVAÇÃO E INTERVENÇÃO EM DESPORTO CIFI2D

Free and informed consent for participation in research study

Subject: Request for authorisation to participate in research with elite athletes with Cerebral Palsy

Title: Profiling elite athletes with Cerebral Palsy

Dear athlete,

I, Bárbara Fontes Costa de Freitas Vasconcelos, attending the Doctoral Programme in Sports Science, supervised by Professor Rui Corredeira and Professor Tânia Bastos, hereby request your consent to participate in a study which aims to characterise elite athletes with Cerebral Palsy.
The evaluations, essential for the study, will involve a short questionnaire, anthropometric measures, evaluation of upper limb strength, mobility, heart rate and lactate. These will have a duration of about 30 minutes and will be carried out in a convenient venue, on a date to be previously informed.
All information taken from the study will be coded to protect each subject's name. No names or other identifying information will be used when discussing or reporting data. The investigator will safely keep all files and data collected.
I am at your complete disposal to clarify any doubts, through the following contacts: mobile +351 916 743 748 or e-mail *fontes.b94@gmail.com*.
I am sure that you will contribute to this study by giving your consent.

Madeira, June 2022

Best regards,

____

Bárbara Vasconcelos

I declare that I have read and understood this document, as well as the verbal information given to me by the person signing above. I was guaranteed the possibility of refusing at any time to participate in this study without any type of consequence. Thus, I agree to participate in this study and allow the use of the data that I voluntarily provide, trusting that they will only be used for this research and the guarantees of confidentiality and anonymity given to me by the researcher.

Name: ____

Signature: ____

Date: _____ / _____ / ________

APPENDIX II

FREE AND INFORMED CONSENT (MINOR): MADEIRA

U.PORTO UNIVERSIDADE DO PORTO FACULDADE DE DESPORTO

CENTRO DE INVESTIGAÇÃO FORMAÇÃO INOVAÇÃO E INTERVENÇÃO EM DESPORTO CIFI2D

Free and informed consent for participation in research study

Subject: Request for authorisation to participate in research with elite athletes with Cerebral Palsy

Title: Profiling elite athletes with Cerebral Palsy

Dear athlete,

I, Bárbara Fontes Costa de Freitas Vasconcelos, attending the Doctoral Programme in Sports Science, supervised by Professor Rui Corredeira and Professor Tânia Bastos, hereby request your consent to participate in a study which aims to characterise elite athletes with Cerebral Palsy.
The evaluations, essential for the study, will involve a short questionnaire, anthropometric measures, evaluation of upper limb strength, mobility, heart rate and lactate. These will have a duration of about 30 minutes and will be carried out in a convenient venue, on a date to be previously informed.
All information taken from the study will be coded to protect each subject's name. No names or other identifying information will be used when discussing or reporting data. The investigator will safely keep all files and data collected.
I am at your complete disposal to clarify any doubts, through the following contacts: mobile +351 916 743 748 or e-mail *fontes.b94@gmail.com*.
I am sure that you will contribute to this study by giving your consent.

Madeira, June 2022

Best regards,

____

Bárbara Vasconcelos

I declare that I have read and understood this document, as well as the verbal information given to me by the person signing above. I was guaranteed the possibility of refusing at any time to participate in this study without any type of consequence. Thus, I agree to participate in this study and allow the use of the data that I voluntarily provide, trusting that they will only be used for this research and the guarantees of confidentiality and anonymity given to me by the researcher.

Name: ____

ID Nr.: ______________ **Date of expiration:** _____ / _____ / ________

Type of representation: ____________________

Signature: ____

IF YOU DO NOT SIGN YOURSELF DUE TO AGE OR INCAPACITY

(if the minor has discernment, she/he must also sign below if she/he consents)

Name: ____

Signature: ____

Date: _____ / _____ / ________

APPENDIX III

SOCIODEMOGRAPHIC QUESTIONNAIRE AND REGISTRATION FORM: MADEIRA

U.PORTO UNIVERSIDADE DO PORTO FACULDADE DE DESPORTO CENTRO DE INVESTIGAÇÃO FORMAÇÃO INOVAÇÃO E INTERVENÇÃO EM DESPORTO CIFI2D

ID Number: _______

QUESTIONNAIRE

1. Birth date (dd/mm/aaaa): ___ / ___ / _____
2. Gender: Female _____ Male _____ Other _____
3. Profession: _________________
4. Sports: ____________________
5. Sports classification: ______
6. Years of practice: ________
7. Years of competition: _____
8. Specific training sessions per week
   8.1. Duration: _____
   8.2. Frequency: _____
9. Strength and conditioning training: Yes _____ No _____
   9.1. If yes:
      9.1.1. Duration: ______
      9.1.2. Frequency: ______

10.	Type of Cerebral Palsy	Right	Left	Notes
	Spastic diplegia			
	Spastic quadriplegia			
	Spastic hemiplegia			
	Dyskinetic choreo-athetoid			
	Dyskinetic dystonic			
	Ataxic CP			

11. Medication or treatment to reduce the effects of spasticity within six months:
    Yes _____ No _____
12. Associated diseases: ____
13. Ambulatory gait: Yes _____ No _____
14. Walking aid devices: ____

REGISTER FORM

1. STRENGTH (cm and 00:00.00)

1st trial _______________________ 3rd trial _______________________

2nd trial _______________________ Mean _______________________

2. RESTING HEART RATE _______________________________________

3. LACTATE CONCENTRATION __________________________________

Weight (kg): ______ **Height (cm):** ______ BMI (kg/m^2): _______

ID Number: ________

4. ANTHROPOMETRY		Right			Left		
		1st	2nd	3rd	1st	2nd	3rd
SKINFOLDS (mm)	**Triceps**						
	Subscapular						
	Biceps						
	Iliac crest						
	Supraespinale						
	Abdominal						
	Front thigh						
	Medial calf						
GIRTHS (cm)	Arm flexed						
	Arm tensed						
	Waist						
	Calf						
BONE BREADTH (cm)	**Humerus**						
	Femur						
	Bi-acromial						
	Bi-iliac						

5. MOBILITY		**RIGHT**		**LEFT**	
JOINT	**MOVEMENT**	V.I.	V.F.	V.I.	V.F.
Glenohumeral joint	(S) Flexion (0º-180º)				
	(S) Abduction (0º-180º)				
	(DD) Internal rotation (0º-70º)				
	(DD) External rotation (0º-90º)				
	(DV) Hyperextension (0º-60º)				
Humeroulnar joint	(DV) Flexion (0º-150º)				
	(DV) Supination (0º-90º)				
	(DV) Pronation (0º-90º)				
Wrist joint	Flexion (0º-80º)				
	Extension (0º-70º)				

APPENDIX IV

FREE AND INFORMED CONSENT (ADULT): LABIOMEP

Informed, clarified, and free consent for participation in research study

Subject: Authorization request for participation in research with elite athletes with Cerebral Palsy

Title: Profiling elite athletes with Cerebral Palsy

Dear Athlete,

I, Bárbara Fontes Costa de Freitas Vasconcelos, currently enrolled in the Doctoral Program in Sports Sciences and supervised by Professor Rui Corredeira, Professor José Irineu Gorla, and Professor Tânia Bastos, kindly request your consent to participate in a study aimed at characterizing elite athletes with Cerebral Palsy.

The evaluations, which are essential for the study, will involve a short questionnaire, anthropometric measurements, upper limb strength assessment, mobility, heart rate, lactate levels, a DXA scan (bone densitometry), and kinematic and electromyographic assessments during throwing. These evaluations will take approximately 90 minutes and will be conducted at LABIOMEP, located at the Faculty of Sports of the University of Porto, on a date to be scheduled in advance.

All information obtained during the study will be coded to protect the identity of each participant. No names or other identifying information will be used when discussing or reporting data. The researcher will securely store all files and collected data. Once the data have been fully analyzed, they will be destroyed.

I am available to clarify any doubts you may have through the following contacts: mobile phone +351 916 743 748 or email fontes.b94@gmail.com.

I am confident that you will contribute to the progress of this study by granting your authorization.

Porto, November 2022

With kind regards,

____

Bárbara Vasconcelos

Consent Declaration

I declare that I have read and understood this document, as well as the verbal information provided to me by the above-signed individual. I have been assured that I may, at any time, refuse to participate in this study without any consequences. Accordingly, I agree to participate in this study and allow the use of the data I voluntarily provide, trusting that it will only be used for this research and with the guarantees of confidentiality and anonymity provided by the researcher.

Name: ____

Signature: ____

Date: _____ / _____ / ________

APPENDIX V

FREE AND INFORMED CONSENT (MINOR): LABIOMEP

Informed, clarified, and free consent for participation in research study

Subject: Authorization request for participation in research with elite athletes with Cerebral Palsy

Title: Profiling elite athletes with Cerebral Palsy

Dear Athlete/Parent/Legal tutor,

I, Bárbara Fontes Costa de Freitas Vasconcelos, currently enrolled in the Doctoral Program in Sports Sciences and supervised by Professor Rui Corredeira, Professor José Irineu Gorla, and Professor Tânia Bastos, hereby request your consent to participate in a study aimed at characterizing elite athletes with Cerebral Palsy.

The evaluations, essential for the study, will include a short questionnaire, anthropometric measurements, upper limb strength assessment, mobility, heart rate, lactate levels, a DXA scan (bone densitometry), and kinematic and electromyographic assessments during throwing. These evaluations will last approximately 90 minutes and will be conducted at LABIOMEP, located at the Faculty of Sports of the University of Porto, on a date to be scheduled in advance.

All information collected in the study will be coded to protect the participant's identity. No names or other identifying information will be used when discussing or reporting data. The researcher will securely store all files and collected data. Once the data have been fully analyzed, they will be destroyed.

I am available to clarify any questions you may have through the following contacts: mobile phone +351 916 743 748 or email fontes.b94@gmail.com.

I am confident that you will contribute to the progress of this study by granting your authorization.

Porto, November 2022

With kind regards,

Bárbara Vasconcelos

UNIVERSIDADE DO PORTO FACULDADE DE DESPORTO
CENTRO DE INVESTIGAÇÃO FORMAÇÃO INOVAÇÃO E INTERVENÇÃO EM DESPORTO CIFI2D

Consent Declaration

I declare that I have read and understood this document, as well as the verbal information provided to me by the above-signed individual. I have been assured that I may, at any time, refuse to participate in this study without any consequences. Accordingly, I agree to participate in this study and allow the use of the data I voluntarily provide, trusting that it will only be used for this research and with the guarantees of confidentiality and anonymity provided by the researcher.

Name: ____

ID Nr: ________________ **Expiration date:** ____ / ____ / ______

Type of responsability: _________________________________

Signature: ____

Date: ____ / ____ / ______

IF UNABLE TO SIGN DUE TO AGE OR INCAPACITY

(if the minor has the capacity to understand, they should also sign below, if they consent)

Name: ____

Signature: ____

Date: ____ / ____ / ______