apunts
EDUCACIÓN FÍSICA Y DEPORTES

Published July 1, 2023
https://doi.org/10.5672/apunts.2014-0983.es.(2023/3).153.05

ISSUE 153

OPEN ACCESS

PHYSICAL EDUCATION

Evidence-Based Classification in Wheelchair Sports: A Systematic Review

Karina Sá[1,*], Cláudio Nogueira[2], José Gorla[1], Andressa Silva[3], Marília Magno e Silva[4] & Anselmo Costa e Silva[5]

[1] Faculty of Physical Education, University of Campinas, Campinas (Brazil).
[2] Physical Education Department, Castelo Branco University, Rio de Janeiro (Brazil).
[3] Federal University of Minas Gerais, Belo Horizonte (Brazil).
[4] Faculty of Physical Therapy and Occupational Therapy, Federal University of Pará, Belém (Brazil).
[5] Faculty of Physical Education, Federal University of Pará, Belém (Brazil).

Cite this article

Sá, K., Nogueira, C., Gorla, J., Silva, A., Magno e Silva, M. & Costa e Silva, A. (2023). Evidence-based Classification in Wheelchair Sports: A Systematic Review. *Apunts Educación Física y Deportes, 153*, 52-66. https://doi.org/10.5672/apunts.2014-0983.es.(2023/3).153.04

Editor:
© Generalitat de Catalunya
Departament de la Presidència
Institut Nacional d'Educació Física de Catalunya (INEFC)

ISSN: 2014-0983

***Corresponding author:**
Karina Sá
karina-sa@outlook.com

Section:
Physical Education

Original language:
English

Received:
September 21, 2022
Accepted:
January 19, 2023
Published:
July 1, 2023

Front cover:
Two surfers practicing freestyle kitesurfing. Adobestock ©MandicJovan. Mediteraneo

Abstract

The purpose of this study is to answer the following questions: What kind of evidence-based classification test is being discussed for wheelchair Paralympic sports? What kind of tool does the research use to quantify these evidence-based classification tests? A systematic review was carried out in the databases of PubMed and ScienceDirect. The main parameters studies described were muscle strength of upper limbs and trunk, and measures of mobility performance, especially speed. The main tests these studies carried out were isometric strength tests, tilt tests, sprints, and acceleration tests. The instruments most commonly used in the studies were load cells and dynamometers, video systems, laser devices, force platforms, and inertial sensors. Biomechanics tools are important allies for evidence-based classification. Classification tests with equipment and sensors that provide objective measurements of parameters allow validating simple field tests and obtaining reliable values concerning such parameters during athletes' classification.

Keywords: evidence-based classification, measurement, Paralympic sports, technologies in sport, wheelchair sports.

Introduction

Eleven out of twenty-two Paralympics summer sports are wheelchair modalities: wheelchair rugby, wheelchair basketball, World Para Athletics, wheelchair tennis, table tennis, para badminton, wheelchair fencing, paratriathlon, para shooting, para archery, and boccia (International Paralympic Committee, 2020). Wheelchair sports athletes are typically classified with the following eligible impairments: impaired muscle power (e.g. spinal cord injury, muscular dystrophy, post-polio syndrome, and spina bifida), impaired passive range of movement (e.g. arthrogryposis and contracture resulting from chronic joint immobilization or trauma affecting a joint), limb deficiency (e.g. amputation, and dysmelia), leg length difference, hypertonia (e.g. cerebral palsy, traumatic brain injury and stroke), ataxia (e.g. cerebral palsy, traumatic brain injury, stroke, and multiple sclerosis), and athetosis (e.g. cerebral palsy, traumatic brain injury and stroke) (International Paralympic Committee, 2017).

Over the years, since the development of adapted modalities, there has been some sort of classification. Initially, the classification of athletes was based on the individual's medical diagnosis, comprising distinct classes for people with spinal cord injury (ISMWSF), amputations and others (ISOD), blindness and visual impairment (IBSA), cerebral palsy (CPISRA), as well as such as hearing impairment (ICSD) and intellectual disability (Special Olympics and INAS) (Reina et al., n.d.). With the maturing of the Paralympic movement and the popularization of the modalities, some inconsistencies appeared in the classification system: people with the same diagnosis could present different functionalities and so the system was updated and is now based on the athletes' functionality (Reina et al., n.d.; Tweedy & Vanlandewijck, 2014).

In addition, thinking in terms of functionality, there is a taxonomic relationship between the International Classification of Functioning, Disabilty and Health (ICF) of the World Health Organization and the Paralympic Functional Classification, in which it is possible to apply the language and structure of the ICF to the context of Paralympic sport (Tweedy, 2002). Thus, the Functional Classification system is based on the definitions and language of the ICF (Tweedy & Vanlandewijck, 2014). Therefore, the classification ceased to consider the injury itself and started to take into account the impact of the injury on performing tasks, that is, on its functionality, and the classification code was updated until it reached the form we know today.

For fair play matters, sports federations must evaluate and classify an athlete's impairment (Vanlandewijck et al., 2011). The federations of each sport, regulated by the International Paralympic Committee (IPC), have their own classification rules. According to the definition of the IPC, athletes are grouped into classes according to how much their permanent disability affects the fundamental activities of each sport (*IPC Athlete Classification Code, 2015*). Sport classification may be partly a subjective-quantitative process (Vanlandewijck et al., 2011). The classification rules for each wheelchair Paralympic sport have similar principles, but each sport has its assessment characteristics and classes.

Classification has a significant impact on successful performance in Paralympics (Tachibana et al., 2019). Classification systems sometimes are based on the judgment of experienced classifiers and these evaluations may lead to questionable classifications, allocating athletes to classes that can give them advantages or disadvantages over their competitors (Tweedy & Vanlandewijck, 2014; Van der Slikke et al., 2018). In this sense, the evidence-based classification (EBC) has been gaining popularity throughout the last years. An EBC system aims to provide more objective classifications according to empirical evidence based on quantitative methods.

In this sense, an evidence-based system requires that scientific research be developed, in order to answer questions relevant to the athletes' classification process. So, Tweedy et al. (2016) developed a scheme that aims to resolve doubts about the process of developing evidence-based classification systems. This process is sequential and consists of six steps:

- Step 1 Identify the target sport and the types of disability to be classified. In this step the type of disability is selected based on the 10 types of disability that are eligible for Paralympic sport (impaired muscle power, impaired passive range of movement, limb disability, leg length difference, hypertonia, ataxia, athetosis, short Stature, vision impairment and intellectual impairment) and within these types, the eligible disabilities for each sport are chosen.
- Step 2 Develop the theoretical model of the determinants of sports performance. In this step, the researcher determines how general sports performance is evaluated and identifies the factors that determine overall performance in this sport, such as muscle strength, range of motion, among others.

- Step 3a Develop valid measures of impairment(s). This step identifies ways to directly measure one of the ten types of eligible impairments, that is, methods to infer impairment based on knowledge of intact bodily structures and functions.
- Step 3b develop standardized, sports-specific measure(s) of performance. This step develops standardized, sport-specific measures that quantify performance individually or collectively. Thus, test selection needs to take into account whether the outcome is predictive of performance, whether the outcome measure is sensitive to differences in impairment measures, and whether factors that are not rated have minimal influence.
- Step 4 Assess the relative strength of association between valid measures of impairment and sport-specific measure(s) of sport performance. In this step the relative strength of association between measures of disability and sport-specific measures of performance in athletes with disabilities is assessed. Tests that have strong and statistically significant associations can be incorporated into rating systems, helping to guide practitioners in decision-making during the rating process.
- Step 5 Use outcomes from Step 4 to determine minimum impairment criteria, number of classes, and methods for allocating classes. In this step, the minimum disability criteria are defined, that is, it is determined that the disability is severe enough to adversely affect performance in that sport. In addition to determining the number of classes according to the degrees of commitment in each sport, statistical methods to achieve these results are used.

The quest to make the classification evidence-based requires a lot of studies, going through each of these steps, in order to make the assessments as close as possible to the ideal, increasing confidence in the processes and allowing the Paralympic vision to be realized (Tweedy et al., 2016, 2018).

This topic raises at least two questions: What type of EBC tests are under discussion for wheelchair Paralympic sports? What type of tools does research use to quantify such EBC tests? Therefore, the objective of this systematic review was discussing what type of quantitative tests, based on movement analysis techniques (e.g., inertial measurements, videophotogrammetry, etc.), literature has been applying for the EBC concerning wheelchair Paralympic sports.

Materials and methods

Preliminary settings

The present study is in agreement with Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement. It was registered in the International Prospective Register of Systematic Review (PROSPERO; https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42020166767) on 28/04/2020 (registration number CRD42020166767) (Booth et al., 2012). The inquiries of this study fit PICO's strategy as follows: (1) Participants: wheelchair athletes; (2) Intervention: Research on evidence-based classification; (3) Comparison: descriptive data on evidence-based classification; and (4) Outcomes: main tests and instruments that make the classification of Paralympic sports more objective.

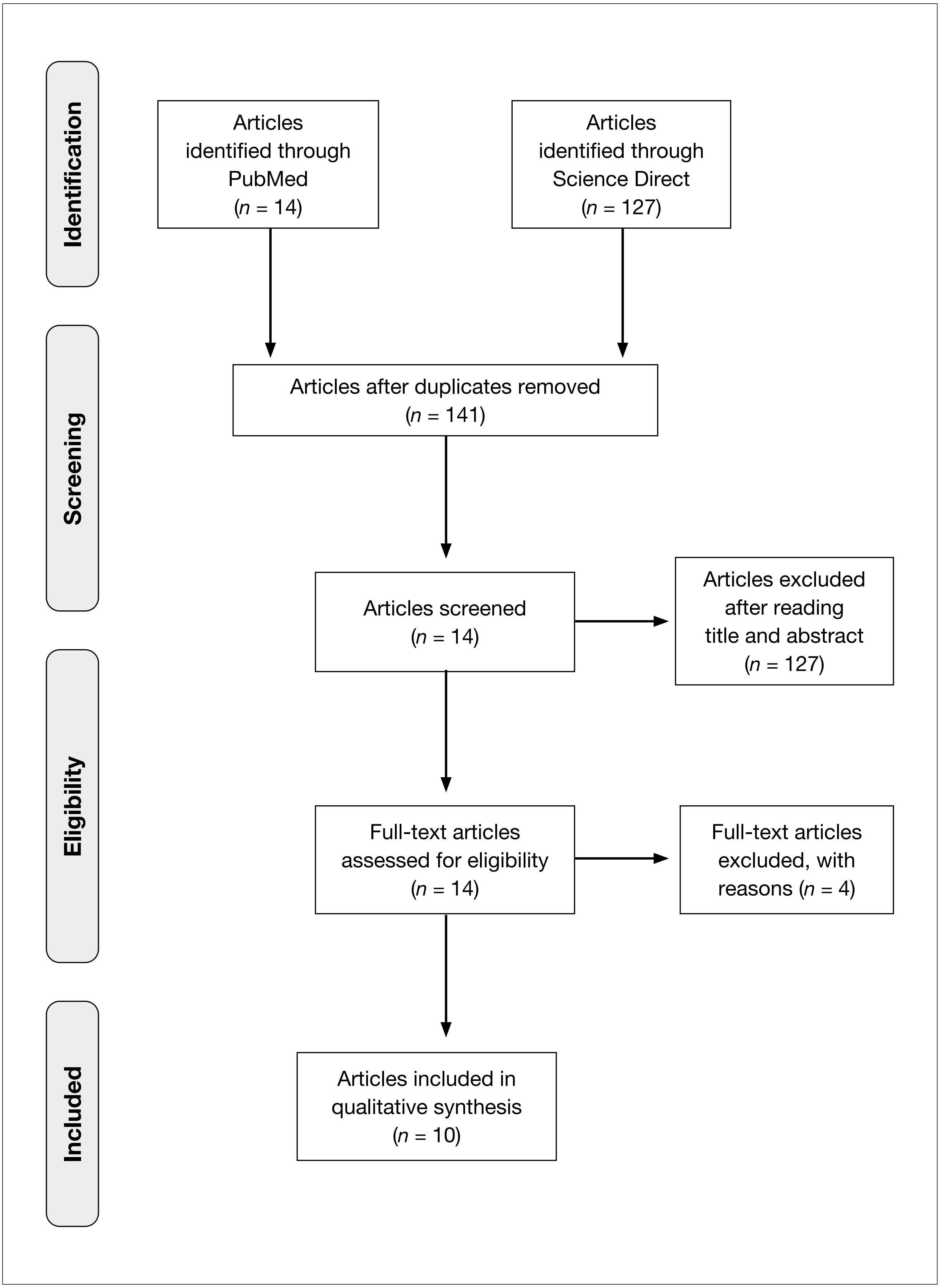
Eligibility criteria

To be considered, manuscripts had to: (1) be cross-sectional studies written in English; (2) present methodologies for the quantification of the performance of wheelchair sports; (3) present quantitative data of evidence-based classification in wheelchair sports; and (4) involve movement analysis in Paralympics athletes. This research excluded studies that were: (1) introduction of conference proceedings; (2) duplicate studies; (3) studies applying evidence-based classification of Paralympic sports without a wheelchair.

Search strategy

Systematic searches were conducted in the following databases with English language restriction and without date restriction: PubMed/Medline and ScienceDirect. The search terms used were: "evidence-based classification" AND "wheelchair sports". After searching, two researchers selected articles independently, excluding duplicated papers. Decision-making was based on the titles and abstracts of the articles and the inclusion criteria previously described (Figure 1). A third researcher solved occasional disagreements.

Figure 1
Flow diagram.



Data extraction

Data extraction was performed independently by two researchers and when inconsistencies were presented, a third researcher solved them. The following features were extracted from selected studies: author's name, year, purpose, sport, sample, evaluated parameter, tests, sensors and equipment, and main results.

Quality assessment

The studies were evaluated through the Appraisal tool for Cross-Sectional Studies (AXIS tool) (Downes et al., 2016). This tool consists of twenty questions that evaluate the quality and risk of bias of cross-sectional studies.

Results

Included studies

This study identified a total of 141 articles in the databases and selected 14 articles by reading the title and abstract. Afterward, the articles were fully read and the inclusion criteria mentioned above were applied. Only four studies did not meet the inclusion criteria: one study was a systematic review (Morriën et al., 2017); a book section (Ungerer, 2018); one study did not focus on classification aspects (Van der Slikke et al., 2015); and one study focused in people without physical impairments (Vanlandewijck et al., 2011). Finally, 10 articles remained for this review (Figure 1). Taking into account the chronology of these studies, the first was published in 2014 (Borren et al., 2014), and the two most recent in 2020 (Mason et al., 2019; Van der Slikke et al., 2020), until the submission of this review.

Quality assessment

The selected studies had the quality assessment and methodological rigor evaluated by the AXIS tool. We identified that for the 20 questions present in the AXIS tool, none of the articles reported items 7, 9 (methods), and 14 (results). In addition, items 3 (methods), 13 (results), and 19 (others) were negative for all articles. In general, all articles have good methodological quality, which makes their results reliable (see supplementary material 1). This assessment did not influence the selection of studies.

Studies Summary

We found that wheelchair rugby was the most studied sport (*N* = 8) (Altmann et al., 2016, 2017; Borren et al., 2014; Hyde et al., 2016; Mason et al., 2019; Santos et al., 2017; Squair et al., 2017; Van der Slikke et al., 2020), followed by wheelchair basketball (*N* = 4) (Altmann et al., 2016; Borren et al., 2014; Hyde et al., 2016; Van der Slikke et al., 2020), World Para Athletics (*N* = 2) (Connick et al., 2017; Hyde et al., 2016), and wheelchair tennis (*N* = 1) (Van der Slikke et al., 2020). Some of the articles evaluated over one sport (Altmann et al., 2017; Hyde et al., 2016; Van der Slikke et al., 2020). Regarding the EBC, the main instruments researchers used to carry out their evaluations were: load cells and dynamometer (*N* = 3) (Altmann et al., 2017; Connick et al., 2017; Mason et al., 2019); video systems (*N* = 3) (Borren et al., 2014; Connick et al., 2017; Hyde et al., 2016); laser device (*N* = 2) (Altmann et al., 2016; Connick et al., 2017); inertial sensors (*N* = 2) (Van der Slikke et al., 2018, 2020); and force platform (*N* = 1) (Santos et al., 2017). The most widespread tests were: isometric strength tests (*N* = 4) (Altmann et al., 2017; Connick et al., 2017; Hyde et al., 2016; Mason et al., 2019); tilt tests (*N* = 2) (Altmann et al., 2016, 2017); sprints (*N* = 2) (Altmann et al., 2016; Connick et al., 2017); acceleration (*N* = 2) (Altmann et al., 2016, 2017); match and field tests (*N* = 2) (Van der Slikke et al., 2018, 2020); pass tests (*N* = 1) (Borren et al., 2014); throwing test (*N* = 1) (Hyde et al., 2016); and trunk inclination to the sides (*N* = 1) (Santos et al., 2017). Some of the computed variables were: strength (*N* = 4) (Altmann et al., 2017; Connick et al., 2017; Hyde et al., 2016; Mason et al., 2019); speed and acceleration values (*N* = 2) (Van der Slikke et al., 2018, 2020); tilt height (*N* = 2) (Altmann et al., 2016, 2017); and Seated limits of stability (LoS) (*N* = 1) (Santos et al., 2017). For more information see table 1.

EBC aims to make classification in Paralympic sports more precise by using tests and measures. To do so, it is important to 1) select the most relevant parameters to be assessed and the conditions for the assessment; 2) choose adequate instruments and tests to assess such parameters; 3) provide objective values to assist decision-making concerning an athlete's class choice.

Table 1
Data extracted from the eligible studies regarding evidence-based classification in wheelchair sports.

Study	Purpose	Para Sport /Sample	Evaluation of the Test	Quantification Tools	Quantified Variables	Main results for classification
(Borren et al., 2014)	Analyze wheelchair rugby athletes while performing different passing techniques and compare athletes from different classes.	Wheelchair Rugby / 15 athletes	Chest pass. Impact pass. Overarm pass. Sidearm pass.	Kinematic Analysis.	Throw force, power, and speed for each one of the passing techniques.	The group without triceps function had an average pitch of 3.5 m and the group with triceps function had an average pitch of 8 m. In this way, athletes with higher classes had better results than athletes with low legs. In addition, the study showed that the current classification had a good correlation with what was found in the study.
(Hyde et al., 2016)	Investigate the influence of the assistive pole, seat configuration, and upper-body and trunk strength during sitting throws in athletes with spinal cord injury (SCI).	Wheelchair Rugby, Wheelchair basketball and World Para Athletics / 10 athletes	Seated throwing and strength tests.	kinematic analysis; Grip Strength; Dynamometer.	3D kinematic data were collected (150 Hz) for both conditions using standardized and self-selected seat configurations. Dominant and nondominant grip strength were measured using a dynamometer, and upper-body and trunk strength was measured using isometric contractions against a load cell.	The athletes performed better when they used an assistive pole. The seat configuration had no influence on performance. Grip strength measures were significantly correlated with the speed of the throw. These results contribute to the investigation of the evidence-based classification.
(Altmann et al., 2016)	Assess the impact of trunk impairment, using the Trunk Impairment Classification (TIC) on performance.	Wheelchair rugby / 55 athletes: - 21 with TIC score 0. -13 with TIC score 0.5. - 11 with TIC score 1.0. -10 with TIC score 1.5.	10 m sprint test, Turn test. Tilt test. Maximal initial acceleration test. Hitting test.	Infrared sensors; A sensor (AMR Sports).	10 m sprint test: time to perform the test [s]. Turn test: time to cover the 10 m distance [s]. Tilt test: tilt height [mm]. Maximal initial acceleration test [m/s^2]. Hitting test: Distance [m] needed to reach a difference of 81 cm between athletes per TIC score; and, sprint momentum [kg*m/s].	The study demonstrated that trunk impairment has an impact on acceleration in the first 2 meters, so we can infer that athletes with limited trunk impairment are more proficient in wheelchair rugby than athletes with severe trunk impairment.

Caption: this table presents the main information of the articles that were selected for this review.

Table 1 (Continuation)
Data extracted from the eligible studies regarding evidence-based classification in wheelchair sports.

Study	Purpose	Para Sport /Sample	Evaluation of the Test	Quantification Tools	Quantified Variables	Main results for classification
(Santos et al., 2017)	They evaluated the influence of the classification of rugby in a wheelchair (WR) and the competitive level in the function of the trunk using seated stability limits (LoS).	Wheelchair rugby / 28 athletes divided into three groups according to national or international competition following IWRF categories: a low-point group, comprising 0.5–1.5-point players, *N* = 8; a mid-point group, with 2.0–2.5-point players, N = 14; and a high-point group, with 3.0–3.5-point players, N = 6.	Participants had to sit down on a wooden block, leaning and stretching their bodies as widely as possible towards eight pre-defined directions. Research arranged all eight directions in a diamond shape, separating them by 45-dregree intervals.	Force platform.	Seated limits of stability (LoS) were computed as the area of ellipse adjusted to maximal CoP excursion achieved in each one of the eight directions.	High point players had a higher limit of seated stability (LoS) when compared to low point players. LoS can be a valid form of assessment for trunk impairment, which contributes to evidence-based classification.
(Connick et al., 2017)	Validate isometric strength tests and analyze whether strength measures can be used to classify athletes.	Wheelchair-Racing / 32 athletes	Maximum Isometric strength tests: arm extension (right and left), combined arm extension + trunk flexion, isolated trunk flexion combined forearm pronation with grip strength (right and left). Wheelchair racing performance	S-type load cell; Musclelab unit; Video camera; Dartfish Prosuite; T-dynamometer; Laser devices.	Isometric strength tests: peak force Racing performance: maximum speed (0–15 m) (m/s), maximum speed (absolute) (m/s).	All six strength tests correlated with performance (r = 0.54-0.88). Through cluster analysis, 4 classes were identified and for 6 athletes the allocation differed from their current class, classes T53 and T54 had no significant differences in any of the performance results. This demonstrates that perhaps the class system adopted for this sport needs to be revised. These results contribute to the classification based on evidence of wheelchair racing.

Caption: this table presents the main information of the articles that were selected for this review.

Tabla 1 (Continuation)
Data extracted from the eligible studies regarding evidence-based classification in wheelchair sports.

Study	Purpose	Para Sport /Sample	Evaluation of the Test	Quantification Tools	Quantified Variables	Main results for classification
(Squair et al., 2017)	Establish an ideal autonomic test protocol to predict cardiovascular capacity during wheelchair rugby competition.	Wheelchair Rugby / 26 athletes.	Neurological level and completeness of injury. Autonomic completeness of injury. Resting hemodynamic. Orthostatic challenge test. Cold-pressor test. In-competition exercise performance.	International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI); Sympathetic skin responses (SSRs) electrodes one-lead electrocardiography; Automated BP cuff.	Motor scores for upper and lower limbs (on a scale of 0-5). Sympathetic skin responses (on a scale of 0-2). Measure SSRs of median nerve stimulation. Resting hemodynamic (HR, SBP). Orthostatic intolerance. Cold-pressor test = changes in BP and HR with temperature change. Peak HR during competition	Changes in PAS during the orthostatic challenge test and foot and hand TCP correlated significantly with cardiovascular response in competition. The results demonstrate the importance of incorporating cardiovascular capacity assessments in the classification to ensure more equitable competitions.
(Altmann et al., 2017)	Evaluate the relationship between impaired trunk strength and performance in Wheelchair Rugby through the concept of "natural classes".	Wheelchair Rugby and wheelchair basketball / 27 athletes	Maximum isometric trunk muscle strength test (three directions: forward, to the left and to the right). Activity limitation: tilt test (lifting the non Fixed wheel from the floor by using their legs), and trunk acceleration test (perform maximum acceleration, maintaining speed for 3 to 5 m and then decelerate)	Load cell; Cheetah LMT.	Maximum isometric trunk muscle strength test: mean isometric force (N). Tilt test: The height of the tilt (difference between H1 and H0 [mm]). Acceleration test: Displacement of the wheelchair (m) and time (s).	The inclination height had significant correlations with the left force, right force, frontal force and acceleration. The cluster analysis demonstrated that at least one cutoff point in performance, supporting the concept of "natural classes". The Strength of the trunk plays a fundamental role in the classification of this sport.

Caption: this table presents the main information of the articles that were selected for this review.

Tabla 1 (Continuation)
Data extracted from the eligible studies regarding evidence-based classification in wheelchair sports.

Study	Purpose	Para Sport /Sample	Evaluation of the Test	Quantification Tools	Quantified Variables	Main results for classification
(Van der Slikke et al., 2018)	Evaluating whether measurements with inertial sensors could offer an alternative point of view for classification.	Wheelchair Basketball / 76 athletes	First group: match. Second group: standardized field test.	Inertial sensors.	Six key outcomes of wheelchair performance: Average speed (m/s). Average best speed (m/s). Average acceleration (m/s²). Average rotational speed (m/s²). Average best rotational speed (°/s). Average rotational acceleration (°/s)	Low class athletes showed lower performance results when compared to middle class athletes, however there were no differences between middle class athletes and high class athletes. The Two Step Statistical Method revealed two clusters, one of low class and another of middle / high class, the most important predictors of the model being the results of the forward movement. These results demonstrate the possibility of revising the basketball classes.
(Mason et al., 2020)	Validate and test the reliability of a battery of uniarticular isometric strength tests, for the evidence-based classification in wheelchair rugby (WR).	Wheelchair Rugby / 20 athletes (WR) and 30 healthy participants able-bodied (AB)	Seated participants performed a battery of isometric strength tests: shoulder flexion and extension and elbow flexion and extension	S-type load cell; MuscleLab.	Peak isometric force (N)	The battery of tests revealed that there is an increase in flexural strength around the shoulder and elbow. In addition, the test battery achieved good reliability. Thus, the results suggest that the battery of tests can be used to safely infer the impairment of strength in WR athletes. Supporting an evidence-based classification system.
(Van der Slikke et al., 2020)	Apply the Wheelchair Mobility Performance Monitor (WMP) to athletes to identify factors and results that have an impact on classification and performance.	Wheelchair basketball (WB), Wheelchair tennis (WT) and Wheelchair rugby (WR) / 29 WB athletes; 32 WR athletes; 15 WT athletes	The athletes were evaluated during competitive matches in each para sport	Inertial sensors.	Average speed (m/s) Average best speed (m/s) Average acceleration in the first 2 m from standstill (m/s²) Average rotational speed during a curve (m/s) Average best rotational speed during a turn on the spot (m/s) Average rotational acceleration (m/s²).	The WB achieved better performance results in the VMP, followed by the WT and finally the WR. In all sports, a substantial amount of time, ~ 10% was spent at reverse speed. Through the results found in this work it was possible to identify that intensity is an important factor for WB training programs, as well as maneuverability for WT and level of disability for WR.

Caption: this table presents the main information of the articles that were selected for this review.

Discussion

Our findings provide information, as follows: 1) most studies mention muscle strength of upper limbs and trunk and mobility performance measures (mainly speed) as main parameters; 2) most studies carry out the following tests: isometric strength tests; tilt tests; sprints; and acceleration; 3) most studies use the following instruments: load cells and dynamometer; video systems; laser device; force platform; and inertial sensors.

Overview of wheelchair sports and the classification system

The para sport evolved in the articles were wheelchair basketball, wheelchair rugby, World Para Athletics and wheelchair tennis. Although these para sports have quite different features, they have similar characteristics within their classification aspects. In general, the classification system of wheelchair sports assesses athletes' trunk, and upper and lower limbs. Wheelchair rugby, wheelchair basketball, and wheelchair tennis evaluate one's lower limb functions as an eligibility criterion: athletes eligible for competition have at least one impairment in their lower limbs that prevents them from playing in stand up position (*IWBF Official Player Classification Manual, 2021; WWR Classification Rules, 2022*). Since there are multiple categories of competition within World Para Athletics, the function of an athlete's lower limbs determines his/her classification. In this sport, athletes do not have to have mandatory lower limb impairment, as in some track competitions athletes with upper limb impairment compete. (*WPA Classification Rules and Regulations, 2018*). Van der Slikke et al. demonstrated in their manuscript a clear relation between functional classification and performance (Van der Slikke et al., 2018). The higher the athlete's class, the better is the performance in tests that assess skill and in match tests. In this sense, the use of these tests during classification process could assist classifiers in decision-making.

Classifications concerning all four abovementioned sports are based on athletes' trunk and upper limbs function. The current classification system of wheelchair rugby—which is practiced by athletes with quadriplegia or those with equivalent physical impairment—consists of seven classes ranging from 0.5 to 3.5 (*WWR Classification Rules, 2022*). The classification system of wheelchair basketball—practiced by athletes with motor or physical impairment—has classes ranging from 1.0 to 4.5 (*IWBF Official Player Classification Manual, 2021*). In World Para Athletics, there are two competition categories: track and field events. Athletes with alterations of their motor coordination may fit into classes of T32-T34 (tracking) and F31-F34 (throwing). Athletes with limb deficiency or changes in their muscle power, may fit into classes T51 -T54 (tracking) and F51-F57 (throwing) (*WPA Classification Rules and Regulations, 2018*). To be eligible for wheelchair tennis, athletes need to have limited mobility. There are two wheelchair tennis classes: Open and Quad (*Wheelchair Tennis Classification Rules, 2019*).

In general, when evaluating the minimum commitment criteria for these sports, we follow the premise that the eligible disability affects the athlete's functions to perform specific tasks and activities fundamental to the sport. Thus, the difference lies in the eligible disabilities determined in each of these sports. In the case of wheelchair basketball, we have impaired muscle power, impaired passive range of movement, limb disability, leg length difference, hypertonia, ataxia, and athetosis. In wheelchair rugby, leg length difference is not considered an eligible disability and the same is true for wheelchair tennis that does not consider leg length difference and limb disability as eligible. In the World Para Athletics, for classes that compete in the wheelchair, we have classes T51-T54: limb disability, impaired passive range of movement, impaired muscle power, and leg length difference; for classes T32-T34 we have hypertonia, athetosis, and ataxia; for classes F31-F34: hypertonia, athetosis, and ataxia, and finally, for classes F51 F57: limb disability, impaired passive range of movement, impaired muscle power, and leg length difference.

A classification system is not simply about verifying who is eligible for competition. It provides a structure that controls and/or mitigates the impact of an athlete's physical impairment on the final results of a competition by establishing adequate classes concerning each sport (Tweedy & Vanlandewijck, 2014).

Evaluated parameters and tests

Several parameters can make classification more precise by enabling evidence-based classification: strength, speed, acceleration, distance covered and angulations—all described in the studies listed above. Tests are necessary to offer objective and reliable measures concerning such parameters.

Studies focused on strength analysis showed that muscle strength (upper limb and trunk) is strongly related to sports performance (Altmann et al., 2016, 2017; Borren et al., 2014; Hyde et al., 2016; Mason et al., 2019). Therefore, it is recommended to assess the existing strength that each individual has and thus infer how much strength has been impaired (Beckman et al., 2017). Thus, both multiarticular isometric tests in joint angles that facilitate maximum strength production (Altmann et al., 2017; Beckman et al., 2017; Mason et al., 2019) and pitch tests (Borren et al., 2014; Hyde et al., 2016) seem appropriate to assess muscle strength. In addition, trunk strength relates to one's ability of performing lateral inclinations and trunk flexion/extension, directly linked to sports classes. Santos et al. (2017) demonstrated how force platforms objectively assess trunk by using data from center of pressure (CoP) and seated limits of stability (LoS) collected through trunk inclination tests in eight different directions. Roldan et al. assessed trunk control in boccia athletes through the BISFEed trunk scale and a posturographic test battery consisting of two static and the dynamic tasks. BISFed TFS was not able to discriminate sports classes; however, posturographic tasks were able to discriminate classes ($p = 0.004$). They concluded that it is necessary to develop new field tests to assess trunk stabilization (Roldan et al., 2020).

In the same way, speed (variation of position in space in relation to time) is closely linked to acceleration (rate of change of an object's speed over time) and both relate to good performance in sports that require wheelchair moving maintaining maximum speed and ability to respond with acceleration quickly after braking (Goosey-Tolfrey et al., 2012). Tests such as Illinois Agility Test (Rietveld et al., 2019; Usma-Alvarez et al., 2010), 20-meter speed test (De Groot et al., 2012; Rietveld et al., 2019), spider test, and butterfly-sprint test (Rietveld et al., 2019) aim to analyse these variables by measuring an athlete's ability to deliver a task in the shortest time possible (high speed and high acceleration). Squair et al. (2017) proposed cardiovascular capacity tests would be an interesting tool concerning wheelchair rugby. The study observed that a change in systolic blood pressure (SBP) during an orthostatic challenge test was correlated with peak HR in competition. Such finding is truly relevant: cardiovascular functions may be a limiting factor in an aerobically demanding sport such as wheelchair rugby. Including cardiovascular assessments when classifying these athletes may help ensuring a level playing field, avoiding advantages or disadvantages related to poor cardiovascular control. However, despite the importance of this measure, its applicability remains a challenge for EBC because it is difficult to discriminate between cardiovascular capacity and lack of training, and for this reason the use of this measures for EBC deserve further investigation. This parameter is not included in the current classification process of this para sport.

Instruments

It is necessary to emphasize the importance of using equipment that provides reliable measures to target evaluations. This review noted that the main equipment used in wheelchair rugby was force analysis equipment, inertial measurement units, infrared sensors, video systems and force platforms. In wheelchair basketball, it was video systems, inertial measurement units and force analysis equipment. In the World Para Athletics, video analysis and strength analysis equipment and inertial measurement units in wheelchair tennis.

Researchers use video-based systems (both in 2D or 3D) for biomechanical analysis. Image resolution, temporal resolution, and frame rate per second are characteristics a researchers needs to consider when analysing video. Frame rates ≥ 120 Hz, for example, provide images that are rich in details and enable carrying out motion analysis (Souza, 2016). In wheelchair sports, Borren et al. (2014) used video to analyse throwing techniques and trajectories. The authors identified that athletes with lower sport class obtained lower results of speed and throwing distance when compared with higher sport class. These results indicate that throwing speed and distance are related to an athletes' functionality. Hyde et al. (2016) also used video to analyse throwing. The researchers used a video system to quantify the influence of both seat configuration and the use of an auxiliary pole. Through video analysis, the authors assessed throwing speed and identified that shooting with an auxiliary pole resulted in significantly higher hand speed than shooting without a pole and that there was no significant difference in hand speed in release between standard and self-selected seat configurations during seated throwing with or without an auxiliary pole. Throwing speed is linked to sports performance and impairment, quantifying such parameter as an evaluation measure may help classification decision-making. The study also used video as auxiliary equipment for positioning an athlete's trunk and receiving real-time feedback (Connick et al., 2017). Video-based systems carry out not only pitch analysis, but also analysis of speed, acceleration, and distance a wheelchair covers. Corroborating such scope, Connick et al. (2017) used laser to measure wheelchair speed.

Research uses equipment such as load cells (devices that measure force by converting the charge acting on it into a measurable electrical output) and dynamometers (a device that measures the force through the deformation of a spring that suffers due to the action of a force applied to it, so the intensity is indicated in the graduation existing in the structure) to assess muscle strength. The cells are tension gauges that capture force electronically, amplifying and recording it in newtons. Such devices are sensible for assessing trunk and upper limbs strength in isometric strength tests (Stark et al., 2011; Steeves et al., 2019). Isokinetic dynamometers are computerized machines which are considered the gold standard in muscle strength evaluation, including peak strength, endurance, power, maximum force angle. However, they are not accessible equipment given their high price and difficult mobility. The digital manual dynamometer rises as an alternative. A hand dynamometer suffers from the force of the handgrip, measuring the intensity of this force digitally in newtons and hand grip strength is linked to the total strength of an individual. It is used to measure isometric torque and has a good correlation with the reference method (Stark et al., 2011).

The inertial measurement unit (IMU) is a device in which the signals from an accelerometer, a gyroscope and, in some cases, a magnetometer, are fused and used in movement analyses (Kianifar et al., 2019; Toft Nielsen et al., 2018). Van der Slikke et al. (2018) evaluated whether inertial sensors could offer alternative measures for classification in wheelchair basketball. By using wheelchair speed and acceleration measures, the study verified that athletes with high sport class (class 4.0-4.5) delivered better performance results when compared with athletes with lower sport class (class 1.0-1.5). In addition, authors identified that athletes with middle sport class (class 2.0-3.0) delivered similar performance results if compared with high-level athletes. This indicates that athletes with middle sport class could be incorporated into upper classes, suggesting that some wheelchair basketball classes that currently exist would cease if the classification process were based on deeper efficient studies. Van der Slikke et al. (2020) also used inertial sensors to investigate which are the most important aspects concerning wheelchair mobility performance (WMP) for each sport. These authors identified that wheelchair basketball is the sport that requires the highest performance intensity, whereas in wheelchair tennis manoeuvrability is a key performance factor. In rugby, researchers have identified that WMP is related to the athlete's level of physical/motor impairment. Such results could be used directly incorporated in classification and training guidelines, bringing more emphasis on intensity matters for wheelchair basketball, focussing on manoeuvrability for wheelchair tennis, and impairment-level based training programs for wheelchair rugby. In addition, the authors emphasized the importance of using these sensors in future classifications. Through measures such as acceleration, speed, and trunk oscillation, one can obtain evaluation parameters that can be incorporated into the classification system.

Research also uses force platforms to obtain objective measures of balance. Such measures are based on the displacement of one's pressure center, that is, the point of application of vertical forces acting on a support base (Harro & Garascia, 2019). Santos et al. (2017) evaluated whether wheelchair rugby classification and competitive level influence the trunk function of athletes with physical impairment, concerning seated limits-of-stability (LoS) through center of pressure (CoP), which the study analysed through tilt test of trunk in 8 different directions. The research identified that LoS were greater in athletes with high sport class (3.0-3.5) compared with athletes with low sport class (0.5-1.5). Thus, LoS may be a valid assessment of trunk impairment, potentially contributing to the development of an evidence-based classification for wheelchair rugby.

The instruments described above provide measurements that are useful for generating patterns of movement and allow analyses to have a reduced risk of error. Machine learning may assist such process by reporting movement patterns and generating prediction equations based on such patterns (Heo et al., 2019). However, the first step to be taken in this direction is properly collecting data and correctly interpreting them within biomechanics and movement analysis to extract important parameters for each para sport. The challenge is making classification increasingly technological, what requires resources and professional training so that classifiers can efficiently use assessment equipment.

Challenges to implement an evidence-based classification system

The path to make a more technological classification comes up against many factors, such as financial investment and professional training. The implementation of instruments during the classification process or even for carrying out surveys would entail a lot of expense due to the purchase of such equipment, the professional training of classification officers and, in addition, all of this would take time. However, the significant value of these changes would justify the expense and there are alternatives, such as partnering with universities and research centers (as the IPC is already doing, basing its code updates on research carried out at large universities).

As future recommendations, this study provides a vision of a future in which it will be possible to use technological instruments throughout the classification process and tests that can provide reliable and objective measures, such as those presented here above, can be used.

EBC: Isolated tests or during match play?

As we have seen throughout the study, the classification of wheelchair sports moves towards the use of empirical evidence to support the choice of athletes' classes. This evidence directs us to the use of tests, whether isolated or field tests (skill or performance tests that are given on the court or the field, such as the Illinois Test and the 20-meter speed test) and match tests (tests that simulate competitive matches), in addition to the possibility of using technology to help in the decision. In this perspective, when we analyze isolated tests such as manual strength tests and range of motion assessments, they evaluate specific (isolated) domains that, when united, will form a set of information that guides the classifier in its decision-making. This feature is interesting for assessing eligibility for the sport and perhaps as a differentiating criterion when there are doubts. Skills tests and match tests, on the other hand, provide us with information regarding the athlete's performance, which we have already seen is closely linked to the functional class. These tests would be interesting to classify athletes; however, there are points to be considered. Athletes with more practice time compared to athletes with less time but who are in the same class could present different performances, which would confuse at the time of classification. Therefore, the combination of isolated tests and tests of skills and match tests seems to be an appropriate way forward. In addition, portable technologies are of great help during these tests.

Perspectives

This topic is relevant and current and this systematic review presents and discusses several tests and instruments that can be used in the evidence-based classification of wheelchair sports. In this sense, this study presents a path for the practical application of these resources—and possible barriers to their implementation—. It can be used by researchers to generate new studies and also by professionals who deal more closely with the classification of athletes in different sports.

Conclusion

This study shows the important role technology has within the classification process based on evidence. Using instruments, we can access objective measures of the parameters evaluated in the classification process and validate simple tests that can be applied in classification guidelines. In addition, studies indicate that a technological approach has been increasing in wheelchair sports classification. The measurements collected with the aforementioned instruments can guide and assist research during the classification process, mitigating human error. Training classifiers is also essential to bring reliable outcomes to the process. Over time, the inclusion of adequate technology within the classification process will take sports competitions to a new level. The delimitation of clear parameters, with a lower risk of errors, will bring greater clarity to athletes and will benefit them to develop better in their respective classes.

Acknowledgments

This research was funded in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brazil (CAPES) - Finance Code 001.

References

Altmann, V. C., Groen, B. E., Hart, A. L., Vanlandewijck, Y. C., & Keijsers, N. L. W. (2017). Classifying trunk strength impairment according to the activity limitation caused in wheelchair rugby performance. *Scandinavian Journal of Medicine & Science in Sports*, *28*(2), 649–657. https://doi.org/10.1111/sms.12921

Altmann, V. C., Groen, B. E., Hart, A. L., Vanlandewijck, Y. C., van Limbeek, J., & Keijsers, N. L. W. (2016). The impact of trunk impairment on performance-determining activities in wheelchair rugby. *Scandinavian Journal of Medicine & Science in Sports*, *27*(9), 1005–1014. https://doi.org/10.1111/sms.12720

Beckman, E. M., Connick, M. J., & Tweedy, S. M. (2017). Assessing muscle strength for the purpose of classification in Paralympic sport: A review and recommendations. *Journal of Science and Medicine in Sport*, *20*(4), 391–396. https://doi.org/10.1016/j.jsams.2016.08.010

Borren, G. L., Gooch, S. D., Ingram, B., Jenkins, A., & Dunn, J. (2014). Classification Efficiency in Wheelchair Rugby: Throwing Analysis. *IFAC Proceedings Volumes*, *47*(3), 4772–4777. https://doi.org/10.3182/20140824-6-ZA-1003.01335

Connick, M. J., Beckman, E., Vanlandewijck, Y., Malone, L. A., Blomqvist, S., & Tweedy, S. M. (2017). Cluster analysis of novel isometric strength measures produces a valid and evidence-based classification structure for wheelchair track racing. *British Journal of Sports Medicine*, *52*(17), 1123–1129. https://doi.org/10.1136/bjsports-2017-097558

De Groot, S., Balvers, I. J. M., Kouwenhoven, S. M., & Janssen, T. W. J. (2012). Validity and reliability of tests determining performance-related components of wheelchair basketball. *Journal of Sports Sciences*, *30*(9), 879–887. https://doi.org/10.1080/02640414.2012.675082

Goosey-Tolfrey, V. L., Mason, B., & Burkett, B. (2012). The role of the velocometer as an innovative tool for Paralympic coaches to understand wheelchair sporting training and interventions to help optimise performance. *Sports Technology*, *5*(1–2), 20–28. https://doi.org/10.1080/19346182.2012.686503

Harro, C. C., & Garascia, C. (2019). Reliability and Validity of Computerized Force Platform Measures of Balance Function in Healthy Older Adults: *Journal of Geriatric Physical Therapy*, *42*(3), E57–E66. https://doi.org/10.1519/JPT.0000000000000175

Heo, J., Yoon, J. G., Park, H., Kim, Y. D., Nam, H. S., & Heo, J. H. (2019). Machine Learning-Based Model for Prediction of Outcomes in Acute Stroke. *Stroke*, *50*(5), 1263–1265. https://doi.org/10.1161/STROKEAHA.118.024293

Hyde, A., Hogarth, L., Sayers, M., Beckman, E., Connick, M. J., Tweedy, S., & Burkett, B. (2016). The Impact of an Assistive Pole, Seat Configuration, and Strength in Paralympic Seated Throwing. *International Journal of Sports Physiology and Performance*, *12*(7), 977–983. https://doi.org/10.1123/ijspp.2016-0340

International Paralympic Committee. (2017). Classification Model Rules for Para Sports. https://www.paralympic.org/sites/default/files/document/170217125550391_2017_01_18+Classification+Model+Rules+for+Para+Sports.pdf

International Paralympic Committee. (2020). Paralympic Sports - List of Para Sports and Events. https://www.paralympic.org/sports

IPC Athlete Classification Code. (2015). International Paralympic Committee (IPC). https://www.paralympic.org/sites/default/files/2020-05/170704160235698_2015_12_17%2BClassification%2BCode_FINAL2_0-1.pdf

IWBF Official Player Classificationn Manual (2021). IWBF. https://iwbf.org/the-game/classification/

Kianifar, R., Joukov, V., Lee, A., Raina, S., & Kulić, D. (2019). Inertial measurement unit-based pose estimation: Analyzing and reducing sensitivity to sensor placement and body measures. *Journal of Rehabilitation and Assistive Technologies Engineering*, *6*. https://doi.org/10.1177/2055668318813455

Mason, B. S., Altmann, V. C., Hutchinson, M. J., & Goosey-Tolfrey, V. L. (2019). Validity and reliability of isometric tests for the evidence-based assessment of arm strength impairment in wheelchair rugby classification. *Journal of Science and Medicine in Sport*, *23*(6), 559–563. https://doi.org/10.1016/j.jsams.2019.12.022

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

Reina, R., Vivaracho, I., García-Alaguero, J. L., & Roldán, A. (n.d.). *Guía sobre la clasificación en el deporte paralímpico*.

Rietveld, T., Vegter, R. J. K., Van der Slikke, R. M. A., Hoekstra, A. E., Van der Woude, L. H. V., & de Groot, S. (2019). Wheelchair mobility performance of elite wheelchair tennis players during four field tests: Inter-trial reliability and construct validity. *PLoS ONE*, *14*(6). https://doi.org/10.1371/journal.pone.0217514

Roldan, A., Barbado, D., Vera-Garcia, F. J., Sarabia, J. M., & Reina, R. (2020). Inter-Rater Reliability, Concurrent Validity and Sensitivity of Current Methods to Assess Trunk Function in Boccia Player with Cerebral Palsy. *Brain Sciences*, *10*(3). https://doi.org/10.3390/brainsci10030130

Santos, P. B. R., Vigário, P. S., Mainenti, M. R. M., Ferreira, A. S., & Lemos, T. (2017). Seated limits-of-stability of athletes with disabilities with regard to competitive levels and sport classification. *Scandinavian Journal of Medicine & Science in Sports*, *27*(12), 2019–2026. https://doi.org/10.1111/sms.12847

Souza, R. B. (2016). An Evidence-Based Videotaped Running Biomechanics Analysis. *Physical Medicine and Rehabilitation Clinics of North America*, *27*(1), 217–236. https://doi.org/10.1016/j.pmr.2015.08.006

Squair, J. W., Phillips, A. A., Currie, K. D., Gee, C., & Krassioukov, A. V. (2017). Autonomic testing for prediction of competition performance in Paralympic athletes. *Scandinavian Journal of Medicine & Science in Sports*, *28*(1), 311–318. https://doi.org/10.1111/sms.12900

Stark, T., Walker, B., Phillips, J. K., Fejer, R., & Beck, R. (2011). Hand-held Dynamometry Correlation With the Gold Standard Isokinetic Dynamometry: A Systematic Review. *PM&R*, *3*(5), 472–479. https://doi.org/10.1016/j.pmrj.2010.10.025

Steeves, D., Thornley, L. J., Goreham, J. A., Jordan, M. J., Landry, S. C., & Fowles, J. R. (2019). Reliability and Validity of a Novel Trunk-Strength Assessment for High-Performance Sprint Flat-Water Kayakers. *International Journal of Sports Physiology and Performance*, *14*(4), 486–492. https://doi.org/10.1123/ijspp.2018-0428

Tachibana, K., Mutsuzaki, H., Shimizu, Y., Doi, T., Hotta, K., & Wadano, Y. (2019). Influence of Functional Classification on Skill Tests in Elite Female Wheelchair Basketball Athletes. *Medicina*, *55*(11). https://doi.org/10.3390/medicina55110740

Toft Nielsen, E., Jørgensen, P. B., Mechlenburg, I., & Sørensen, H. (2018). Validation of an inertial measurement unit to determine countermovement jump height. *Asia-Pacific Journal of Sports Medicine, Arthroscopy, Rehabilitation and Technology*, *16*, 8–13. https://doi.org/10.1016/j.asmart.2018.09.002

Tweedy, S. M. (2002). Taxonomic Theory and the ICF: Foundations for a Unified Disability Athletics Classification. *Adapted Physical Activity Quarterly*, *19*(2), 220–237. https://doi.org/10.1123/apaq.19.2.220

Tweedy, S. M., Connick, M. J., & Beckman, E. M. (2018). Applying Scientific Principles to Enhance Paralympic Classification Now and in the Future. *Physical Medicine and Rehabilitation Clinics of North America*, *29*(2), 313–332. https://doi.org/10.1016/j.pmr.2018.01.010

Tweedy, S. M., Mann, D., & Vanlandewijck, Y. C. (2016). Research needs for the development of evidence-based systems of classification for physical, vision, and intellectual impairments. In Y. C. Vanlandewijck & W. R. Thompson (Eds.), *Training and Coaching the Paralympic Athlete* (pp. 122–149). Hoboken (NJ): John Wiley & Sons, Ltd. https://doi.org/10.1002/9781119045144.ch7

Tweedy, S. M., & Vanlandewijck, Y. C. (2014). International Paralympic Committee position stand—Background and scientifi c principles of classification in Paralympic sport. British Journal of Sports Medicine 2011;*45*: 259-269. https://doi.org/10.1136/bjsm.2009.065060

Ungerer, G. (2018). Classification in para sport for athletes following cervical spine trauma. In *Handbook of Clinical Neurology* (Vol. 158, pp. 371–377). New York: Elsevier. https://doi.org/10.1016/B978-0-444-63954-7.00035-5

Usma-Alvarez, C. C., Chua, J. J. C., Fuss, F. K., Subic, A., & Burton, M. (2010). Advanced performance analysis of the Illinois agility test based on the tangential velocity and turning radius in wheelchair rugby athletes. *Sports Technology*, *3*(3), 204–214. https://doi.org/10.1080/19346182.2011.564284

Van der Slikke, R. M. A., Berger, M. a. M., Bregman, D. J. J., Lagerberg, A. H., & Veeger, H. E. J. (2015). Opportunities for measuring wheelchair kinematics in match settings; reliability of a three inertial sensor configuration. *Journal of Biomechanics*, *48*(12), 3398–3405. https://doi.org/10.1016/j.jbiomech.2015.06.001

Van der Slikke, R. M. A., Berger, M. A. M., Bregman, D. J. J., & Veeger, D. H. E. J. (2020). Wearable Wheelchair Mobility Performance Measurement in Basketball, Rugby, and Tennis: Lessons for Classification and Training. *Sensors (Basel, Switzerland)*, *20*(12). https://doi.org/10.3390/s20123518

Van der Slikke, R. M. A., Bregman, D. J. J., Berger, M. A. M., de Witte, A. M. H., & Veeger, D.-J. H. E. J. (2018). The Future of Classification in Wheelchair Sports: Can Data Science and Technological Advancement Offer an Alternative Point of View? *International Journal of Sports Physiology and Performance*, *13*(6), 742–749. https://doi.org/10.1123/ijspp.2017-0326

Vanlandewijck, Y. C., Verellen, J., & Tweedy, S. (2011). Towards evidence-based classification in wheelchair sports: Impact of seating position on wheelchair acceleration. *Journal of Sports Sciences*, *29*(10), 1089–1096. https://doi.org/10.1080/02640414.2011.576694

Wheelchair Tennis Classification Rules. (2019). International Tennis Federation.

WPA Classification Rules and Regulations. (2018). World Para Athletics. https://www.paralympic.org/sites/default/files/document/180305152713114_2017_12_20++WPA+Classification+Rules+and+Regulations_Edition+2018+online+version+.pdf

WWR Classification Rules. (2022). WWR. https://worldwheelchair.rugby/the-game-classifications/

Conflict of Interests: No conflict of interest was reported by the authors.