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PLACE OF THE GOLD STANDARD ISOKINETIC DYNAMOMETER IN PARALYMPIC SPORTS: A SYSTEMATIC REVIEW

review paper
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SHIRKO AHMADI, MARCO CARLOS UCHIDA
Department of Physical Education, University of Campinas, Campinas, Brazil

ABSTRACT
Purpose. Isokinetic dynamometers are machines that can supply multiple elements for measuring muscle strength, peak force, power, endurance, and angle of maximal force. The purpose of this study was to run a systematic review to find the quality of evidence in studies evaluating the gold standard isokinetic dynamometer (Biodex) in Paralympic sports.
Methods. The search strategy was defined as: ('Paralympic' OR 'Paralympic sport' OR 'Parasport' OR 'disabled athlete' OR 'athletes with a disability') AND ('strength' OR 'isokinetic' OR 'torque' OR 'muscle strength dynamometer' OR 'isokinetic dynamometer' OR 'Biodex'). Four databases were searched: PubMed, Cochrane, ScienceDirect, and Scopus.
Results. From the 981 articles initially found, 10 records were finally included in this systematic review. Five articles were selected as high quality. The Biodex isokinetic dynamometer was introduced about 3 decades ago; still, a small number of papers (10) have been published on applying it in Paralympic sports. We observed different experimental protocols in the included studies. The shortage of standardization in the experimental protocols precludes pooling data for analyses.
Conclusions. As the Biodex isokinetic dynamometer is a gold standard, reliable, and valid instrument to measure human joint function, future research should apply it in Paralympic studies.
Key words: isokinetic dynamometer, Paralympic sport, place

Introduction

The isokinetic exercise concept was presented by Perrine in the early 1960s as an integral part of rehabilitation, resistance training, and musculoskeletal testing [1, 2]. Isokinetic exercise, with specified velocity and changeable resistance, made it possible to accommodate the individual strength all over the range of motion [3–5]. The first isokinetic exercise equipment was made in America in 1967 and named CYBEX 1. In 1990, Biodex (Shirley, USA) released Biodex 2000, which (particularly the new versions, such as Biodex System 3 and 4) attracted scientists and other users. Biodex is a computerized machine dynamometer applied for athlete training and isokinetic testing [6].

The Biodex isokinetic dynamometer (BID) is a real update of the first multi-mode computerized global machine dynamometer. The isokinetic image of BID is a popular concept for evaluating and training muscle strength and function [7, 8]. Moreover, it is often used in scientific research to execute measurements [9, 10]. It includes a seat on which the athlete is stabilized with belts, a lever that could be located at various joints or angles, and a computer unit with specific software. The whole space needed to utilize the system is 6 m^2. It has an electrically controlled servomechanism that could be used with various modes for different modalities and rehabilitation phases. The isokinetic resistance mode gives accelerating or decelerating impact-free [6]. BID can directly record the subsequent parameters: the torque and angular velocity of the lever arm, and time (accuracy of 10 ms). Other factors, i.e. force, power, and the parameters that are reported in BID, are calculated indirectly or entered by an operator (e.g. body height, body mass).

In some studies, BID has been presented as a valid and reliable device for the evaluation of human joint function [11–13], and the specific testing protocol and isokinetic velocity has been shown secure for individuals with disability [14]. Some studies have targeted on the physiological response to exercise [15–17], biomechanics [18, 19], and upper extremity muscle torque

Correspondence address: Shirko Ahmadi, Department of Physical Education, University of Campinas, Av. Érico Veríssimo, 701, Cidade Universitária 'Zeferino Vaz', Campinas, SP, Brazil, e-mail: shirkooahmadi@yahoo.com

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[20–22] of Paralympic athletes. On the other hand, coaches and scientists are extremely concerned about developing ideal training programs to monitor and increase the performance of Paralympic athletes [23].

Paralympic sports, despite their fast improvement in the recent years, still lacks any suitable scientific work to evaluate their therapeutic or functional efficiency [24, 25]. The International Paralympic Committee has encouraged studies based on the scientific principles of athletes' classification in Paralympic sport [26]. We believe that it can identify and find limitations in the case of isokinetic training for Paralympians, and the study of the literature might help this important issue. Presently, several isokinetic dynamometers are available; however, it is BID that has frequently been cited in the literature [27] (although mainly with reference to its application among Olympians rather than Paralympians) [28]. Numerous issues are faced when setting up BID for athletes with a disability that has not been explored in detail. Therefore, this study aimed to review the literature published regarding the gold standard isokinetic dynamometer (BID) applied in Paralympic athletes. This review study provides information that may demonstrate the place of BID in strength testing among athletes with a disability.

Material and methods

Literature search

Studies for this review were identified with a systematic search of 4 databases (PubMed, Cochrane, ScienceDirect, and Scopus), alone or in combination. The search was restricted to English-language articles and those published up to March 2019. The following search string was used for a full search strategy: ('Paralympic' OR 'Paralympic sport' OR 'Parasport' OR 'disabled athlete' OR 'athletes with a disability') AND ('strength' OR 'muscle strength dynamometer' OR 'torque' OR 'isokinetic' OR 'isokinetic dynamometer' OR 'Biodex') for all of the databases. Citation tracking was also done by manually seeking the reference lists of included articles and using Google Scholar.

Study selection

Studies retrieved from the database search were forwarded to EndNote X9. The researchers took out the repeated references and non-original articles (i.e. reviews, editorials, letters to the editor, etc.). Besides, they separately screened the titles and abstracts to recognize studies that would potentially face the eligibility criteria. The full texts of these articles were reviewed and the appropriate papers to the present systematic review were elected. Lastly, the reference list of the chosen studies was checked for identifying further related articles. The consensus-agreement method was used in any case of a difference in the opinions between the 2 reviewers. If a consensus could not be reached, the reviewers reread the article(s) until obtaining a consensus-agreement about it.

Eligibility criteria

Articles were included in this review study if they met the following criteria:

(a) the full text written in English;

(b) the study participants being elite athletes with a disability playing at the international Paralympic level;

(c) inclusion of participant groups of all ages who competed as Paralympians;

(d) using BID.

Articles were excluded if:

(a) there was no clear indication of whether an athlete was a Paralympian;

(b) another type of isokinetic dynamometer was used instead of BID;

(c) the study did not use empirical data (e.g. a review or commentary).

Quality of the evaluation and risk of bias

Each study included in this review was separately evaluated for methodological quality and risk of bias by both authors. To the best of our knowledge, there is no specific criterion for a methodological measurement suitable to the goal of this review study. In their systematic review, De Castro et al. [29] composed a new scale by blending some items from QUADAS [30] and a checklist for evaluating the methodological quality of both randomized and non-randomized studies of health care interventions [31], with adaptations. We used this scale for the current review, which included 15 items divided into 3 parts: (i) study participants; (ii) test method and data analysis; and (iii) results (Table 1). Each item was evaluated as 'yes,' 'no,' 'unclear,' or 'not applied'. A high risk of bias (low quality) was assumed if a study obtained 5 or more 'no' or 'unclear' rates; if a study received less than 5 'no' or 'unclear' rates, it was ascribed a low risk of bias (high quality). The quality evaluation of the studies demonstrated that 5 papers presented a low risk of bias (high quality) and the remaining 5 were associated with a high risk of bias (low quality).

Data extraction

The following information was extracted from the included articles: publishing year, country of origin, number of participants, age, sex, type of disability, sport, BID model, body segment, limb dominance (Table 2), details of BID, and the way of applying it (Table 3). The main results were collected from each study.

Ethical approval

The conducted research is not related to either human or animal use.

Results

The research identified 981 articles. With the first search, 744 papers were excluded because they were duplicates; the remaining 237 were kept for the reading of the titles and abstracts. After the reading, 208 articles were excluded because they did not meet the defined selection criteria; the remaining 29 papers were to be read entirely, and, finally, 10 were included in the systematic review (Figure 1).

Characterization of the studies

Five studies were accomplished in Brazil [32–36], 2 in the Netherlands [37, 38], 1 in the United States [39], 1 in Poland [25], and 1 in New Zealand [40]. The total number of participants in the 10 studies was 219, with 149 being para-athletes; the size of the sample ranged from 4 to 42 subjects. Four of the studies indicated the subjects' sex; in these papers, all participants were men (98 men among the 149 para-athletes) [33–35, 39]. The remaining 6 studies, which included 51 participants, did not present clear sex difference numbers. Among the 149 participants, the disability types included spinal cord injury (SCI) (n = 62), cerebral palsy (CP) (n = 30),

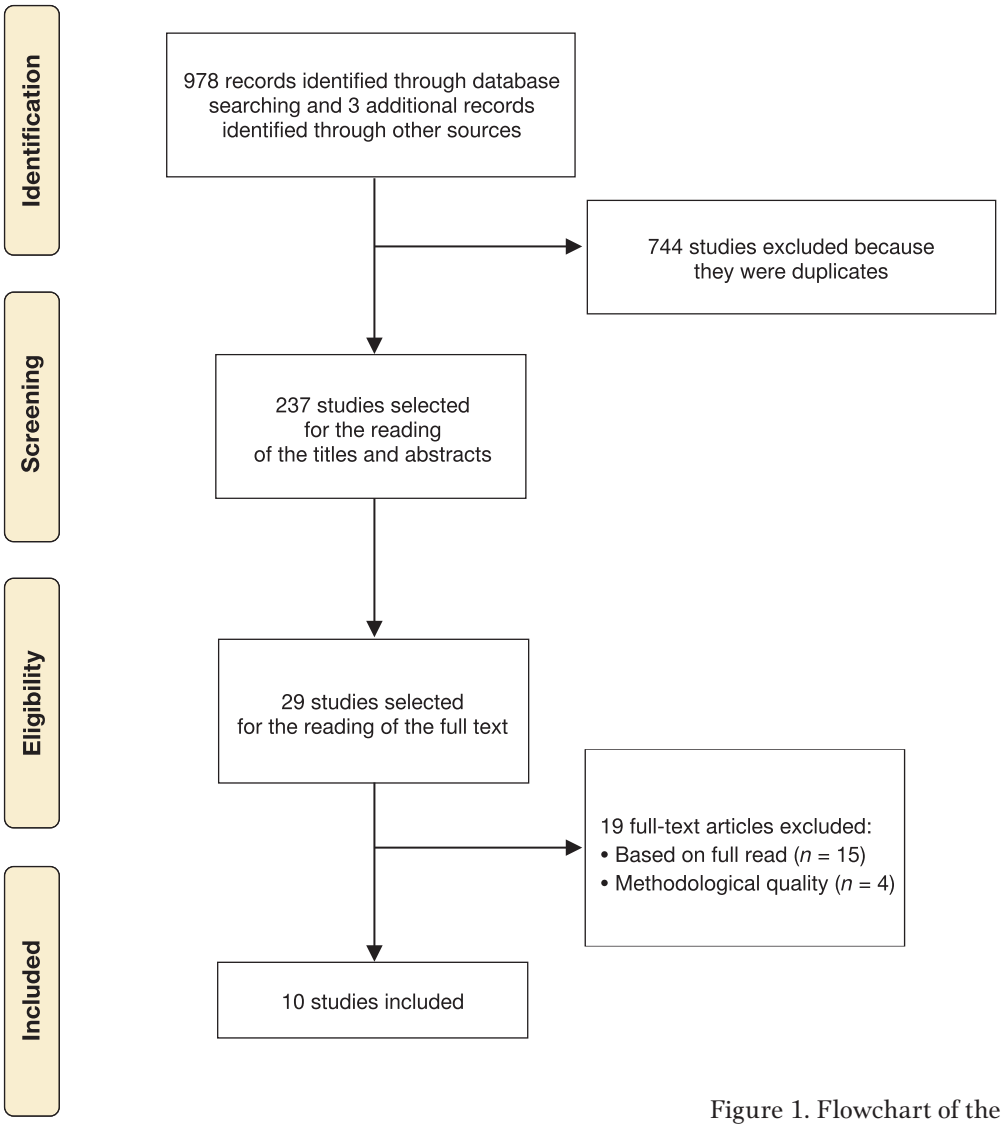

Figure 1. Flowchart of the study phases

amputation (AMP) (n = 20), poliomyelitis sequelae (polio) (n = 16), spinal bifida (SB) (n = 7), arthrogryposis (Art) (n = 4), congenital deformity (CD) (n = 4), and visual impairment (VI) (n = 6). The participants were Paralympians of 6 different sports: athletics (n = 13), cycling (n = 4), football (n = 20), wheelchair basketball (n = 94), swimming (n = 1), and wheelchair rugby (n = 17).

The most often used BID (6 studies) was the Biodex Medical System 3 Pro (USA) [27, 32–34, 37, 39]. Two studies applied the Biodex System 4 Pro [33, 34], and 2 studies did not provide information about the Biodex system used [38, 40]. BID measurements were performed for a variety of joints or body segments in the included studies: for the knee in 4 studies [32, 35, 37, 38], for the elbow in 2 studies [36, 39], for the shoulder in 2 studies [25, 40], and for the trunk in 2 studies [33, 34]. Table 2 presents a more detailed characterization of the articles. All details of the methods applied by the Biodex system in the studies, such as warm-up, position, range of motion, mode, velocity, repetitions, and outcomes (unit), are presented in Table 3.

Discussion

This systematic review gives an overview of studies investigating the interest of scientists in applying BID in Paralympic athletes. The quality of evidence of the analysed articles was measured. Five studies out of the 10 papers included in our systematic review presented a high risk of bias, so data from these articles should be examined with caution. For those using BID to evaluate para-athletes, we suggest referring to data from articles with a low risk of bias, with a similar experimental method. Even though, the papers with a low risk of bias unfitted in some items. It is significant to examine how the pointed items might affect data before using them as a reference. The reliability of BID methods was not

Table 1. Methodological quality of the included studies

Study	Items															Total of n/un
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Machado et al. (2018) [36]	n	n	un	y	y	n	y	y	n	n	un	n	n	y	un	10
Antunes et al. (2017) [35]	y	y	un	y	y	un	y	y	n	y	y	y	un	y	na	4†
Santos et al. (2017) [34]	y	y	y	y	y	y	n	y	un	y	y	un	y	y	y	3†
Santos et al. (2016) [33]	y	y	y	y	y	n	n	y	n	y	y	un	un	y	y	5
Silva et al. (2015) [32]	un	n	un	y	y	n	y	y	un	n	y	n	n	y	y	8
De Groot et al. (2012) [37]	y	y	y	y	y	un	y	n	y	n	y	y	un	y	y	4†
De Groot et al. (2012) [38]	y	y	n	y	y	y	y	y	y	n	y	y	y	y	y	2†
Uzun et al. (2012) [39]	y	y	n	y	un	n	y	y	y	y	y	y	un	y	y	4†
Tabęcki et al. (2009) [25]	n	un	n	n	n	un	y	n	n	n	y	un	n	y	n	12
Miyahara et al. (1998) [40]	n	y	n	y	y	un	n	un	y	y	y	un	y	y	y	6

Items considered for rating:
1. Was the study population adequately described (i.e. sex, age, body mass, body height, kind of physical activity/ life style [sedentary, athlete, level of physical activity])?
2. Was the description of selection criteria presented?
3. Was there justification of appropriate sample size (through calculation or guidelines)?
4. Were warm-ups and familiarization protocol performed?
5. Were the type of muscle action (i.e. concentric and eccentric), sequence of action (i.e. concentric-concentric, concentric-eccentric, eccentric-eccentric), and velocity of movement described?
6. Was the order of tests (velocities and limbs) randomized or counterbalanced?
7. Was the limb dominance considered?
8. Was the standardization of positions, movements, and stabilization performed and properly described?
9. Did the participants receive the same encouragement during the test?
10. Was gravity correction considered?
11. Were the outcome measures clearly described?
12. Were data extracted from the isokinetic load range?
13. Were measures of reliability (e.g. intraclass correlation coefficients, standard error of measurement) presented?
14. Were the results clearly described? 15. Were appropriate inferential statistics presented?

n – no, y – yes, na – not applied, un – unclear
† studies with a low risk of bias

Table 2. Characteristics of the studies included

Author, year, country, aim of study	Total sample and sex	Para-athletes	Age (years) *M* ± *SD* or range	Disability	Sport	Biodex model	Body segment	Limb
Machado et al. [36] 2018 Brazil To investigate athletes' peak torque and fatigue index variables in actions related to wheelchair sprinting	6 ND	6 ND	30.3 ± 6.6	SCI	WR	System 4	Elbow	Both
Antunes et al. [35] 2017 Brazil To assess muscle power, muscular imbalance, and asymmetry in sprinters with CP	4 M	4 M	18–27	CP	A	System 4	Knee	Both
Santos et al. [34] 2017 Brazil To identify differences in trunk muscle strength and balance among various classes of wheelchair basketball players and to determine if trunk muscle strength and balance correlate with the current observation-based classification	42 M	42 M	28.3 ± 7.6	SCI (17), AMP (10), polio (8), SB (4), Art (2), CP (1)	WB	System 3	Trunk	–
Santos et al. [33] 2016 Brazil To identify quantitative measures of trunk muscle strength and correlate them with the wheelchair basketball players' classification	42 M	42 M	28.3 ± 7.4	SCI (17), AMP (10), polio (8), SB (3), Art (2), CD (1), CP (1)	WB	System 3	Trunk	–
Silva et al. [32] 2015 Brazil To assess and monitor the peak torque of the knee extensor and flexor muscles in flexion and extension and the reports of musculoskeletal complaints in members of the main Brazilian Paralympic athletics team through 1 year	10 M 4 F	9 ND	28.9 ± 6.3	VI (6), CD (3)	A	System 3	Knee	Both
De Groot et al. [37] 2012 The Netherlands To compare muscle strength, sprint power, and maximal aerobic capacity, as well as establish correlations between these variables in adults with and without CP	40 M 4 F	12 ND	28.8 ± 11	CP	2 C 10 FB	ND	Knee	Right

De Groot et al. [38] 2012 The Netherlands To analyse the feasibility and reliability of the tests used to determine muscle strength, sprint power, and aerobic capacity in athletes and non-athletes with CP	16 M 4 F	12 ND	18–49	CP	2 C 10 FB	System 3	Knee	Both
Uzun et al. [39] 2012 USA To investigate muscular endurance and fatigue in wheelchair basketball players with SCI by using surface electromyography and maximal torque values	35 M	10 M	29.6 ± 6.4	SCI	10 WB	System 3	Elbow	Dominant
Tabęcki et al. [25] 2009 Poland To assess the effects of strength training on the physical capacities of disabled persons with cervical spine injuries	4 ND	4 ND	ND	SCI	1 S 3 WR	System 3	Shoulder	Both
Miyahara et al. [40] 1998 New Zealand To examine the relationship of shoulder pain to demographic details, isokinetic strength, and muscle balance in 8 elite quadriplegic rugby players	8 ND	8 ND	26.8 ± 5	SCI	WR	ND	Shoulder	Both

A – athletics, AMP – amputation, Art – arthrogryposis, C – cycling, CD – congenital deformity, CP – cerebral palsy, F – female, FB – football, M – male, ND – not described, polio – poliomyelitis sequelae, S – swimming, SB – spinal bifida, SCI – spinal cord injury, VI – visual impairment, WB – wheelchair basketball, WR – wheelchair rugby

Table 3. Methods of using Biodex in the included studies

Study	Warm-up	Position; ROM	Mode; velocity; repetitions	Outcomes (unit)
Machado et al. (2018) [36]	5 repetitions of concentric action at 210°/s	The seat was at 0° rotation and 85° slope and the dynamometer at 0° rotation and 15° slope; ND	Concentric; 210°/s, 300°/s, and 300°/s; 5, 15, and 30 repetitions	PT (Nm) and FI (%)
Antunes et al. (2017) [35]	20 knee flexion-extension concentric submaximal repetitions at 120°/s	Manufacturer's recommendations; 70° (30–100°, considering 0° = total knee extension)	Concentric/concentric; 60°/s, 120°/s, and 180°/s; 5 repetitions and eccentric reactive; 60°/s and 120°/s; 5 repetitions	PT (Nm)

Santos et al. (2017) [34]	The muscles of their lower back were stretched for a few minutes	The subject was seated on the 'dual position back Ex/Flex attachment' of the Biodex dynamometer with the trunk positioned at 90° relative to the thigh segments and with the knees flexed at ca. 45° relative to the shank segments; the position of the subject was adjusted so that the trunk was aligned at an angle of –15° for flexor strength testing and +15° for extensor strength testing in relation to the vertical position	Flexion/extension; ND; 5 and 5 repetitions	PT (Nm)
Santos et al. (2016) [33]	Undergone prior spinal joint warm-up	The trunk was at 90° in relation to the femur and the knees were flexed at 45° in relation to the lower legs; limited to –15° of extension and 15° of flexion	Flexion/extension; ND; 10 repetitions	PT (Nm) and TR (%)
Silva et al. (2015) [32]	A cycle ergometer at 75 W and constant speed of 20 km/h for 5 minutes	The knees at 90° flexion and the resistance was distally applied to the ankle joint 5 cm above the medial malleolus; 90° (between full knee extension and 90° flexion)	Concentric/concentric (flexion/extension); 60, 180, and 300°/s; 5, 10, and 15 repetitions	PT (Nm)
De Groot et al. (2012) [37]	ND	The hip angle ranged from 90° to 110° and the centre of the knee joint aligned with the dynamometer centre of rotation; 70° (90–160°)	Flexion/extension; 60°/s; 3 repetitions	PT (Nm)
De Groot et al. (2012) [38]	The participants performed 1 isometric exertion for extension and flexion	The hip angle ranged from 90° to 110° and the centre of the knee joint aligned with the dynamometer centre of rotation; ND	Flexion/extension; 60°/s; 3 repetitions	PT (Nm)
Uzun et al. (2012) [39]	ND	The arm was maintained in the horizontal plane to eliminate the effects of gravity, with an elbow angle of 90° flexion, the hand was in a semi-pronated position, subjects gripped a rigid handle and rested their forearm on a padded support; ND	ND	PT (Nm)
Tabęcki et al. (2009) [25]	ND	ND	Flexion/extension; 30°/s and 300°/s; ND	PT (Nm) and power (W)
Miyahara et al. (1998) [40]	Given 3–5 submaximal trials and 1 maximal familiarization trial	ND	Concentric/concentric (abduction/adduction and internal/external rotation); 60°/s and 180°/s; ND	PT (Nm)

FI – fatigue index, ND – not described, PT – peak torque, ROM – range of motion, TR – torque ratio

defined in 7 articles (13th item). There is a scarcity of articles tracking test-retest reliability for evaluations of para-athletes. Differences in the determined reliability among articles might be due to differences in BID methods and participants. Additionally, future studies may examine tracking para-athletes to present reliability evaluations specifically related to their methods. This is necessary for assigning the internal consistency of the method and testing the effect of interventions.

BID was introduced in 1990; in the recent 3 decades, just 10 papers have been published about BID applied in Paralympic sports. Although BID is a gold standard for biomechanical data measurement [41], the small number of studies in Paralympic fields shows a lack of scientists' interest to use the method in their

studies. Among the included studies, 50% were performed in Brazil in years 2015–2018 [32–36], which indicates a tendency of Brazilian researchers to investigate this topic to a higher degree than in the case of other countries, particularly in the recent years.

Page et al. [42] found that male and female Paralympic athletes were not significantly different in their sports orientations and differed very little in their mean scores on the scales. On the other hand, the sex of the subjects who participated in the included studies was not always indicated but there seemed to be more men than women. This suggests a deficiency of studies in the field of BID applied in women as compared with men in Paralympic sports.

The criteria of our systematic review for carrying out a meta-analysis were not paired. Particular experimental procedures for BID assessments were provided by the manufacturers. However, we observed using some experimental methods (i.e. warm-up, positions, range of motion, types of mode, the velocity of movement, repetitions, etc.) in the included studies. Therefore, comparisons among studies should be made with caution. Generally, the lack of standardization in the experimental methods precludes pooling data for analyses.

An important limiting factor in this study was the selection of studies that only used BID, whereas other isokinetic dynamometers (i.e. Cybex or Kin-Com) were probably applied in many studies performed among Paralympic athletes. We recommend that future studies measure and report differences of the conclusions that may present a more comprehensive understanding of isokinetic exercises for para-athletes.

Conclusions

This systematic review revealed the characteristics and methodologies of several studies applying BID in the Paralympic athletes' population. Data from all included studies were summarized. BID was introduced about 3 decades ago and just 10 papers were published about its usage in Paralympic sports. However, BID is a gold standard, reliable and valid instrument to measure human joint function. Future well-conducted studies aiming to utilize BID in Paralympic athletes are encouraged.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

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