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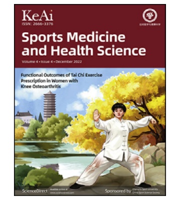

Assessment of muscle strength in para-athletes: A systematic review of observational studies

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A R T I C L E I N F O

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A B S T R A C T

Accurate and reliable evaluation of muscle strength in para-athletes is essential for monitoring the effectiveness of strength training and/or rehabilitation programmes, and sport classification. Our aim is to synthesise evidence related to assessing muscle strength in para-athletes. Four databases were searched from January 1990 to July 2021 for observational studies focusing on strength assessment. Independent screening, data extraction, and quality assessment were performed in duplicate. A total of 1764 potential studies were identified. Thirty met the inclusion criteria and were included in the review. The mean age of participants was 30.7 years (standard deviation [*SD*]: 2.4). The majority were men (88%) participating in wheelchair sports, including basketball, rugby, and tennis (23/30: 76%). Overall quality varied, with more than half of the studies failing to identify strategies for dealing with confounding variables. Despite manual muscle testing being a standard component of para-sport classification systems, evidence examining strength characteristics in para-athletes is derived primarily from isometric and isokinetic testing. In studies that included comparative strength data, findings were mixed. Some studies found strength values were similar to or lower than able-bodied athletic controls. However, an important observation was that others reported higher shoulder strength in para-athletes taking part in wheelchair sports than both able-bodied and disabled non-athletes. Studies need to develop accessible, standardised strength testing methods that account for training influence and establish normative strength values in para-athletes. There is also a need for additional studies that include female para-athletes and para-athletes with greater functional impairments.

Introduction

Muscle strength assessment is a core component of routine clinical examination. Strength is the maximum voluntary output that muscles can exert under specific test conditions.[1] Strength deficits are present in many health conditions, including spinal cord injury, cerebral palsy, and muscular dystrophy, and are often associated with impaired physical function and performance.[2–4] In para-sports, accurate and reliable strength assessment is essential for injury risk surveillance, for monitoring the effectiveness of rehabilitation and/or strength training programmes, and for sport classification purposes.[5] Sport-specific classification systems typically incorporate strength measurements alongside assessment of other factors, including the range of motion and limb deficiency.[6,7] These systems are used to standardise the impact of impairment level on competitive outcomes, ensuring events include individuals with comparable activity limitations.

Different methods are available to determine muscle strength,

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Abbreviations

SD	standard deviation
°/s	degrees per second
1RM	one repetition maximum
AB	Able-bodied
ASIA-A:	American Spinal Injury Association impairment – complete
Category A	represents wheelchair basketball players classified as level 1.0 to 2.5 as per the International Federation for Wheelchair Basketball
Category B	corresponds to levels 3.0 to 4.5 for player classification as per the International Federation for Wheelchair Basketball
CI	Confidence intervals
CP	Cerebral Palsy
CV	Coefficient of variation
d	Effect size (Cohen's *d*)
ER	External rotation
ES	effect size;
ESR	External Shoulder Rotation
H	Kruskal-Wallis test
HHD	Hand-held dynamometer
HPA	high paraplegic athletes
ID	isokinetic dynamometer
ISR	internal shoulder rotation
LPA	low paraplegic athletes
ICC	intraclass correlation coeeficient
ID	isokinetic dynamometer
ISR	Internal Shoulder Rotation
IR	Internal rotation
m	metres
MeSH terms	Medical subject heading terms
MMT	Manual muscle testing
MPV	Mean propulsive velocity
MVC	maximum voluntary contraction
MVE	maximum voluntary effort
n	sample size;
N	Newtons
Nm	Newton metres
p:	p-value
r	Pearson correlation coefficient
R^2	coeeficient of determination
RBI	brain impairement
RR1,2,3	Race Running classes 1, 2 and 3
PM	Peak moment
T37 or T38 classes	disability sport classifications
TIC	Trunk Impairment Classification
WBP	Wheelchair Basketball Player
WR	Wheelchair racing
MPV	Mean propulsive velocity
1RM	1 Repetition Maximum
ICCs	intraclass correlations
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines

including isokinetic or hand-held dynamometry, one-repetition maximum (1-RM), and manual muscle testing (MMT). Isokinetic dynamometry is often considered a gold standard for evaluating strength.[8–10] It can examine concentric, eccentric, and isometric contraction types, but such testing can be time-intensive and requires access to specialist equipment. This means it is often less practical and accessible when compared to other methods. Previous recommendations have indicated that the most appropriate methods for determining strength deficits in para-athletes include isometric tests at joint angles relevant to their specific sport to facilitate maximum force production.[11] MMT is a common component of many para-sport classification systems, including wheelchair basketball,[12] rugby,[6] and tennis.[7] It is frequently considered a suitable method for assessing muscle performance, as it is brief and does not require specific instrumentation. However, the method has greater subjectivity, particularly at the higher muscle test grades or when assessing larger muscle groups. It also assesses isometric contraction only and may be less able to detect physical performance deficits, including dynamic jump, speed, and agility tests.[13-17] The reliability and appropriateness of strength measurements can therefore be influenced by both the choice of testing method and the procedures used, and affected by factors such as the athlete's familiarity with testing and the experience or training of the assessor.[18,19]

The aim of this systematic review was to synthesise evidence related to the assessment of muscle strength in para-athletes. Specific objectives were:

i. to determine the characteristics of methods used to assess muscle strength
ii. to explore the relationship between strength outcomes and functional performance
iii. to examine differences in strength outcomes compared to available control group data (including unimpaired participants, non-athletic participants with a physical impairment, or the unaffected limb of para-athletes)

Materials and methods

The review was undertaken according to the methods described in the Cochrane Handbook for Systematic Reviews of Interventions[20] and is reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[21] The review protocol was registered with the PROSPERO database [CRD42021254795].

Search methods for identification of studies

Searches of four databases (Medline [via Ovid]; CINAHL Plus; EMBASE, and PEDro [Physiotherapy Evidence Database]) were conducted, covering publications from 1st January 1990 to 30th July 2021. Combinations of Medical subject heading (MeSH) terms, including “Assessment, Outcomes”, “Muscle Strength”, “Isometric Contraction”, “Isotonic Contraction”, “Dynamometry”, “Dynamometer”, “Isokinetic”, “Parasports”, “Para-athletics”, and/or “Wheelchair Athletes” were used. The Medline search strategy is shown in **Supplementary File 1** and was adapted for searching the other databases. Reference lists of included studies were searched, and hand searches of relevant journals were carried out. Grey literature searches were also conducted using OpenGrey (http://www.opengrey.eu/).

Eligibility

Included studies were required to meet the following criteria:

i. any interventional, including observational, study design.
ii. include individuals with a physical impairment participating in any para-sport event or activity at Paralympic, international, national, regional, or recreational level.
iii. include a measurement of the lower limb, upper limb, or trunk muscle strength or power (including manual testing, handheld device testing or dynamometry, and isokinetic assessment).

Studies could be published in any language and conducted in any geographic region.

Studies were excluded if they:

i. were case studies, systematic reviews, or conference proceedings.
ii. included only participants over 65 years.
iii. included muscle strength or power assessed only as an outcome measure as part of interventional studies, including rehabilitation or training programmes.
iv. included muscle strength or power assessed as part of a combined battery of tests where muscle strength or power data was not available separately.
v. assessed strength measures in response to neuromuscular electrical stimulation.

Data collection and analysis

Citations retrieved from the database searches were imported into a reference management programme (EndNote X9.3.1), and duplicates were removed. Two independent reviewers (SOC, NH) screened titles and abstracts for potentially eligible studies. Reviewers were not blinded to authorship or journal information. The screening was performed using a previously developed, standardised tool that was piloted and modified before use. Full-text versions of all articles appearing to meet the study inclusion criteria were downloaded and reviewed to confirm eligibility. Any disagreements regarding final inclusion were resolved through discussion between all reviewers. Reasons for exclusion were documented at each stage. The process of study selection was reported using the PRISMA flow chart. The following data were extracted from each study:

A. Author.
B. Journal/source of publication.
C. Year of publication.
D. Country where the study was carried out.
E. Aims/purpose.
F. Study population and sample size.
G. Study design.
H. Type of para-sport.
I. Performance level.
J. Type of strength measurement used.
K. Reliability/validity data.
L. Key findings related to review research questions.

Data were extracted by the same two reviewers who performed screening (SOC, NH), and any discrepancies regarding data extraction were resolved by a third reviewer (BP).

Quality assessment

All included studies were assessed by at least two independent reviewers (BP, KF, SW) using the Joanna Briggs Institute checklist for cross-sectional studies.[22] For the purposes of this review, the tool was modified, with item three (relating to the valid and reliable measurement of exposure) removed due to the non-analytical nature of the included studies. Item two was also modified to assess descriptions of study participants and study settings separately. The checklist, therefore, consisted of eight items, including questions on study inclusion criteria, participants and settings, validity and reliability, confounding variables, and use of appropriate statistical analysis. Each question was rated as 'yes', 'no', or 'unclear'. Any discrepancies were resolved using consensus decisions agreed on by all reviewers. Quality assessment was not used to determine study inclusion or perform sub-group analysis based on methodological quality or risk of bias.

Data synthesis and analysis

For review questions i and ii, data on strength assessment methods, protocols used, and results related to the association between strength outcomes and performance were summarised in tabular form, with findings and conclusions summarised descriptively. For review question iii (examining muscle strength in para-athletes in comparison to control group data), there was substantial clinical and statistical heterogeneity. Therefore, this precluded carrying out a meta-analysis based on pooling of between-group, mean or standardised mean differences and 95% confidence intervals, using a fixed or random effects model. Therefore, these findings were also described and synthesised narratively, with studies grouped according to strength assessment methods utilised, muscle groups tested, and any comparison groups used.

Results

Search results

The electronic database searches returned 1721 citations, with 43 identified from other sources. This resulted in a total of 1764 citations (See Fig. 1). The most common reasons for exclusion at this stage included studies not directly related to strength assessment and participants being from non-athletic or non-disabled populations. After the initial screening of titles and abstracts, 1699 citations were excluded, leaving 65 papers that were identified and downloaded for full-text review. Following this stage, a further 35 studies were excluded. This was primarily due to an ineligible participant population, separate strength data not being available, or strength being assessed only as part of a rehabilitation program or other intervention. A total of 30 studies were therefore included in the review.

Characteristics of included studies

Characteristics of the studies are summarised in Table 1. The overall number of participants was 929 (*Mean*: 30.9; standard deviation [*SD*]: 20.8) and ranged from nine to 87. The mean age was 30.7 years (*SD*: 2.4), and the majority of participants were male (88%), with 16 studies including only male participants. Participant sex was not stated in three studies. Participants took part in several different para-sport events. Wheelchair sports, including basketball, rugby, and tennis, were the most common (23/30: 76%), followed by football and running events (8/30: 23%). Many participants competed at an international (14/30: 47%) or national level (10/30: 33%). The competition level was not stated in five studies. Studies typically tested the strength of multiple muscle groups. These were predominantly upper limb muscles, including the shoulder internal and external rotators (15/30: 50%) and elbow flexors (5/30: 17%). Handgrip strength was measured in five studies (5/30: 17%). Five studies (5/30: 17%) tested functional or sport-specific upper limb patterns, including unilateral pull-down or pushing movements. Other measures included trunk flexion and extension (6/30: 20%) and hip or knee (7/30: 23%) strength. Twelve studies included comparison groups (12/30: 40%). These comparator groups varied widely and comprised non-disabled and individuals with a disability from athletic and sedentary populations.

Quality assessment

Quality assessment of the included studies is displayed in Table 2. Overall scores ranged from 3 to 7 points, with a mean score of 6 (*SD*:1). Participants and settings were generally well described (*Items* 2 and 3), and statistical analysis methods were appropriate (*Item* 8). However, many studies (14/30: 47%) did not provide specific inclusion criteria (*Item* 1), and more than half (17/30: 57%) failed to identify any strategies for dealing with key confounding variables (*Item* 6), such as level of impairment, modified testing methods, or the influence of training, skill or performance level.

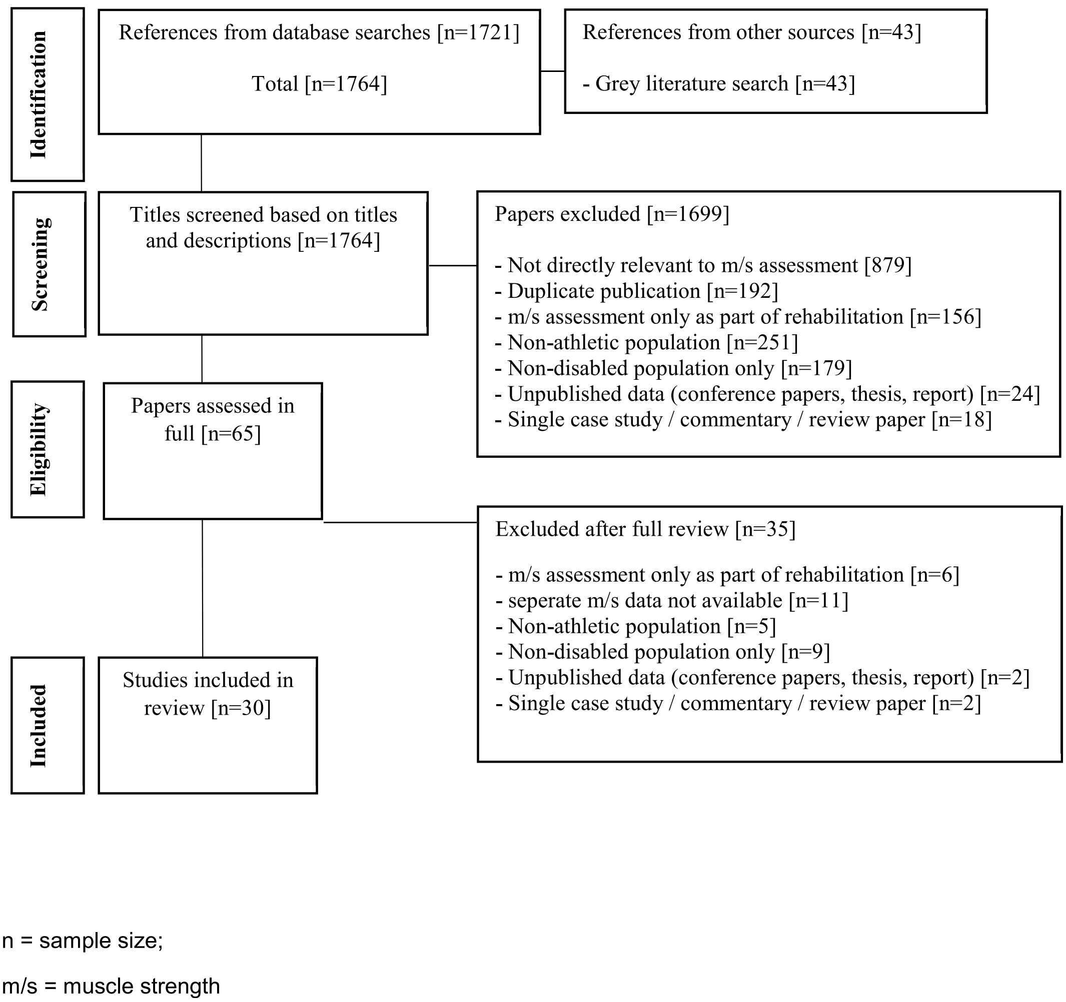

Fig. 1. Flowchart showing study selection process during the review.

Methods used to assess muscle strength

The majority of studies assessed strength using isometric (16/30: 53%)[23–38] or isokinetic testing protocols (10/30: 33%).[39–48] Two studies combined isometric and isokinetic testing.[49,50] A further two studies used the one-repetition maximum[51,52] and one used manual muscle testing (See Table 3).[53] Only five studies[23,28,31,45,48] included reliability data. These primarily assessed isometric shoulder strength, with reported intraclass correlations (*ICCs*) ranging from 0.81 to 0.98. Set up and testing protocols were similar across the studies in terms of positioning and stabilisation, which were dependent on the joints being tested. Warm-up and familiarisation procedures were also comparable, typically ranging between two and five sub-maximal contractions followed by a rest period of 20–60 s. During formal testing, standard verbal encouragement was given to participants in the vast majority of studies. A small number also provided visual feedback during testing. However, the studies varied considerably in other procedures, even between those that used the same strength testing methods. For example, the testing order differed, with some studies using a random order, while others tested the right side first or the dominant side first.

Isometric tests predominantly used load cells[23–25,27,29–32,36] or dynamometers[26,29,33,35,38,49] and used measures of peak force obtained at different durations. This testing included measures obtained after 1 s or 2 s, with effort maintained for a further three to 10 s. Isokinetic testing was carried out at typical test velocities (between 60 and 300°/s [degrees per second]). However, some studies tested only at slower speeds of 60°/s,[40,46] while others used a range of speeds including 60, 90, 180, and 300°/s.[31–33,36,46,50] Maximum force (Newtons, N) or peak torque (Newton metres, N·m) were recorded, with analysis based on the single highest value obtained, or averages calculated from between three or five contractions. Values were corrected for body weight in a small number of studies.[30,43,44] Some studies (both isometric and isokinetic) calculated muscle group ratios, including concentric external and internal rotator strength ratios.[39,41–43,47]

Strength outcomes and functional performance

The relationship between strength measurements and performance outcomes was reported in a number of the included studies. In relation to lower limb strength, one study that examined Paralympic running[25] concluded that strength imbalance between limbs affected performance (assessed using acceleration and top speed during a 60-m maximal sprint) rather than the severity of impairment. However, impairments in the study were mild, with most participants in T37 or T38 classes (disability sport classifications), and moderate to minimal hemiplegia; therefore, more robust associations with performance may have been observed if strength impairments were greater. Similarly, a recent study that used a two-factor cluster analysis reported that peak isometric force of the knee extensors in para-athletes with spastic hemiplegia did not discriminate between impaired and unimpaired leg function.[34] Conversely, in the upper limb, classification approaches using a battery of single-joint isometric strength tests have been suggested to have validity in terms of assessing arm strength impairments in wheelchair rugby athletes.[31] Cluster analysis of combined strength tests also successfully identified

Table 1
Characteristics of included studies.

Author	Country	Design	Population	Sample size	Age (years)	Gender (Male: *n* (%))	Sport	Participation level	Comparison group(s)
Altman 2016	Netherlands	Cross-sectional	Disabled athletes with a minimum of 1-years experience	34	34.5[a] (range 18–59)	Not stated	WCR, WCB	National	Nil
Altmann 2018	Netherlands	Cross-sectional	Disabled athletes (at least 18 years) with a minimum of 1-year experience	27	37.4 (*SD*: 10.2)	27 (100%)	WCR, WCB	National/ International	Nil
Andrade 2005	Brazil	Descriptive	Disabled athletes with spastic hemiplegia	21	26 (*SD*: 3.0)	21 (100%)	Football (7-a-side)	International	Nil
Aytar 2012	Turkey	Clinical pilot trial	Amputee athletes	11	24.6 (*SD*: 6.5)	11 (100%)	Amputee soccer	Club level	Nil
Basar 2013	Turkey	Comparative	Disabled athletes aged between 15 and 31 years	28 (Young National Group I: $n = 14$)	26.1 (*SD*: 2.7)	28 (100%)	WCB	National	National Junior Group II: $n = 14$[b]
Beckman 2016	Australia	Cross-sectional	Athletes with brain impairment (RBI)	41 (Athletes with brain impairment (RBI): $n = 13$)	23.7 (*SD*: 6.7)	41 (100%)	Competitive runners or running sports	Not stated	Age matched, non-disabled runners ($n = 28$)
Bernard 2004	France	Cross-sectional	Athletes divided into high paraplegic athletes (HPA): $n = 12$ and low paraplegic athletes (LPA): $n = 9$)	49 (Wheelchair athletes: $n = 21$)	30.8 (*SD*: 4.2)	Not stated	WCT, WCR	Not stated	Nonathletes ($n = 12$) and able bodied tennis players ($n = 15$)
Benardi 2012	Italy	Cross-sectional	Winter sport (seated position) athletes with spinal cord injury, poliomyelitis or lower limb amputation	75	38.2 (*SD*: 7.1)	75 (100%)	AS, NS, curling, ISH	International	Nil
Cobanglu 2020	Turkey	Cross-sectional	Disabled athletes active in sports for at least 2 years	52 (Wheelchair basketball players: $n = 17$)	25.1 (range 19–39)	52 (100%)	WCB	Not stated	Able-bodied basketball players ($n = 18$) and sedentary individuals ($n = 17$)
Connick 2018	Australia	Cross-sectional	Disabled athletes from classes T51–54	32	32.2 (*SD*: 9.0)	32 (100%)	WCR	International	Nil
Freitas 2019	Brazil	Cross-sectional	Athletes with complete SCI participating for at least two years	36 (Wheelchair basketball players: $n = 18$)	35.6 (*SD*: 1.6)	36 (100%)	WCB	Not stated	Paraplegic non-athletic individuals ($n = 18$)
Hogarth 2019	Australia	Cross-sectional	Athletes with physical impairment	72 (Para-swimmers: $n = 42$)	29.0 (*SD*: 7.3)	41 (57%)	Para-swimming	National/ International	Non-disabled participants ($n = 30$)
Hyde 2017	Australia	Cross-over	Paralympic athletes	10	32 .0 (*SD*:10.0)	8 (80%)	WCR, WCB or athletics (seated throws)	State/ National	Nil
Iturricastillo 2019	Spain	Cross-sectional	Disabled athletes	9	34.0 (*SD*: 8.0)	Not stated	WCB	National	Nil
Juul-Kristensen 2020	Denmark	Descriptive	Tetraplegic athletes	12	41.0 (*SD*: 11.0)	11 (92%)	WCR	Club level	Nil
Kulunkoglu 2018	Turkey	Cross-sectional	Disabled athletes	19 (Wheelchair basketball players: $n = 10$)	26.1 (*SD*: 3.1)	0 (0%)	WCB	Club level/ National	Non-disabled participants ($n = 9$)[b]
Marcolin 2020	Italy	Cross-sectional	Disabled athletes	16	26 .0 (*SD*: 6.0)	16 (100%)	WCR	International	Nil
Mason 2020	UK	Cross-sectional	Disabled athletes with impaired arm strength	50 (Wheelchair basketball players: $n = 20$)	31.5 (*SD*: 5.0)	35 (70%)	WCR	Not stated	Physically active, able-bodied (AB) participants: $n = 30$ (15 male, 15 female)
Mason 2021	UK	Cross-sectional	Athletes with strength impaired arms and no trunk function	57	33.0 (*SD*: 7.0)	53 (93.0%)	WCR	International	Nil
Moon 2013	Korea	Cross-sectional	Disabled athletes with spinal cord injury or amputation	12	33.4 (*SD*: 8.2)	12 (100%)	WCT	National	Nil
Porto 2008	Brasil	Comparative	Tetraplegic athletes	24 (Paralympic disabled rowers: $n = 16$)	45.4 (*SD*: 9.6)	24 (100%)	Rowing/WCB	International	Recreational disabled WCB players: $n = 8$)[b]

(*continued on next page*)

Table 1 (*continued*)

Author	Country	Design	Population	Sample size	Age (years)	Gender (Male: *n* (%))	Sport	Participation level	Comparison group(s)
Reina 2020	Spain	Cross-sectional	Para-athletes with cerebral palsy	87	25.8 (*SD*: 6.7)	87 (100%)	Football	International	Nil
Schwingel 2009	Brasil	Comparative	Athletes with amputations or cerebral paralysis	9	30 (*SD*: 7.9)	9 (100%)	Rowing	International	Nil
Soylu 2020	Turkey	Cross-sectional	Disabled athletes, who had been playing at least for 3 years	26	26.6 (*SD*: 9.4)	24 (92%)	WCB	National	Nil
Umezu 2003	Japan	Cross-sectional	Athletes between 20 and 46 years of age with complete (ASIA-A) T4–L1 paraplegia	15 (Wheelchair athletes: $n = 9$)	29.0 (*SD*: 8.2)	15 (100%)	Wheelchair marathon racing	International	Height-and weight-matched recreational WCB players ($n = 6$)
Van der Linden 2018	UK	Cross-sectional	Athletes with hypertonia, ataxia, athetosis in RaceRunning classes RR1/RR1 assist, RR2 or RR3, aged between 14 and 45 and with at least one year of experience	27	23.6 (*SD*: 7.01) (Range: 14–42)	16 (59.2%)	RaceRunning	National/ International	Nil
Vanlandewijk 2011	Belgium	Cross-sectional	Disabled athletes with normal arm strength, normal trunk strength, or impaired trunk strength	13 (Wheelchair track athletes with impaired trunk strength: $n = 7$)	25.6 (*SD*: 6.6)	10 (78%)	Wheelchair track athletes	International	Wheelchair track athletes with normal trunk strength ($n = 6$)
Villacieros 2020	Spain	Comparative	Disabled athletes	12 (category A (functional classes 1.0–2.5): $n = 5$)	29.9 (*SD*: 7.3)	12 (100%)	WCB	National	Category B (functional classes 3.0–4.5): $n = 7$)
Wang 2005	US	Cross-sectional	Disabled athletes with at least two years of participation	37	28.7 (*SD*: 7.5)	16 (43%)	WCB	International	Nil
Yanci 2015	Spain	Cross-sectional	Disabled athletes	8 (Category A (1.0–2.5 pts.)	33.0 (*SD*: 7.0)	14 (87%)	WCB	National	Category B (3.0–4.5 pts.: $n = 8$)

RR1,2,3: Race Running classes 1, 2 and 3; ASIA-A: American Spinal Injury Association impairment – complete; AB: able-bodied; *SD*: Standard Deviation; n: sample size; WCR: Wheelchair Rugby; WCB: Wheelchair Basketball; AS: Alpine skiing; NS: Nordic skiing; ISH: Ice sled hockey; RBI – brain impairement; HPA: high paraplegic athletes; LPA: low paraplegic athletes; SCI: spinal cord injury; T51-54 – disability sport classification; ASIA-A T4-L1 – level of spinal cord injury; Category A: represents wheelchair basketball players classified as level 1.0 to 2.5 as per the International Federation for Wheelcahir Basketball; Category B: corresponds to levels 3.0 to 4.5 for player classification as per the International Federation for Wheelchair Basketball.

[a] Estimated from median values.

[b] Age significantly different from comparison group.

wheelchair track racing athletes with similar levels of activity limitation.[25,27,36] Isometric shoulder flexion and extension strength have also been shown to successfully classify para-swimmers based on a random forest algorithm.[28] Isometric strength at the shoulder and hand is correlated with hand speed at release during seated throwing, inferring potential loss of strength in para-athletes in wheelchair-based sports.[29] Significant correlations were also identified between performance (including 20-m distance time and shooting ability in wheelchair basketball) and isokinetic shoulder internal and external rotator strength.[50] However, this association was not apparent for grip strength in the latter of these studies,[50] or between acceleration and trunk flexion strength.[36]

Strength outcomes in comparison to control group data

In the thirteen studies that included comparative data, control groups varied widely. They comprised able-bodied participants and individuals with physical impairment from both athletic and sedentary populations or participants with different levels of functional impairment.[25,28,31,33,35,36,38,41–45,48] This contributed to the substantial clinical heterogeneity between control groups that precluded meta-analysis. Available data were extracted and summarised based on each group's mean strength values and standard deviations. Overall findings were mixed. Several isometric testing studies reported that para-athletes had comparable,[33,35] or significantly lower strength values than able-bodied participants[25,28,31] and showed greater variability in strength outcomes. For example, para-athletes in competitive running or other running sports had significantly impaired leg flexor and extensor strength compared to age-matched, able-bodied runners.[25]

Similarly, lower values were reported for hip and shoulder strength in para-swimmers relative to able-bodied participants, although this pattern was not seen for shoulder flexion in females and dominant hip flexion in males with hypertonia.[28] An important observation based on a number of the included studies ($n = 6$) was that overall, higher shoulder strength values were observed in para-athlete groups relative to controls.[42–45,48,49] This was most clearly demonstrated in studies using isokinetic testing to assess shoulder strength compared to sedentary, able-bodied, and disabled controls. For example, significant differences were found in higher shoulder extensor and flexor strength in wheelchair basketball players versus able-bodied controls at 60 and 180°/s.[43] A further study noted significantly higher internal rotator strength in wheelchair tennis players and racers at 180 and 300°/s, but not at slower test velocities of 60°/s.[42]

Discussion

This systematic review sought to assess and synthesise evidence related to the assessment of muscle strength in para-sport athletes.

Table 2
Quality ratings using a modified Joanne Briggs Checklist for assessment of cross-sectional studies.

Author	Were the criteria for inclusion in the sample clearly defined?	Were the study subjects described in detail?	Was the setting described in detail?	Were objective, standard criteria used for measurement of the condition?	Were confounding factors identified?	Were strategies to deal with confounding factors stated?	Were the outcomes measured in a valid and reliable way?	Was appropriate statistical analysis used?	Total Score/ 8
Altman 2016	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	7
Altmann 2018	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	7
Andrade 2005	No	Yes	Yes	Yes	Yes	No	No	Yes	5
Aytar 2012	Yes	Yes	Yes	Yes	No	No	Unclear	No	4
Basar 2013	No	Yes	Yes	Yes	Unclear	No	No	Yes	4
Beckman 2016	No	Yes	Yes	Yes	Yes	Yes	No	Yes	6
Bernard 2004	No	Yes	Yes	Yes	Yes	No	No	Yes	5
Benardi 2012	Unclear	Yes	Yes	Yes	Unclear	No	No	Yes	3
Cobanglu 2020	Yes	Yes	Yes	Yes	Unclear	Yes	No	Yes	6
Connick 2018	Yes	Yes	Yes	Yes	Unclear	Yes	Yes	Yes	7
Freitas 2019	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	Yes	7
Hogarth 2019	Yes	Yes	Yes	Yes	Unclear	Yes	No	Yes	6
Hyde 2017	Yes	Yes	Yes	Yes	Unclear	Yes	Yes	Yes	7
Iturricastillo 2019	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7
Juul-Kristensen 2020	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8
Kulunkoglu 2018	Yes	Yes	Yes	Yes	Yes	Yes	No	Unclear	6
Marcolin 2020	No	Yes	Yes	Yes	Yes	Yes	No	Yes	6
Mason 2020	No	Yes	Yes	Yes	Yes	No	No	Yes	5
Mason 2021	No	Yes	Yes	Yes	Yes	No	No	Yes	5
Moon 2013	No	Yes	Yes	Yes	Unclear	No	No	Yes	4
Porto 2008	No	Yes	Yes	Yes	Yes	No	No	Yes	5
Reina 2020	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	7
Schwingel 2009	No	Yes	Yes	Yes	Yes	No	No	Yes	5
Soylu 2020	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8
Umezu 2003	Yes	Yes	Yes	Yes	Unclear	No	No	Yes	5
Van der Linden 2018	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	7
Vanlandewijk 2011	No	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	6
Villacieros 2020	No	Yes	Yes	Yes	Unclear	Yes	Yes	Yes	6
Wang 2005	Yes	Yes	Yes	Yes	Unclear	No	No	Unclear	4
Yanci 2015	Yes	Yes	Yes	Yes	Unclear	Yes	Yes	Yes	7
									5.8 (*SD*: 1.3)

SD: standard deviation.

Specifically, the review aimed to determine the characteristics of methods used to assess strength in the available evidence and explore the associations between strength and performance. An additional objective was to examine differences in strength compared to control groups. Thirty observational studies met the inclusion criteria for the review. Only one study examined manual muscle testing, with the other identified studies primarily involving the assessment of muscle strength using isometric and isokinetic methods. The methods and testing protocols used varied considerably despite the included studies using similar strength testing approaches. Strength comparisons in thirteen of the 30 studies were made with a control group. These control groups included able-bodied athletes and non-athletic participants with or without physical impairments. A planned meta-analysis to examine between-group differences was not possible due to the substantial clinical heterogeneity found between the studies. The overall quality of the studies was also mixed, with many failing to identify strategies for dealing with confounding variables, such as level of impairment or modified testing methods. Studies primarily included male participants taking part in wheelchair-based events. Participants in the included studies typically also had relatively low levels of impairment. For example, few studies included athletes with a high spinal cord injury, and by excluding these athletes from research there is a risk that classification systems are built on data solely representing athletes with low levels of impairments. These issues and a lack of standardisation between testing methods limit the generalizability and the strength of evidence available to inform the development of methods for assessing muscle strength in para-sport athletes.

Strength assessment methods need to be reliable and accurate if they are to be used either to evaluate the effectiveness of strength training or rehabilitation programmes or alongside other measurements as part of para-sport classification systems. The reliability of strength testing methods has been extensively examined in different populations, but data from para-athletes is limited. Although manual muscle testing is seen as a rapid and non-complex measure, previous studies have highlighted its poor reliability.[54,56] A study that included patients with paresis of the forearm muscles, excluding those with grades 0 and 5, was found to decrease reliability. This highlights that with manual muscle testing, assessing different grades of mild or partial paresis can be more challenging than assessing muscles that cannot contract or are evaluated as normal.[57] The reliability of isokinetic testing has been more widely demonstrated than other muscle strength assessment methods.[58,59] It has been stated that isokinetic testing is less practical, particularly in para-sport classification, as it requires more time and relatively large and costly equipment.[12] However, this is also the case for some lab-based

Table 3
Key findings from studies included in the systematic review.

Author	Strength assessment method(s) and muscle groups tested	Key finding(s)	Study limitations identified	Interpretation of findings
Altman 2016	Maximum isometric trunk strength using mean force in newtons during 1 s in plateau phase	- Significant main effect for TIC scores on trunk muscle strength for all directions ($p = 0.001$) - Post hoc analysis showed maximal isometric forces to left were significantly lower in athletes with TIC score 0 compared with athletes with scores 1.0 and 1.5 - Maximal isometric force to right, forward, backward, and backward with support of feet was significantly lower in athletes with TIC score 0 compared with those with scores 0.5, 1.0, and 1.	- Low number with TIC scores 0.5, 1.0, and 1.5 included	- Most with TIC score 0 showed no difference in muscle strength between directions, other scores showed differences in strength between lateral and forward and backward directions - TIC distinguishes athletes with severe trunk impairment (TIC 0) from other athletes
Altmann 2018	Maximum isometric strength using mean isometric force in newtons during 1 s in plateau phase	- Moderate to strong correlations between left-right strength and chair tilting ($r = 0.50$), forward strength and 1 m acceleration ($r = 0.59$), and forward strength and sprint momentum ($r = 0.79$). - Significant difference in tilting height for clusters based on left and right trunk muscle strength (H(3,23) = 13.9, $p = 0.03$). - Significant difference in 1-m acceleration test for clusters based on the forward trunk muscle strength (H(3,23) = 10.4, $p = 0.016$).	- Low number of athletes with moderate to no trunk impairment	- Forward trunk strength and acceleration and sprint momentum performance increased with an increase in trunk strength. - In athletes with moderate to no impairment, ability to perform a tilting movement with sufficient height seemed to be dependent on skill, rather than strength.
Andrade 2005	Isokinetic knee flexor and extensor strength at 60°/s	- Peak torque values of involved flexors and extensors (88.4 ± 26.0 Nm and 155.4 ± 37.2 Nm) had significantly lower ratios than the uninvolved side (116.2 ± 24.8 Nm and 201.6 ± 38.8 Nm).	Not reported	- Soccer players with CP have increased injury risk due to strength asymmetries, quadriceps weakness and imbalance between antagonistic knee muscles.
Aytar 2012	Isokinetic concentric trunk flexion and extension strength at 60°/s, 120°/s and 180°/s	- Correlation between flexor isokinetic trunk muscle strength at 60°/s and modified plank test ($r = 0.630$, $p = 0.038$). - Negative correlation between flexor isokinetic trunk muscle strength at 180°/s and Oswestry Disability Index score ($r = -0.649$, $p = 0.031$).	- Small sample size and no control group	- Flexor trunk strength had a positive relationship with core stability but a negative relationship with disability.
Basar 2013	Isokinetic shoulder rotator strength at 60°/s and 180°/s in scapular plane	- In group I, peak left shoulder external rotator torques were higher compared to group II ($p < 0.05$). - No significant differences were observed in deficit ratios between groups ($p > 0.05$).	Not reported	- Findings indicate peak torques in young national players were superior to those of the national junior team. - Differences may originate from sport-specific skills and training habits.
Beckman 2016	Maximal isometric contractions of leg extensors and flexors, and plantar flexors	- Strength was significantly lower in the affected leg compared with controls on all tests. - Extension and flexion strength on the less affected leg was not significantly different from controls.	Not reported	- Participants had significant impairments to lower limb strength compared to controls. - Imbalance between stronger and weaker sides affected running performance, rather than severity of strength impairment. - Isometric strength protocols with a slow ramping of force are necessary for use in Paralympic classification to ensure tests are training resistant. - Impairments to muscle strength were mild and stronger relationships between strength and performance may be observed where strength impairments are greater.
Bernard 2004	Isokinetic strength of shoulder rotators at 60, 180, and 300°/s	- For peak torque at 60°/s there were no significant differences in internal and external rotation. - At 180 and 300°/s, internal rotators showed significant differences between groups ($p < 0.02$ to $p < 0.05$). - Internal/external ratios for both sides were significantly higher in the wheelchair athlete group ($p < 0.001$ to $p < 0.05$), except for 60°/s. - Ratios were significantly different among groups on the nondominant side at 180°/s ($p < 0.04$) and the dominant size at 300°/s ($p = 0.02$).	Not reported	- Level of lesion did not influence internal rotators but did influence external rotators. - Comparison between sides in both paraplegic groups showed that in two-thirds of the cases the values of the external rotators were significantly higher than those of the internal rotators on the nondominant side for peak torque and mean power. - Ratios on dominant side were higher than the nondominant side with significant differences in two-thirds of cases.
Benardi 2012	Maximum voluntary isometric contraction of upper limb muscles	- Alpine skiers and sledge hockey players had higher absolute strength than other groups but relative strength was not significantly different.	Not reported	- Absolute strength differences may be a training adaptation to reduce injury risk and an important factor for performance.

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Table 3 (*continued*)

Author	Strength assessment method(s) and muscle groups tested	Key finding(s)	Study limitations identified	Interpretation of findings
Cobanglu 2020	Isokinetic strength testing of shoulder rotators at 60°/s for concentric and 90°/s for eccentric tests	- Significant differences observed between groups in concentric-eccentric ER and IR strength on dominant and non-dominant sides ($p = 0.05$). - Concentric ER and IR strength of dominant side, eccentric ER strength of dominant sides and concentric strength of non-dominant sides of the wheelchair basketball and able bodied basketball groups were similar and greater than that of the Control group. - Eccentric ER and IR of non-dominant sides and the eccentric IR strength of dominant sides were found to be greater in the WBP group compared to controls. - Concentric and eccentric ER/IR ratio was similar in both sides in three groups.	- Wheelchair basketball players included those who did not use a wheelchair to provide mobility in daily life and had low classification scores. - Significant age differences between groups.	- Muscle strength of the shoulder rotator cuff muscles were similar in wheelchair basketball and able bodied basketball groups and higher than controls. - Concentric and eccentric ER/IR ratio was similar in all groups but ER/IR ratios were lower in wheelchair basketball players compared to the other two groups and normative values. - Exercises for ER strengthening should be included in WCB training.
Connick 2018	Maximum isometric strength of arm extensors, trunk flexors, forearm pronators, handgrip strength	- Significant correlations were found between strength and performance outcomes ($r = 0.54$–0.88). - Analysis yielded four clusters with reasonable overall structure (mean silhouette coefficient = 0.58) and large intercluster strength differences. - Six athletes (19%) were allocated to clusters that did not align with their current class.	- sample not large enough - Should be replicated to determine if outcomes in female population.	- Strength tests provide the basis for less subjective classification system, pending replication of findings in a larger, representative sample. - Athletes with no trunk function are at a significant disadvantage compared with those with partial or full trunk function. - Mean effect size of the difference between adjacent clusters (1.87 *SD*) was larger than current Para-athletics classes (1.43 *SD*).
Freitas 2019	Isokinetic peak torque of rotator cuff muscle group at 60°/s and 180°/s, and 300°/s.	- Wheelchair basketball athletes presented higher strength values compared to non-athletes at 60°/s, 180°/s, and 300°/s. - There was no statistical difference for the internal rotators of the non-dominant limb at 180°/s and 300°/s and no statistical differences between the dominant and non-dominant limb in all variables at all speeds. - Muscle imbalances between IR and RE could not be detected.	- Classification of functional capacity not taken into account.	- Internal rotators and ER relationship of shoulder rotators in both groups registered muscular balance, indicating the similarity between athletes and non-athletes and no influence of WB on ER/IR strength ratio.
Hogarth 2019	Maximum isometric strength of rotator cuff and hip muscle groups	- Significantly lower strength scores for all tests seen except for shoulder flexion in females and dominant hip flexion in males with hypertonia. - Larger differences in strength scores compared with non-disabled participants for the non-dominant limbs (shoulder extension (mean ± range = 0.96 ± 0.12 versus 0.82 ± 0.51; $d = 0.81$, $p \leq 0.05$) - Dominant and non-dominant shoulder extension strength had strongest correlations with maximal clean swim speed for Para swimmers with hypertonia ($r = 0.46$ to 0.66, $p \leq 0.04$) and impaired muscle power ($r = 0.47$ to 0.51, $p \leq 0.04$). - Para swimmers with hypertonia showed significant correlations between clean swim speed and strength scores for dominant shoulder flexion ($r = 0.66$, $p < 0.01$) and dominant hip flexion ($r = 0.44$, $p = 0.05$).	Not reported	- Fewer correlations were found for both groups when Para-swimmers with hypertonia or impaired muscle power were analysed independently, highlighting the impairment-specific nature of activity limitation. - Strength test battery has utility in Para-swimming classification to infer loss of strength, guide minimum eligibility criteria, and define impact that strength impairment has on performance. - Isometric strength tests limit assessment to a fixed range of motion, and might be susceptible to fatigue induced by prior activity, or might be responsive to sport-specific training.
Hyde 2017	Maximum isometric muscle strength of shoulder, trunk, forearm, hand	- Grip strength ($r = 0.59$–0.77), push/pull synergy ($r = 0.81$–0.84) and trunk flexion ($r = 0.50$–0.58) strength measures showed large and significant correlations with hand speed at release during seated throwing with and without an assistive pole.	- Small sample - Athletes from a range of Para-sports.	- Strength impairments should be evaluated in both pole and no pole conditions in classification research. - Possible implications regarding classification system are that athletes who throw with and without a pole compete in separate competitions and that seated throwers use the same equipment. - Isometric strength tests were strongly correlated with hand speed at release during seated throwing with and without an assistive pole, and may have utility to infer loss of strength during the classification process for seated throwing athletes who have strength impairment.

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Table 3 (*continued*)

Author	Strength assessment method(s) and muscle groups tested	Key finding(s)	Study limitations identified	Interpretation of findings
Iturricastillo 2019	Isoinertial bench press test with increasing loads up to the 1RM for the individual determination of the full load-velocity relationship	- Near perfect inverse relationship ($r = -0.97$; R^2 219 = 0.945; $p < 0.001$) was found between MPV and %1RM. - 1RM was 81.8 ± 26.9 kg while power outcomes were 151.4 ± 51.2 W, 151.4 ± 224 51.2 W and 360.9 ± 304.8 W, respectively. - Maximum loads were obtained between 48.1 and 59.4% of the 1RM (MPV = 0.90–1.09 m·s-1233; inter-player CV = 10.0 to 234 18.3%).	Not reported	- Absence of association between BP performance and field tests might be due to factors such as wheelchair-user interface, trunk muscular activity or propulsion technique and not strength variables.
Juul-Kristensen 2020	Maximum voluntary isometric and isokinetic contractions of shoulder rotator muscles	- No significant difference found between isometric HHD and ID, except for larger activity in ID for IS during ER compared with isometric HHD (median difference: −17.35% MVE; 25, 75 perc: −24.91, 2.26; $p = 0.047$). - A, larger co-activation ratio was seen in ID for IS/LD during ER (median difference −0.58% MVE; 25, 75 perc: −2.30, −0.34; $p = 0.028$).	- Convenience sampling method and small sample limit generalizability	- Relative muscle activity in isometric HHD was not different from ID during maximum shoulder rotation, but higher co-activation in isometric HHD during ER was indicated. - Measurement of shoulder rotation strength using isometric HHD found to be feasible and valid.
Kulunkoglu 2018	Isokinetic strength of the shoulder joint at 60°/s and 180°/s	- Significant differences were found in terms of all parameters and were higher in wheelchair basketball players versus non-disabled controls ($p < 0.05$)	- Small, female only sample - Significant age difference between groups.	- Differences in strength between groups mostly derived from using wheelchairs due to training.
Marcolin 2020	Sport-specific isometric test to study muscular strength of chest and shoulder	- Peak force correlated with the IWRF classification ($r = 0.74$; $p = 0.0011$; 95% CI = 0.37 to 0.91), but not when values were normalized to body weight ($r = 0.33$; $p = 0.2180$; 95%CI = −0.22 to 0.72).	- Limited number of national team players did not allow more than three groups to perform the multivariate permutation-based ranking analysis	- Normalized peak force of the isometric strength test showed weak correlations with the IWRF classification.
Mason 2020	Maximum isometric strength of shoulder rotator muscles	- No significant differences existed between dominant and non-dominant sides for either WR ($p \geq 0.124$) or AB ($p \geq 0.143$) participants. - AB participants produced significantly higher force values for all measures of isometric strength than WR athletes ($p \leq 0.0005$; $d \geq 2.14$). - Strength ratios of 0.65 ± 0.17 and 0.32 ± 0.24 revealed a substantial increase in flexor strength around the shoulder and elbow respectively in WR athletes.	Not reported	- A battery of single-joint isometric strength tests was valid for assessment of arm strength impairment in WR players which infers they can be of use in the development of evidence-based classification. - Normative strength data acquired from male and female AB participants with unimpaired arm strength may also serve as valuable information for the future investigation of a female specific classification system in WR and to help explore cases of intentional misrepresentation.
Mason 2021	Maximum isometric strength of shoulder rotator muscles	- Significant correlations were identified between all measures of isometric strength and performance and ranged from −0.43 to −0.77 for 2 m times and −0.55 to −0.82 for 10 m times. - Cluster analyses with 4-clusters (to mirror current International Wheelchair Rugby Federation system) and 3-clusters showed 3-cluster structure provided a more valid structure than both the 4-cluster and existing system, as evidenced by clearer differences in strength (Effect sizes [ES] ≥ 1.0) and performance (ES ≥ 1.1) between adjacent clusters and stronger mean silhouette coefficient (0.64).	Not reported	* A 3-cluster structure for classifying proximal arm strength impairment resulted in less overlap between athletes from adjacent classes and reduced likelihood of athletes being disadvantaged due to impairment.
Moon 2013	Isokinetic strength of shoulder and elbow flexors and extensors at 60°/s	- Shoulder extension strength was significantly higher than flexion ($p < 0.001$) - Elbow flexion strength was significantly higher than extension ($p < 0.05$). - Strength ratios were lower than normal range.	Not reported	- Bilateral strength ratios of shoulder flexion, and ipsilateral and bilateral elbow extension were lower than normal range and strengthening exercises are proposed.
Porto 2008	Maximum isometric hand grip strength	- Strength levels, measured by right and left handgrip, were not different between disabled rowers and controls.	Not reported	- The absence of handgrip statistical differences could reflect inappropriate training or that the daily activities of wheelchair users imposed a high development of handgrip strength.
Reina 2020	Peak isometric knee extensor strength	- Peak forces of 412.4 N (SD: 113.9) were recorded and effect size differences between clusters (based on level of disability) were minimal	- No assessment of spasticity - use of isokinetic dynamometer could improve classification decisions	- Muscle strength testing did not discriminate between impaired and unimpaired lower limbs.
Schwingel 2009	Bench press test lying T-bar test and leg press with increasing loads up to the 1RM	- No differences found for lying T-bar row and bench press exercises between measured and predicted 1RM values ($p = 0.84$ and 0.23 for lying T-bar row and bench press).	Not reported	- Equations could be applied to rowers with motor disabilities for 1RM prediction. - For the leg press, none provided accurate results so should not be used

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Table 3 (*continued*)

Author	Strength assessment method(s) and muscle groups tested	Key finding(s)	Study limitations identified	Interpretation of findings
		- Leg press showed significant differences between measured and predicted values ($p = 0.01$).		in practice to predict lower limb maximal strength. -Concerning lower limb strength, it is more accurate to directly measure 1RM values of amputated and cerebral paralyzed rowers.
Soylu 2020	Isokinetic strength of shoulder rotator muscles at 60°/s, 180°/s and handgrip strength	- Significantly higher values for IR and ER at both angular velocities were observed in athletes from category B with a large effect size (Cohen's $d > 0.5$) ($d = -0.54$–0.85; $p < 0.05$). - No significant differences were found in grip strength.	- Limited number of female athletes	- Athletic performance in athletes with different classification scores is related to upper extremity muscle strength.
Umezu 2003	Maximum voluntary contraction (MVC) of elbow extensors	- Mean MVC of the athletes and controls (42.4 ± 8.8 Nm) (range: 33–55 and 41.6 ± 9.3 Nm [range 32–56]) respectively, did not differ.	Not reported	- Elite marathoners and active wheelchair users had similar triceps brachii strength.
Van der Linden 2018	Manual Muscle Testing of hip abductors, hip and knee extensors, hip flexors	- Knee extension strength was negatively associated with RaceRunning speed ($p = 0.01$) but not no association was found for hip extension strength.	- Measures not ratio-scaled and were summed to calculate total scores	- Impaired muscle strength was negatively associated with performance and supports use of this measurement as part of evidence based classification systems.
Vanlandewijk 2011	Maximum isometric strength at chest/Shoulder/Trunk	- Results confirmed the outcome of the clinical division with both groups without full trunk strength having relative trunk strength that is equal ($M = 0.29$). - This ratio in participants without full trunk strength was significantly lower than the ratio of those with full trunk strength ($M = 0.42$) ($p = 0.02$).	Not reported	- Impairment of trunk strength has minimal effect on wheelchair acceleration and indicate the T54 class is valid. - Results do not infer that athletes with no trunk strength should compete with those who have partial or full trunk strength.
Villacieros 2020	Isokinetic strength of internal shoulder and external shoulder rotation at 60°/s, 150°/s and 180°/s	- Significant differences were found between functional class groups for ISR in PM at 60°/s in the dominant limb ($p < 0.05$, $d = 0.71$, $CI = 61.14$–88.86, $p = 0.82$) and at 180°/s ($p < 0.05$, $d = 0.67$, $CI = 53.85$–83.65, $p = 0.81$). 0.75). - There were no significant differences for external rotation or elbow flexion.	- Limited sample size	- ISR on the dominant side was different for both groups and showed significant relationship with velocity in all tests. - At higher speeds elbow flexion and extension were correlated with velocity in sports-specific actions.
Wang 2005	Maximal isometric contraction at shoulder, elbow, and wrist	- Elbow extension and wrist extension had significant contributions to performance (average points). - Shoulder internal rotation, and elbow flexion had significant contributions to performance (average rebounds). - The strength of the flexors were stronger than the extensors for upper-extremity joints.	- Use of stepwise regression model with 37 participants is limited	- Shoulder internal rotation, elbow extension, and wrist flexion/ extension muscle strength are important to performance.
Yanci 2015	Maximal isometric grip strength	- Strength measurements were highest in participants from category B (higher function) compared to participants with lower function and matched able bodied controls (48.29 kg ± 12.06 versus 40.71 kg ± 9.95 and 44.50 ± 11.33)	Not reported	- Higher relative strength compared with AB players may be related to differences in fitness, amount of training, training intensity and/or motivation, interfering effects between training modes, and the differences in the physiological adaptations to the wheelchair in WB players

°/s: degrees per second; %: percentage; 1RM – one repetition maximum; AB: Able-bodied; BP: blood pressure; CI: confidence intervals; CP: Cerebral Palsy; CV: Coefficient of variation; *d*: Effect size (Cohen's *d*) was also calculated to determine the magnitude of any differences in performance; ER: External rotation; *ES*: effect size; ESR: External Shoulder Rotation; H: Kruskal-Wallis test; HHD: Hand-held dynamometer; ID: isokinetic dynamometer; ISR: Internal Shoulder Rotation; IR: Internal rotation; 1 m: 1 m; MVC: maximum voluntary contraction; MVE: maximum voluntary effort; Nm: Newton metres; *p*: *p*-value; r: Pearson correlation coefficient; p: p-value; R^2: coeeficient of determination; *SD*: standard deviation; N: Newtons; PM: Peak moment; T54 – disability sport classification; TIC: Trunk Impairment Classification; WBP: Wheelchair Basketball Player: WR: Wheelchair racing; MPV: Mean propulsive velocity; 1RM: 1 Repetition Maximum; Group 1: isokinetic training of the shoulder internal and external rotators in scapular plane motion performed in a sit-ting position with shoulder joint in 45° of flexion and abduction, Group 2 isokinetic training of the shoulder internal and external rotators in frontal plane motion performed in a supine position with the shoulder in 90° of abduction; Category A: represents wheelchair basketball players classified as level 1.0 to 2.5 as per the International Federation for Wheelcahir Basketball; Category B: corresponds to levels 3.0 to 4.5 for player classification as per the International Federation for Wheelchair Basketball.

isometric testing which uses load cells for measurement. Isometric testing using handheld dynamometry is recommended as an alternative to more complex testing, as it requires limited equipment. It has been shown to have acceptable correlations with isokinetic measures for both lower limb and upper limb strength.[40–66] Isometric strength testing, particularly slower ramping force measurements, may also provide the most appropriate measure of voluntary maximal strength, as it could be more resistant to training than isokinetic testing.[67] However, measurement errors using handheld dynamometry have been highlighted, linked to tester strength,[68] poor stabilisation during testing, and variations in participant effort. It has also been emphasised that the lower test range of some handheld dynamometers may be exceeded by the force exerted by larger muscle groups.[69,70] The use of other devices, including portable fixed dynamometry methods, may be needed to overcome some of the issues with isometric testing and to help improve reliability.[71]

In addition to examining methods used to assess muscle strength, this review assessed the influence of strength measures on performance. It explored differences in strength between para-athletes compared to available control group data. Two included studies[23,24] reported that trunk impairment classification was able to distinguish between athletes with severe impairment but found that for moderate to no trunk strength impairment, the ability to perform movements seemed to depend on skill rather than strength. In addition, wheelchair-user interface, trunk muscular activity, or propulsion technique, and not strength variables might contribute to the association between performance and strength testing.[52] Our findings suggest that muscle imbalances could also play a role and be associated with performance characteristics. For example, strength testing could identify knee flexor muscle weakness relative to antagonistic quadriceps strength.[39] Further, an imbalance between stronger and weaker sides has been shown to affect running performance more than the severity of strength impairment.[25] However, this relationship and its impact on para-sport classification have not been widely examined.

Some studies in this review, which predominantly assessed isometric strength of different muscle groups, suggested that strength in para-athletes was comparable to or lower than able-bodied athletic controls. An important observation was that other studies indicated that shoulder strength, in particular, might be higher in para-athletes compared to non-athletes (both able-bodied and disabled). The finding that isokinetic shoulder strength appeared to be higher in para-athletes relative to able-bodied and disabled, non-athletic controls supports the contention that sport-specific training may account for the differences in strength observed in a number of the included studies. Significantly, the differences in isokinetic strength were typically only found at higher test speeds (>180°/s). Slower isokinetic speeds (60–90°/s) may more closely match slower ramping force measurements of isometric testing. These findings should be interpreted with caution due to the low number of included studies in this review. However, our findings do support those of previous work in the area that found isometric strength to be a more frequently used measure of strength in para-sports classification.[72] A review by Hutchinson et al.[72] also highlighted how the validity and reliability of isometric testing outweigh the subjectivity and ordinal scaling of manual muscle testing. While isokinetic testing is infrequently used as part of classification systems or to monitor strength training programmes, it should not be disregarded, particularly at slower test speeds. It provides an objective, reliable testing method that can still provide important evidence and help to improve classification decisions.

Strengths and limitations

This review has a number of strengths, including a comprehensive and systematic search and the use of independent data extraction and quality assessment procedures. The review also included studies that assessed isokinetic testing, which has not been considered in previous reviews. There are also important limitations. Quality varied between studies, with many not identifying any strategies for dealing with important confounding variables such as level of impairment or the modified testing methods used. A planned meta-analysis to examine between-group differences was not possible due to the substantial clinical heterogeneity between studies.

Conclusions

Despite manual muscle testing being a standard component of many current para-sport classification systems, only one study examined manual muscle testing. Available evidence examining strength in this population is derived primarily from isometric and isokinetic testing. Our findings suggest that some strength outcomes appear similar to or lower than able-bodied athletic controls. However, the strength of some muscle groups, including at the shoulder rotators, might be higher in wheelchair sport para-athletes compared to non-athletes (both able-bodied and disabled). More research evidence is required to develop accessible, standardised strength testing methods that account for training influence, skill, or performance level. Studies should also establish normative strength values in para-sport athletes, and include more female participants and athletes with different functional impairments.

Authors' contributions

Conceptualization, B.P.; N.H.; K.F.; S.W.; SO'C.; methodology, B.P.; N.H.; K.F.; S.W.; C.A.; CJvR.; SO'C.; analysis, B.P.; N.H.; K.F.; S.W.; SO'C.; data curation, B.P.; N.H.; K.F.; S.W.; SO'C.; writing - original draft preparation, SO'C.; N.H.; writing - review and editing, B.P.; N.H.; K.F.; S.W.; C.A.; CJvR.; SO'C. All authors have read and agreed to the published version of the manuscript.

Data availability statement

The data presented in this study are available on request from the corresponding author.

Submission statement

All authors have read and agree with manuscript content. This manuscript has not been submitted elsewhere for review and publication.

Conflict of interest

The authors declare no conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.smhs.2022.07.004.

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