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Measures of impairment applicable to the classification of Paralympic athletes competing in wheelchair sports: A systematic review of validity, reliability and associations with performance

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Title: Measures of impairment applicable to the classification of Paralympic athletes competing in wheelchair sports: A systematic review of validity, reliability and associations with performance.

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Authors: Michael J. Hutchinson¹, Jamie-Lee K. Phillips², Barry S. Mason¹, Victoria L. Goosey-Tolfrey¹, Emma M. Beckman².

Author affiliations: ¹ Peter Harrison Centre for Disability Sport, School of Sport, Exercise and Health Sciences, Loughborough University, Loughborough, LE11 1SB, United Kingdom.

² School of Human Movement and Nutrition Sciences, University of Queensland, Brisbane, Queensland 4072, Australia.

Corresponding author: Dr Emma Beckman; E.Beckman@uq.edu.au; +61 7 33467904

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Abstract

A fundamental aspect of classification systems in Paralympic sport is having valid and reliable measures of impairment. However, minimal consensus exists for assessing impaired strength, coordination and range of motion. This review aimed to systematically identify measures of upper body strength, coordination and range of motion impairments that meet the requirements for use in evidence-based classification systems in wheelchair sports. Three electronic databases were searched from 2003 until August 31st 2019 for studies that assessed upper body function of participants and used a measurement tool that assessed strength, coordination or range of motion. The body of evidence for each identified measure was appraised using the Grading of Recommendations Assessment, Development and Evaluation framework. Twenty-three studies were included: ten measured strength and coordination, and six measured range of motion. There was “moderate” confidence in using isometric strength for assessing strength impairment. Tapping tasks for the assessment of coordination impairment received a “low” confidence rating. All other identified measures of coordination and range of motion impairment received a “very low” confidence rating. Several potential measures were identified for assessing upper body strength, coordination and range of motion impairments. Further research is warranted to investigate their use for classification in Paralympic wheelchair sports.

Keywords: strength, coordination, range of motion, classification, Paralympics

1 Introduction

An integral part of Paralympic sport is classification, the purpose of which is to minimise the impact of eligible impairment types on the outcome of competition [1]. Each Paralympic sport requires its own classification system, which groups athletes according to the level that their impairment impacts on performance in that particular sport. This is to ensure that characteristics such as talent, volume and quality of training, and psychological factors are the determinants of success in Paralympic sport, rather than severity of impairment [1]. Further to the need for each classification system to be sport-specific, the classification code of the International Paralympic Committee (IPC) also requires these systems to be evidence-based in all Paralympic sports [2] which means that the methods used to allocate class must be based on science that supports the system and demonstrates that the aim of classification is achieved. For the development of evidence-based classification systems, sports and researchers must: 1) specify the eligible impairment types; 2) develop valid measures of impairment; 3) develop standardised, sport-specific measures of performance; and 4) assess the strength of association between the measures of impairment and performance [3].

There are ten impairment types eligible for competition in Paralympic sports: impaired muscle power, impaired range of motion (ROM), hypertonia, ataxia, athetosis, leg length difference, limb deficiency, short stature, visual and intellectual impairment [1]. Hypertonia, ataxia and athetosis all affect motor coordination. Paralympic sports are able to specify which of the ten eligible impairment types they are to include within their classification system. Once this determination is made, a primary issue of importance for all sports is to ensure they use appropriate methods for assessing impairment. The IPC position stand on classification stipulates that methods for assessing impairment should be: objective (ratio-scaled), reliable, parsimonious, impairment-specific, sport-specific and resistant to training [3].

Examples of three Paralympic sports that are working towards evidence-based classification systems are wheelchair basketball, wheelchair rugby and wheelchair tennis. For these sports the eligible impairments are: impaired muscle power (strength impairment), impaired ROM, hypertonia, ataxia, athetosis, leg length difference and limb deficiency [4–6]. Though it is likely that function of the lower limb will contribute to sports performance, observation of the sports highlights that assessment of upper body and trunk impairment is likely to be of fundamental importance to their classification systems. Wheelchair tennis involves high velocity wheelchair propulsion and mobility, racket grip strength, powerful overhead service and a strong forehand and backhand [7,8]. Wheelchair basketball and wheelchair rugby also require high velocity wheelchair mobility performance, as well as ball handling skills such as passing, catching and dribbling. These aspects of performance will all be impacted by impairments to strength, coordination (hypertonia, ataxia and athetosis) and ROM of the upper body and trunk. This emphasises the requirement for methods of assessing these impairment types based on the varying determinants of performance in the different sports.

The need is further highlighted by investigating the existing classification systems of the sports. Current classification processes for wheelchair rugby and wheelchair tennis do include measures of impairment, however they are most often clinical measures relying on expert opinion. For example, strength impairment is currently assessed using manual muscle testing [5,6]. This method uses an ordinal scale and previous research has demonstrated unacceptable inter-rater reliability [9], making it unsuitable for use as part of an evidence-based classification system. Furthermore, no specific methods for assessing upper body coordination impairment are provided within current classification manuals [5,6] and whilst eligibility criteria exist for classifying static ROM impairment [5,6], there is no guidance for what method(s) to use, or whether dynamic tests should also be included. In contrast to wheelchair rugby and wheelchair

tennis, wheelchair basketball uses a functional classification system that assigns a sports class based on observation of an athlete's volume of action in performing fundamental activities during training and match play [4]. As such, there is no direct assessment of an athlete's level of impairment, as required by evidence-based classification. This most likely contributed to the decision of the IPC in January 2020 to deem the International Wheelchair Basketball Federation as non-compliant with the classification code and, as of June 2020, be stripped of the sport's place at the 2024 Paralympic Games [10].

In order to aid the development of evidence-based classification systems in wheelchair sports, potential methods for assessing upper body strength, coordination and ROM impairments need to first be identified. Once identified, their use as part of sport-specific classification systems can then be investigated, including by studying the association with determinants of sports performance. Therefore, the principal aim of this review was to systematically identify methods for assessing upper body (including trunk) strength, coordination and ROM impairment that could be used for the development of evidence-based classification systems in wheelchair sports. A subsequent aim was to investigate, for each identified method, the validity for it to measure impairment, the test-retest reliability and the association between impairment and sports performance.

2 Methods

This review was undertaken in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines [11]. The PRISMA checklist for this review can be found in Supplement 1. This review protocol was not registered.

2.1 Information sources

Studies were identified by searching three databases: PubMed, Web of Science and SPORTSDiscus. In addition to database searches, a manual search of personal databases and

reference lists of included studies were undertaken to identify studies and grey literature that did not appear in the databases listed above. Two key searches were used to distinguish between Para sport and non-Para sport studies for use in Paralympic classification. Two different searches were undertaken to differentiate between studies that had already been evaluated for use in Paralympic sport and studies that have been conducted in a clinical context to assess an impairment that is also eligible for wheelchair sport.

For all databases the search for Para sport was: Paralympic AND sport AND classif* AND (test OR measure OR assess) AND impairment. For non-Para sport the search strategy employed was: (ataxia OR athetosis OR hypertonia) AND (test OR measure OR assess OR analys*) AND (strength OR coordination OR range)) NOT rehabilitation.

Specific strategies were employed for each database. In PubMed “ataxia”, “athetosis” and “hypertonia” were searched as MeSH terms, whilst for Web of Science the search terms were applied to all fields. For the search in SPORTSDiscus the option to search within the full text was selected. Searches were conducted from 2003 up to 31st August 2019, based on discussions with an academic librarian.

2.2 Study eligibility

Studies that met the following criteria were included in the present review:

- Examined assessment methods of upper body (including trunk) impairment that have been tested for the use in Paralympic sport.
- Examined clinical measurements or novel tests that assess eligible impairment types for Paralympic sport: strength, coordination or ROM.
- Participants between the age of 15-55 years old ($\pm 5\%$). Age range selected to represent the competition age of a typical Paralympic athlete.

- Published as a full-text article in English, in a peer-reviewed journal.

Studies that contained no upper extremity components (i.e. examining lower extremity only); were older than 15 years; or that assessed strength, coordination or ROM in non-disabled participants unless designed to inform Paralympic classification were excluded from this review.

2.3 Eligibility screening

Two reviewers (Authors 1 & 2) conducted eligibility screening independently, with differences assessed at each stage. Consensus was reached through discussion with the corresponding author (Author 5). Studies were screened in two stages: title screening and full text screening. Titles were excluded that clearly did not meet eligibility criteria. The full texts of remaining articles were then reviewed, with reasons for exclusion recorded.

2.4 Data extraction

One reviewer (Author 2) performed the data extraction of included studies, which was checked by a second reviewer (Author 1). The following data was extracted from each study: (1) author/s and publication year (2) objective of the study (3) sample size, sex and age (4) description of the sample size (5) Measurement focus (strength, coordination or range of motion) (6) Assessment tool/technique and method of data collection (7) outcome measures (8) results. In studies examining both upper and lower body, only the information relevant to the upper body was included in the review.

2.5 Risk of bias and quality assessment

All included studies were assessed for risk of bias and quality assessment using a modified appraisal tool for cross-sectional studies (AXIS) [12], eliminating the questions not relevant to the included studies. The modified tool includes 17 questions assessing various

factors of quality and bias. The questions were answered yes, no, unclear or not reported for each study.

For each identified method of assessing strength, coordination or ROM impairment an evidence summary was produced. Subsequently, the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) framework [13] was used to assess the body of evidence for each identified method and to assign a confidence rating in the body of evidence. Evidence was assessed for i) risk of bias, ii) inconsistency, iii) imprecision, iv) indirectness and v) publication bias in accordance with published procedures [14–18], resulting in a confidence rating ranging of “very low”, “low”, “moderate” or “high” for the evidence found. The body of evidence for each method begins with an initial “high” confidence rating, with a stepwise down-grading for the existence of any of the 5 aforementioned assessment factors [13].

3 Results

3.1 Literature search

The electronic search produced 3595 records. After removing duplicates, 2916 studies remained. The title of each study was screened, and 147 potential studies were archived. After reading the full text of each study, 23 were included and 124 excluded from the review. A flow chart depicting the study selection process is shown in Figure 1.

3.2 Description of included studies

Of the 23 included studies, 10 investigated methods for assessing strength impairment [19–28], 10 coordination impairment [23,29–37] and 6 ROM impairment [25,29,38–41]. Studies investigating strength impairment had a combined sample of 382 participants, comprising 234 disabled participants (9 studies) of which 201 were Para-athletes (8 studies),

and 148 non-disabled participants (2 studies). Coordination impairment was investigated in a total of 414 participants, of which 288 were disabled (8 studies; 94 Para-athletes across 2 studies) and 126 were non-disabled (5 studies). For ROM a total of 173 participants were investigated: 110 disabled (6 studies; 94 Para-athletes across 5 studies) and 63 non-disabled (3 studies). Extracted data are presented for studies investigating strength (Table 1), coordination (Table 2) and ROM (Table 3) impairments.

3.3 Methods for measuring strength impairment

The methods identified for measuring upper body strength impairment were isometric strength, handgrip dynamometry and trunk stability, both static and dynamic (Table 1). Isometric strength using a load cell was investigated in seven studies [19–22,24,25,28], handgrip dynamometry in four [21–23,25] and trunk stability in three [20,26,27]. In terms of the type of analysis employed by studies, eight assessed the validity for it to measure impairment [19–24,26,27], three investigated the test-retest reliability of the method [21,23,24], and five investigated the association between the measure of impairment and performance [19,22,24,25,28].

3.3.1 Isometric strength

Regarding the validity of isometric testing for measuring impairment, cluster analysis of several isometric strength tests was able to produce clusters of athletes with similar levels of activity limitation in a group of wheelchair track racing athletes [22]. Similarly, random forest algorithm correctly classified 95% of Para-swimmers based on shoulder flexion and extension isometric strength [24]. Isometric strength was shown to be highly reliable (Intraclass Correlation Coefficient (ICC): 0.71-0.95 [21]; 0.94-0.97 [24]) across various upper body movements in non-disabled participants.

Measures also need to be evaluated by investigating their relationship with performance. In a study of wheelchair rugby players, isometric trunk flexion strength was shown to significantly correlate with wheelchair propulsion acceleration performance [19], whilst isometric shoulder extension strength significantly correlated with freestyle swim speed in Para-swimmers [24]. Arm extension, trunk flexion and combined arm-trunk strength also correlated with top speed in wheelchair racing propulsion across a group with different sport classes [22], however trunk flexion strength did not correlate with acceleration performance in athletes with the same classification [28].

Using the GRADE framework to assess the evidence for using isometric strength, results in a “moderate” confidence rating. There are consistent findings for the valid and reliable use of isometric strength tests across a number of different sports, whilst the evidence shows good directness as the evidence is in Para-athletes. Though the findings are consistent across sports, there are only isolated studies within each sporting example, so these results in themselves lack corroboration.

3.3.2 Handgrip dynamometry

Validity of handgrip dynamometry is demonstrated by the significant differences in handgrip strength between adjacent classes produced by cluster analysis [22]. Handgrip strength was also shown to be reliable in patients with spastic ataxia (ICC: 0.97 and 0.98; Standard error of measurement: 1.6 and 1.3 kg for right and left limb, respectively) [23]. Finally, handgrip strength was shown to correlate with absolute top speed ($r = 0.79$) in elite wheelchair racers [22] and hand release speed ($r = 0.59-0.77$) in seated throwers [25].

Applying the GRADE framework results in a “very low” confidence rating for using handgrip dynamometry. There is inconsistency due to a lack of corroborating studies assessing validity and the relationship between impairment and performance. Furthermore, there is a risk

of bias regarding the reliability as it has only been investigated in a single study [23]. This study also shows indirectness as it was in a non Para-athlete population.

3.3.3 Trunk stability

For investigations of trunk stability, static balance was not different amongst wheelchair rugby players based on an ordinal-scaled Trunk Impairment Classification system [20]. However, dynamic limits of stability during maximal trunk leaning were significantly greater in athletes with less trunk impairment [27]. Furthermore, trunk stability was greater during perturbations in sit-skiers with lower levels of trunk impairment [26]. There were no studies investigating the reliability, or association with performance, of trunk stability.

Evidence into dynamic trunk stability assessments contain a risk of bias due to small samples sizes of studies and the lack of corroborating evidence, meaning there is no consistency of results. The test-retest reliability of the method remains to be investigated also. Though there is good directness through the use of Para-athletes, overall there is “very low” GRADE confidence in the use of trunk stability assessment.

3.4 Methods for measuring coordination impairment

Methods identified for measuring upper body coordination impairment were tapping tasks, standardised finger to nose test (SFNT), Archimedes spiral, box and block test (BBT), nine-hole peg test (9HPT) and Purdue pegboard (PP) (Table 2). Tapping tasks were investigated in four studies [31,33,36,37], SFNT [23,34,35], BBT [32,34,37] and 9HPT [23,32,35] in three studies each, with the Archimedes spiral [23,30] and PP [34,35] investigated in two studies. Regarding the type of analysis, eight investigated the validity of the method for measuring impairment [23,29,30,32,34–37], six the test-retest reliability of the method [23,31–

33,36,37], and two investigated the association between the measure of impairment and performance [36,37].

3.4.1 Tapping tasks

Regarding the validity of tapping tasks for measuring impairment, random forest algorithm correctly classified 96% of either non-disabled or Para-swimmers, with reciprocal tapping task performance significantly correlating with freestyle swim speed [36]. A reciprocal vertical tapping task was also able to distinguish between adjacent sport classes in boccia players [37]. Tapping tasks were shown to be reliable in non-disabled participants [31,33,36], though reciprocal (ICC range 0.54-0.93) tapping tasks showed lower ICC compared to discrete tasks (ICC range 0.85-0.92) [31]. Furthermore, using Fitts' Law, deliberate submaximal performance, also known in the classification process as Intentional Misrepresentation (IM), could be detected using tapping tasks [33].

GRADE assessment results in a “low” confidence rating for the use of tapping tasks. Evidence for tapping tasks contain a small risk of bias due to the small sample sizes. Findings in Para-athletes are consistent, but are limited to two sports, whilst test-retest reliability has only been investigated in non-disabled participants resulting in indirectness.

3.4.2 Archimedes spiral

The assessment of a computer-based Archimedes spiral test was piloted for the first time and was found to be a valid way of measuring coordination impairment, correctly classifying 96% of patients with ataxia based on the mean error result [30]. There were no studies investigating the reliability, or association with sport performance, of the Archimedes spiral test.

GRADE assessment results in a “very low” confidence rating for the evidence on Archimedes spiral. There is a lack of evidence on the test-retest reliability, as well as the relationship between impairment and sport performance. Furthermore, there is a lack of corroborating evidence for the validity of the Archimedes spiral, whilst there is also a lack of evidence in Para-athletes.

3.4.3 Standardised finger to nose test

The SFNT showed excellent inter- (ICC range 0.90-0.98) and intra-rater reliability (ICC range 0.93-0.97) in patients with ataxia [23] whilst also being able to discriminate based on disease stage [34,35]. There were no studies investigating the relationship between SFNT and sport performance.

GRADE assessment results in a “very low” confidence rating for the use of the SFNT. Whilst there is good evidence for its reliability, this is limited to a single study. Furthermore, there is a lack of evidence in Para-athletes.

3.4.4 Box and block test

Performance on the BBT was shown to have a negative correlation with disease duration patients with Friedrich ataxia [32]. The BBT, as well as a modified version using Boccia balls instead of blocks, were also able to distinguish between non-disabled participants and Boccia athletes of different classifications [37]. There were no studies investigating the reliability, or association with sport performance, of the BBT.

There is “very low” confidence in the evidence for using the BBT. There is a lack of corroborating evidence for the validity of the test, whilst there is only a single study performed in Para-athletes [37].

3.4.5 Nine-hole peg test

9HPT was able to distinguish between disease severity [23,35] and disease duration [32] in patients with ataxia. The standard error of the measurement was found to be 6.5 s and 7.1 s for performance with the right and left hand, respectively [23]. No studies investigated the association between performance on 9HPT and sport performance.

GRADE assessment results in a “very low” confidence rating for the 9HPT. This is due to inconsistency resulting from a lack of corroborating evidence, and a lack of studies in Para-athlete groups.

3.4.6 Purdue pegboard

Performance on PP was significantly correlated ($r = 0.82$) with performance on SFNT [34]. The PP was also able to distinguish between disease severity in patients with ataxia [35]. There were no studies investigating reliability, or association with sport performance, of the PP.

GRADE assessment results in a “very low” confidence rating for the PP. This is due to inconsistency resulting from a lack of corroborating evidence, and a lack of studies in Para-athlete groups.

3.5 Methods for measuring range of motion impairment

The methods identified for measuring ROM impairment were an inclinometer, goniometer, motion capture system and video analysis (Table 3). Inclinometer and goniometer were used in a single study [40], motion capture was used in four studies [25,29,38,41], and video analysis in one study [39]. Five studies investigated the ability of the method to measure impairment [29,38–41], a single study investigated the test-retest reliability of the method [40], and two studies investigated the association between impairment and performance [38,41].

3.5.1 Inclinator and goniometer

Elbow flexion and extension, as well as shoulder internal and external rotation were able to distinguish non-disabled from Para-swimmers [40]. Reliability for measuring upper extremity ROM in non-disabled participants was shown to be good to excellent and slightly better for inter-rater reliability when using an inclinometer (ICC range 0.75-0.90) compared to goniometer (ICC range 0.67-0.79) [40]. No studies investigated the association between ROM impairment measured using an inclinometer or goniometer and sport performance.

There is “very low” confidence in the evidence for the use of an inclinometer or goniometer. There is a risk of bias due to small sample sizes, whilst there is also inconsistency due to the small number of included studies. Though there is evidence in Para-athletes, this is limited to a small number of sports.

3.5.2 Motion capture

Kinematic analysis when using a motion capture system showed that trunk flexion and trunk/pelvis rotation was significantly different between non-disabled and Para-kayak athletes with increasing levels of impairment, whilst these variables also correlated with power output when paddling [38]. Trunk inclination and elbow flexion were also shown to be significantly different between boccia players of different classification [41]. There was also a moderate positive correlation ($r = 0.53$) between elbow extension ROM and ball release speed in boccia players [41].

GRADE assessment results in a “very low” confidence rating for the use of motion capture systems. Studies have a small sample size whilst there is limited corroborating evidence. Though studies are in Para-athlete populations, the number of sports studied is limited.

3.5.3 Video analysis

It was found that trunk ROM was significantly greater in wheelchair fencing athletes with less impairment during maximal lunge and fast-return actions [39]. However, no studies investigated the reliability of measuring ROM via video analysis, or the association between ROM from video analysis and sport performance.

GRADE assessment results in a “very low” confidence rating for using video analysis. There is a risk of bias due to the small sample size of the study, whilst there is no corroborating evidence. There is also no evidence as to the test-retest reliability of the method for measuring impairment, or investigations into the relationship between impairment and sport performance using this method.

3.6 Risk of bias and quality assessment within studies

The risk of bias and quality assessment of the fourteen included studies according to the modified AXIS tool is shown in Table 4. All studies demonstrated minimal risk of bias using appropriate research designs, participant selection and recruitment. However, only two studies, one of which was included twice as it investigated coordination and ROM, provided a power calculation to justify their sample size [21,29].

4 Discussion

To develop evidence-based classification systems, identifying methods of measuring impairment is necessary in formulating a test battery [42]. These methods subsequently need to be investigated for their validity in measuring impairment, test-retest reliability, and association with performance. The literature base for Paralympic classification is limited. This makes it difficult to draw clear conclusions about how measures of impairment trialled for use in other sports may be adapted for sports such as wheelchair basketball, wheelchair rugby and

wheelchair tennis. Despite this, all Paralympic classification protocols should abide by the same policies and procedures governing the use of evidence-based classification protocols. Therefore, the current base of evidence-based studies in addition to other clinical tests of impairment can aid in formulating improved classification protocols for wheelchair sports; ultimately leading to additional evidence-based research relevant to Paralympic sport.

4.1 Measures of strength impairment

In terms of methods for measuring strength impairment, this review found isometric strength to be the most commonly reported measure. Current practices utilise manual muscle testing [5,6] however, the validity and reliability for measures of isometric strength across all included studies far outweighs the subjectivity and ordinal scaling of manual muscle testing. Recent literature has also demonstrated that isometric strength provides the best measure of voluntary maximal contractile strength and is more resistant to training when compared to isokinetic and isotonic testing [9]. This is an important factor to consider when the goal is to measure impairment as part of an evidence-based classification system.

Examination of isometric strength protocols on non-disabled athletes demonstrated good to excellent test-retest reliability, an important feature of testing to permit further investigation in Para-athletes [21]. Overall, isometric strength showed strong correlations with activity limitation and acceptable reliability across the included studies (Table 1). Low to moderate correlations found between swim speed and isometric strength in Paralympic swimmers highlights the importance of accounting for all joints involved in swimming, as upon reflection, key strength measures relevant to swimming were missed in the isometric test battery [24]. A possible explanation for these findings could be due to the fact that only a single-joint measurement of strength was conducted. A better method would be to use multi-joint measures in order to account for a greater amount of the variance in sports performance [9].

A study involving both single and multi-joint strength measures was able to produce valid wheelchair racing class structures, using cluster analysis techniques [22]. However, though isolated arm (dominant and non-dominant) and trunk flexion strength ($r = 0.54$, $p < 0.05$) significantly correlated with top speed during wheelchair propulsion, combining arm push with trunk flexion led to a stronger relationship ($r = 0.73$, $p < 0.05$) than the isolated trunk strength measure [22]. Furthermore, isolated trunk flexion strength was only significantly greater in Cluster 4 compared to Clusters 1-3, whereas combined arm-trunk strength was significantly different between each cluster [22]. Due to the multi-joint nature of wheelchair racing propulsion performance, the combination of arm extension with trunk flexion likely contributed to the heterogeneity of the classes produced, due to the greater complexity of strength analysis. Despite this, overlap in clusters was still observed between strength and activity limitation, highlighting the complex nature of classification. Further studies will be required to assess what joint combinations best reflect activity limitation in wheelchair sports when measuring isometric strength with a load cell. This is because wheelchair racing simply requires forward propulsion, but the multidirectional nature of wheelchair court sports also require braking and backwards propulsion manoeuvres.

Attention also must be given to the joint positions used for the measurement of isometric strength [1]. In Para-swimmers shoulder extension strength showed a moderate correlation with freestyle swim speed, with strength assessed in the joint position corresponding to the start of the underwater pull-phase [24]. Within wheelchair sports, actions can occur in a range of different joint positions. For example, in wheelchair tennis the position of the shoulder will be different for service and forehand strokes, as well as for wheelchair propulsion. Research will need to consider the actions that contribute to wheelchair sports performance and the positions that these occur in for future investigations assessing strength impairment in wheelchair sport.

Along with measures of isometric strength of specific joint movements, grip strength was also identified as a method for measuring strength impairment [21,23,25]. Grip strength was found to have one of the strongest correlations with hand speed release in seated throwing sports [25], and was a valuable measurement of strength in combination with pronation measured by a load cell [22]. Grip strength is especially important in wheelchair tennis for both racket grip and wheelchair push grip, thus, is likely to be a useful form of strength measurement for this sport. The inclusion of combining grip strength with pronation/supination strength is related to racket control and should be further explored.

Measurement of static and dynamic trunk stability was a further measure of strength impairment utilised in the existing literature, though is also a term that has been used extensively in relation to the assessment of ROM and balance. Dynamic trunk control was shown to be suitable for identifying wheelchair rugby [20,27] and sit-ski [26] athletes with different levels of trunk strength. Dynamic trunk control would conceivably be advantageous for ball handling performance in wheelchair basketball, particularly if involving collisions with opponents, whilst also contributing to force generation during ball striking in wheelchair tennis. Therefore, it would be of interest to investigate this further in these sports. However, the methods including force platforms and three-dimensional kinematic analysis may not be the most practical for use in classification. Nevertheless, the assessment of trunk impairment will likely be a key feature for many Paralympic sports, and it will be important that future research identifies the specific impairment that they are addressing with each test, be it strength, coordination, ROM.

4.2 Measures of coordination impairment

Though methods for assessing athlete's with strength impairment are advised upon, current classification measures of coordination impairment are not clearly defined in the

classification manuals of wheelchair sports [4–6]. Several tests, such as the finger to nose, fast elbow flexion/extension and fast forearm supination/pronation are ‘suggested’ [6]. These tests can provide visual information about incoordination; however, the missing element of ratio scaling and the apparent freedom of test choice does not meet the standards of Paralympic classification [1].

The use of instrumented tapping tasks is a newly established way of resolving this issue for Paralympic classification. These tests produce ratio scaled measures that allow the determination of how much impairment severity impacts on performance. Indeed, the validity and reliability of various tapping tasks have been widely documented [31,33,36,37], though reliability was better for tasks with a larger target area (0.12 versus 0.05 m) [31]. Further research needs to investigate tapping tasks in larger samples of Para-athletes and to investigate the association of tapping task performance with measures of sports performance. Incorporating sport-specific tapping tests also needs to be considered. Wheelchair propulsion is a repetitive action requiring repeated coordination of shoulder, elbow and wrist movements, meaning reciprocal tapping tasks may be most appropriate for use. Conversely, actions such as ball striking in wheelchair tennis, passing in wheelchair rugby and shooting in wheelchair basketball consist of a single coordinated movement, so may be better represented by a discrete tapping task. Such an approach was used in designing tapping tasks for use in Para-athletics, with various reciprocal tasks classed as “wheelchair specific” and discrete tasks as “throwing specific” [31]. Furthermore, in wheelchair tennis both unilateral (dominant/racket hand) and bilateral coordination is important for racket control and wheelchair propulsion respectively. In Para-swimmers unilateral tapping (dominant and non-dominant limb), but not bilateral upper limb tapping, significantly correlated with maximal freestyle swim speed [36]. This was found despite the apparent greater similarity with freestyle swimming of the bilateral tapping task, and could have been due to differences in technique used [36], an aspect that must therefore be

considered for future investigations. This study also showed that dominant limb tasks showed greater reliability and correlation with freestyle swim speed than non-dominant tasks [36]. In the context of swimming, it is proposed that this result could be due to compensation from the dominant limb during the freestyle action if it is significantly less impaired than the non-dominant limb [36]. The use of tapping tasks are yet to be researched within the context of evidence-based classification for wheelchair sports, however existing findings in other Paralympic sports demonstrate their potential. They also highlight how researchers will need to consider factors such as: target size; reciprocal and/or discrete movements; unilateral and/or bilateral movements and dominant and/or non-dominant limb use when developing tests. These will need to be applied on a sport-specific basis through considering the key determinants of performance in each sport.

Emerging evidence also supports that tapping tasks are sensitive to be able to detect IM in classification [33]. IM is when an athlete deliberately underperforms during classification in order to be placed in a sports class alongside athletes with a greater level of impairment than they actually possess [3]. The difficulty of a tapping task can be calculated by factoring the size of, and the distance between, the two targets [43]. Fitts' Law then states i) that as difficulty increases there is a linear increase in the movement time between the two targets, and ii) that for tasks of equal difficulty, but different combinations of target size and distance between targets, movement times should be equal [43]. Subsequently, conformity with Fitts' Law during a tapping task would satisfy the requirement of maximal performance, with IM being detected if these conditions were not met [33]. Submaximal performance, mimicking IM, could be detected in non-disabled participants during tapping tasks. Such a study needs to be performed in Para-athletes with impaired coordination to investigate if Fitts' Law can be applied for the purpose of detecting IM during classification. Indeed, future research on any method for

assessing impairment needs to consider the extent to which it may be susceptible to IM and what tools may be available in order to aid detection.

Further to the use of instrumented tapping tasks, the development of a computer-based, objective Archimedes spiral test could also be promising for the future of Paralympic coordination classification. This test, which produces mean spiral tracing error demonstrated significant differences between Para-swimmers and non-disabled participants, of which 96% were correctly classified [30]. The paper and pen version of the test relies on calculating maximum error by manual measurement. The ability to calculate mean error electronically and the elimination of pen grasp strength warrants further investigation into the possibility of using this test in Paralympic classification.

Despite these findings regarding instrumented tasks, there may still be a place for clinical tests such as the SFNT for use in sports classification. The SFNT is a reputable test and has shown excellent validity and inter- and intra-rater reliability for the purpose of discriminating between ataxia impairment severity [23]. This test may be more applicable to wheelchair tennis as aiming for the finger of the tester has similarities with aiming for a tennis ball, a small object, with a racket. The reliability of the 9HPT is unclear, with concerns that the greater the impairment of an individual, the less chance this test could be repeated reliably on another occasion [23,32]. Additionally, not all participants could complete the test due to difficulty, which poses another problem for those with higher severity of impairment.

4.3 Measures of range of motion impairment

ROM is traditionally measured with either an inclinometer or goniometer. In existing classification systems, passive ROM is measured using a goniometer and/or video evidence [6]. The use of an inclinometer in a group of Paralympic swimmers with hypertonia and impaired muscle power showed good to excellent intra and inter-rater reliability which

exceeded the reliability of using a goniometer [40]. This study also used active ROM measurement in contrast to passive ROM. As an athlete must actively move their body through range during competition, active ROM is likely to be a better indicator of resultant activity limitation. This was the only study found that directly examined ROM measurement. An alternate method of measuring ROM using motion capture appeared in four studies [25,29,38,41]. Though the specific aims of these studies were not to measure ROM impairment, motion capture was shown to be able to detect differences in ROM between Boccia sport classes during performance [41], as well as non-disabled kayak athletes and Para-kayakers with different sport classes [38]. To the best of our knowledge, the validity and reliability of the use of this type of technology has not been tested for use in Paralympic classification. Given that classification typically occurs away from a laboratory at sporting events, it could be that using motion capture is not a feasible method for classification purposes. However, it still warrants investigation as a method for classifying ROM impairment. This is because if it is shown to be superior to other methods for this purpose, then it may be that existing logistical practices for classifying athletes need to be reconsidered. As such, future studies should determine whether 3D kinematic analysis is a practical way of classifying ROM impairment in Paralympic athletes. Future research could also investigate the validity of devices such as inertial measurement units, against 3D motion analysis systems, as these portable, less expensive devices could also serve as a more practical solution for ROM classification.

4.4 Limitations

The tight inclusion and exclusion criteria used in this study may have eliminated useful and informative studies from the review. This is especially true of the age range and clinical status of individuals. However, it is also important to acknowledge that without these strict criteria, the amount of studies would have been boundless. This is due to the amount of studies

focusing on the assessment of the impairment types in healthy individuals, as well as individuals aged under 15 or over 55 years. Our best efforts were made to identify databases and search terms relevant to the subject matter, however, it is possible that studies may have been found in other databases not searched. The addition, elimination or rewording of the search terms may also have identified a greater number of studies.

4.5 Future recommendations for research

Alongside the results and conclusions of this systematic review, we feel that the following recommendations can help guide future research into measures of impairment in Paralympic Sport:

- Increased focus on investigating populations of interest (i.e. Para-athletes) and minimising the reliance on using non-disabled participants.
- Investigation of the test-retest reliability of measures of impairment in Para-athletes.
- Greater number of investigations into the relationship between measures of impairment and sports performance.
- Consideration of how susceptible measures of impairment may be to IM, as well as how IM could be detected with each method of measuring impairment.
- Consideration of how a method of measuring impairment could be practically implemented as part of a classification system.
- Consideration of impairment and health condition specific contexts such as how elements such as fatigue, training and outdoor environments may affects classification methods.

554 **5 Conclusion**

555 Twenty-three studies investigating methods for measuring strength, coordination and
556 ROM impairment as part of evidence-based classification were found. Across all methods,
557 other than isometric strength for which there was “moderate” support, there was “very low”
558 confidence in the evidence for their use in evidence-based classification. That said,
559 instrumented tapping tasks and computerised Archimedes spiral for measuring coordination
560 impairment and using an inclinometer for measuring ROM impairment show promising results
561 and warrant further investigation. Future research should investigate the identified methods
562 with the aim of developing sport-specific, evidence-based classification systems in wheelchair
563 basketball, wheelchair rugby and wheelchair tennis.

564 **Disclosure statement**

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693 **Figure captions**

694 Figure 1: Flow diagram of studies through the eligibility screening process.

Table 1: Data extracted from the eligible studies regarding strength impairment.

Authors	Objective	Sample size	Population	Assessment tool	Outcome measures	Results
Para sport studies						
Altmann et al. 2016	To assess validity of Trunk Impairment Classification system in wheelchair rugby.	N = 34 (sex unspecified, 18-59 years)	1+ year experience in wheelchair basketball or wheelchair rugby, playing at national or international level.	<p><i>Static balance:</i> Sat on a chair, placed on force platform. Instructed to sit as still as possible for 30 s on i) stable surface (5cm foam cushion) and ii) unstable surface (inflated cushion so buttocks 2 cm raised).</p> <p><i>Dynamic balance:</i> In same position as static balance and sitting on foam cushion. Maximal trunk inclination posterior-anterior; left-right lateral, 90° from sagittal plane; right forward-left backward and left forward-right backward, 45° from sagittal plane.</p> <p><i>Isometric trunk strength:</i> on plinth in harness attached to load cell. Tested forward, left and right.</p>	<p><i>Static balance:</i> Sway area in mm². Defined as the ellipse around the total area of the recorded centre of pressure during the 30 s trial, containing 95% of the sampled positions.</p> <p><i>Dynamic balance:</i> Excursion of the centre of pressure displacement in mm. Pressure coordinates used to calculate maximum and minimum centre of pressure with excursion the difference between the two.</p> <p><i>Isometric strength:</i> Force in Newtons.</p>	<p><i>Static balance:</i> No main effect of Trunk Impairment Classification on sway area in i) stable (p = 0.528) or ii) unstable conditions (p = 0.236).</p> <p><i>Dynamic balance:</i> Main effect of Trunk Impairment Classification on left forward-right backwards excursion (p = 0.12). Larger excursion in 1.5 compared with 0.5 and 1.0.</p> <p><i>Isometric strength:</i> Main effect of classification in all directions (p < 0.001). Left lateral strength greater in 1.0 and 1.5 than 0. Right and forward strength greater in 0.5, 1.0 and 1.5 compared to 0.</p>
Altmann et al. 2018	Assess relationship between trunk strength and activity limitation in wheelchair rugby.	N = 27 (all male, 37.4 ± 10.2 years)	1+ year experience in wheelchair basketball or wheelchair rugby, playing at national or international level.	<p><i>IMPAIRMENT:</i> <i>Isometric trunk strength:</i> On plinth in harness attached to load cell. Tested forward, left and right.</p> <p><i>ACTIVITY LIMITATION:</i> <i>Tilt test:</i> 1 rear wheel fixed to ground, aim to lift other rear wheel off ground as much as possible.</p> <p><i>Acceleration:</i> Maximally accelerate from standstill. Time recorded to push 1 m.</p> <p><i>Sprint momentum:</i> Using the results of the acceleration test, calculate the impulse with which an athlete can hit an opponent.</p>	<p><i>Isometric trunk strength:</i> Force in Newtons.</p> <p><i>Tilt test:</i> Difference in initial (H0) and maximal (H1) height reached, in mm.</p> <p><i>Acceleration:</i> Time in seconds.</p> <p><i>Sprint momentum:</i> Body mass multiplied by the average velocity over the first 2 m (kg·m·s⁻¹).</p>	<p><i>Lateral trunk strength and tilt test:</i> r = 0.50, p = 0.007 between mean L/R force and mean L/R tilt.</p> <p>Significant increase in tilt height from Cluster 1 to 2 and 3. No difference between Cluster 2 and 3.</p> <p><i>Forward trunk strength and acceleration:</i> r = 0.59, p = 0.001 between forward trunk force and 1 m acceleration.</p> <p><i>Forward trunk strength and sprint momentum:</i> r = 0.79, p = 0.0001 between forward trunk force and sprint momentum.</p> <p>Differences between Clusters: 1 < 3, 4; 2 < 3.</p>
Beckman et al. 2014	i) to establish normative	N = 118 (63 males, 55	Regularly active, non-disabled	<i>Isometric strength:</i> Grip strength was assessed using a	Grip strength was measured in kg and converted to Newtons.	Males were significantly stronger than females in all measures.

	performance in nondisabled participants, ii) to evaluate the reliability of isometric performance, iii) to assess the relationship between strength and body mass.	females; 23.2 ± 3.7 years).	participants.	<p>dynamometer in a seated position with elbow flexed at 90°.</p> <p>Uni- and bilateral arm push with a supporting backrest performed using a load cell. Shoulder at 90° abduction, 45° shoulder flexion, 120° elbow extension.</p> <p>Unsupported dominant arm push pull in same position as above.</p>	Isometric force was measured in Newtons.	<p>There was no significant difference between dominant and non-dominant sides.</p> <p>ICCs for test-retest reliability ranged from 0.71-0.95; absolute difference ranged from 3.7-51.0 N (0.2-7.3%); standard error of measurement ranged from 18.1-117.4 N.</p> <p>For males all measures significantly correlated with body mass (r = 0.43-0.51). In females only grip strength significantly correlated with body mass (r = 0.33).</p>
Connick et al. 2018	To investigate if isometric strength testing was valid for classifying wheelchair racing athletes.	N = 32 (all male; 32.2 ± 9.0 years).	International level wheelchair racing athletes (T51, n = 5; T52, n = 6; T53, n = 7; T54, n = 14).	<p><i>IMPAIRMENT:</i></p> <p><i>Isometric strength:</i></p> <p>Using a load cell. Participants were seated in the testing rig with legs and pelvis strapped.</p> <p>i) Arm extension with 90° shoulder abduction, 45° horizontal shoulder flexion and 120° elbow extension.</p> <p>ii) Arm extension and trunk flexion with 30° trunk flexion and the same arm position as previously used.</p> <p>iii) Isolated trunk strength with 45° trunk flexion.</p> <p>iv) Combined pronation and grip strength with elbow at 90° flexion and shoulder neutral in sagittal plane.</p> <p><i>PERFORMANCE</i></p> <p><i>Top speed:</i></p> <p>From a maximal 15 m sprint from stationary position; and an absolute top speed in the finishing straight after accelerating from 150 m from the finish line.</p>	<p><i>Isometric strength:</i></p> <p>Force measured in Newtons.</p> <p><i>Top speed:</i></p> <p>Measured in m·s⁻¹.</p>	<p>Significant correlation between all strength measures and 0-15 m top speed (r = 0.54-0.83) and absolute top speed (r = 0.61-0.88). Weakest correlation was with isolated trunk strength, and strongest correlation was for the dominant arm extension.</p> <p>Cluster analysis produced 4 clusters. Significant difference in all strength measures between adjacent clusters, except for isolated trunk strength which only differed between Cluster 4 and other clusters.</p> <p>Top speed (absolute and 10-15 m) were significantly different between Clusters 1 and 2, and Clusters 2 and 3. Absolute top speed was significantly faster in Cluster 4 versus 3.</p>
Hogarth et al. 2019	To investigate isometric strength tests for use in classification for Para-swimming	N = 72 (41 male, 31 female). Hypertonia: n	i) Para-swimmers who had a national or international classification and	<p><i>IMPAIRMENT</i></p> <p><i>Isometric strength:</i></p> <p>Using load cell. Participants were seated with hip, knee and ankle at 90° and trunk strapped. Tests were performed on</p>	<p><i>Isometric strength:</i></p> <p>Force measured in Newtons.</p> <p><i>Maximal swim speed:</i></p> <p>Speed measured in m·s⁻¹.</p>	<p><i>Validity:</i></p> <p>Non-disabled males were significantly stronger than male Para-swimmers for shoulder flexion and extension on both limbs.</p>

		<p>= 23 (17 male, 26.5 ± 7.0 years; 6 female, 19.8 ± 4.1 years).</p> <p>Impaired muscle power: n = 19 (9 male, 31.5 ± 7.7 years; 10 female, 29.9 ± 10.2 years).</p> <p>Non-disabled: n = 30 (15 male, 23.5 ± 4.1 years; 15 female, 23.3 ± 4.5 years).</p>	<p>were undertaking planned training regimes and competing at a national or international level.</p> <p>ii) Non-disabled participants who were healthy and recreationally active.</p>	<p>both limbs.</p> <p>Shoulder extension with the wrist at shoulder height, in 90° shoulder flexion and neutral elbow, palm facing downwards.</p> <p>Shoulder flexion with the palm facing forwards, elbow and shoulder in a neutral position.</p> <p><i>PERFORMANCE (Para-swimmers only)</i> <i>Maximal swim speed:</i> Using the freestyle stroke, participants accelerated to maximal speed, maintained it for a 10 m period between 2 video cameras.</p>	<p>Non-disabled females were significantly stronger than female Para-swimmers for all strength measures other than shoulder flexion on the non-dominant side.</p> <p>Random forest algorithm successfully classified 25/26 male and 15/16 female Para-swimmers.</p> <p>For the entire cohort of Para-swimmers, shoulder extension for dominant (r = 0.53, p < 0.01) and non-dominant (r = 0.47, p < 0.01) and shoulder flexion for dominant (r = 0.38, p < 0.05) limbs significantly correlated with maximal swim speed. Non-dominant shoulder flexion (r = 0.15, p = 0.35) did not significantly correlate with maximal swim speed.</p> <p><i>Reliability (non-disabled only):</i> ICC ranged from 0.94-0.97, coefficient of variation from 6.8-8.5% and standard error of measurement from 8.6-12.9 N for all strength measures.</p>	
Hyde et al. 2017	To examine how assistive pole and strength impacted seated throwing performance.	N = 10 (8 male, 2 females; 32 ± 10 years).	Athletes with spinal cord injury (C6-L1). All participants were eligible for classification in Paralympic seated throwing, but participated in either seated throwing, wheelchair basketball or wheelchair rugby.	<p><i>Isometric strength test:</i> Grip strength using a handheld dynamometer on both limbs with a neutral shoulder and 90° elbow flexion.</p> <p>Upper limb strength using a load cell: Throwing-arm push test performed in a chair with hips and knees at 90° and strapped; 90° shoulder flexion, 45° horizontal shoulder flexion and 120° elbow extension.</p> <p>Push/pull synergy test performed in the same position, but without the strapping and non-dominant hand gripping the assistive pole.</p> <p>Trunk flexion performed at 45° trunk flexion and 120° elbow extension.</p>	<p>Grip strength was measured in kg.</p> <p>Upper limb and trunk strength were measured in Newtons.</p>	<p>Grip strength (r = 0.59-0.77) and push/pull synergy (r = 0.81 & 0.84) significantly correlated with hand release speed during throwing with and without the assistive pole.</p> <p>Correlation between hand release speed with throwing arm push (r = 0.01 & 0.31) and trunk flexion (r = 0.50 & 0.58) strength were not significantly correlated.</p>
Rosso et al. 2019	To examine the use of a perturbation	N = 15 (10 male, 5 female; 30 ± 6	Elite Paralympic cross-country sit-skiers.	The participant's sit-ski was fixed to a movable plate (0.94 x 0.84 m) positioned on 1.4 m long parallel tracks.	<p><i>Temporal variables:</i> i) delay between onset of sledge acceleration and acromion marker</p>	k-mean cluster analysis divided athletes into 2 clusters: high and low impact of impairment.

	device to quantify trunk stability in sit-skiers.	years).		<p>Participants sat in their sit-ski with strapping as used for a competition and were exposed to 12 unpredictable perturbations (6 forward, 6 backward; maximum acceleration $2.5 \text{ m}\cdot\text{s}^{-2}$; maximum velocity $0.5 \text{ m}\cdot\text{s}^{-1}$) with random intervals in between. Participants were instructed to keep upper limbs in a neutral position and maintain trunk stability as much as possible.</p> <p>Motion analysis system captured trunk angle as the angle between the vertical line from the hip marker and the line between the hip and acromion markers.</p>	<p>acceleration.</p> <p>ii) delay between onset of acromion marker acceleration and trunk inverting of the movement.</p> <p><i>Kinematic variables:</i> Trunk angle in degrees at i) rest before the stimulus, ii) 150 ms after the onset of acromion marker acceleration and iii) when the trunk inverted the movement.</p> <p>Range of motion in degrees was calculated between i) and ii), and i) and iii).</p>	<p>Delay in onset of the trunk inverting the movement was significantly longer for those with high impact of impairment for forward ($p = 0.003$) and backward ($p = 0.01$) perturbations. There was no difference between clusters for onset of acromion marker acceleration.</p> <p>The cluster with high impact of impairment had greater trunk extension at rest ($p = 0.006$) and trunk range of motion at the point of the trunk inverting the movement ($p = 0.004$) compared to the cluster with low impact of impairment.</p>
Santos et al. 2017	To investigate if playing experience and wheelchair rugby classification impact on trunk stability.	<p>N = 28 (all male)</p> <p>International level: $n = 19$, 29 ± 4 years.</p> <p>National level: $n = 9$, 34 ± 6 years.</p>	Wheelchair rugby players competing at either a national or international level within the past year.	<p>Participants sat on a force platform (100 Hz) mounted on a wooden block with feet unsupported and 75% of thigh length (greater trochanter to lateral epicondyle of femur) in contact with the platform.</p> <p>Computer screen (1024 x 768 pixels) 1.2 m in front of the participant displayed the direction participants were required to lean as far as possible and then return to the starting position. There were 8 directions separated by 45° and participants performed each lean three times continuously at a self-selected speed.</p>	<p>Centre of pressure coordinates were calculated from the force platform for each trial and converted to a radial distance's time series.</p> <p>Maximum amplitude in radial distance time series and associated centre of pressure coordinates were calculated. Maximum centre of pressure coordinates were used to adjust a 68% confidence ellipse, of which the area was calculated.</p> <p>Base of support was calculated as the product of 75% thigh length and distance between right and left greater trochanters.</p> <p>Limits of stability were then calculated as the centre of pressure ellipse area as a percentage of the base of support, which were then log transformed.</p>	<p>There was no significant difference ($p = 0.744$) in the limits of stability between national and international level players.</p> <p>Limits of stability were significantly greater ($p = 0.035$) in high versus low point players, but could not distinguish between low and mid point ($p = 0.194$) or mid and high point ($p = 0.505$) players.</p>
Vanlandewijck et al. 2011	To investigate the association between trunk strength and racing wheelchair	N = 13 (10 male, 3 female; 26 ± 7 years).	International level wheelchair racing track athletes.	<p><i>IMPAIRMENT:</i> <i>Isometric strength:</i> Using a load cell positioned at shoulder height in front of the sternum, participants were assessed for maximal</p>	<p><i>Isometric strength:</i> Force measured in Newtons.</p> <p>Relative trunk strength was calculated as the ratio of trunk</p>	Relative trunk strength was significantly greater in participants with full trunk function ($p = 0.02$) compared to those with partial trunk function. Maximum arm and trunk force were not significantly different

propulsion.	arm and trunk strength. Pelvis, and thigh straps were used for both tests as well as a trunk strap for the arm test.	strength to arm strength.	between groups.
	Arm isometric strength with the fingers on the inside of the load cell, elbows at 60° flexion in the sagittal plane, with humeri internally rotated and forearms pronated. The trunk was supported against a backrest.	<i>Wheelchair acceleration:</i> Distance (m) covered at 1, 2 and 3 s.	There was no significant difference in the distance covered at any time interval on either the track or ergometer between those with full trunk function and those with partial trunk function.
	Trunk strength was assessed in 30° trunk flexion with the arms in the same position as for the arm test.		Correlation between trunk strength and acceleration on the track was low (r = 0.27-0.32) and nonsignificant.
	<i>PERFORMANCE:</i> <i>Wheelchair acceleration:</i> Performed on a track in the participant's own chair using a Cheetah LMT system. Participants performed three, maximal 15 m sprints.		
	Performed on an ergometer (radius 0.09 m) against a resistance equal to 4 times that off the track, calculated from a coast down trial on the track.		

Non-Para sport studies

Gagnon et al. 2018	To examine validity and reliability of measures of coordination and strength in spastic ataxia.	N = 33 (15 male, 18 female; 40.0 ± 11.0 years).	Patients confirmed with autosomal recessive spastic ataxia of Charlevoix-Saguenay.	<i>Grip strength:</i> Using a handheld dynamometer and both limbs.	Strength measured in kg.	<i>Inter-rater reliability:</i> ICC was 0.97 and 0.98, and standard error of measurement 1.6 and 1.3 kg, for right and left limb, respectively. <i>Validity:</i> Males were significantly stronger than females (p < 0.001). Grip strength could not discriminate between disease stage (p > 0.629) or age group (p > 0.123).
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Table 2: Data extracted from the eligible studies regarding coordination impairment.

Authors	Objective	Sample size	Population	Assessment tool	Outcome measures	Results
Para sport studies						
Connick et al. 2016	To develop normative values and test-retest reliability of measures of coordination.	N = 20 (10 male, 10 female; 20 ± 1 years)	Non-disabled individuals who regularly participated in sport or physical activity at least 3 times a week.	<p>Musclelab data synchronisation unit with four printed circuit boards were used. Participants wore conductive copper tape on the palmar surface of the index finger to carry out the tasks. Each was performed for 15 s.</p> <p><i>Reciprocal tapping tasks (Wheelchair specific):</i> i) unilateral with 0.05 m target, circuit boards placed 0.303 m apart; ii) unilateral with 0.12 m target, circuit boards next to each other; iii) bilateral tapping with 0.12 m target, boards placed next to each other; iv) bilateral pronation and supination with 0.12 m target and 0.07 m vertical distance between circuit boards.</p> <p><i>Discrete tapping tasks (Throwing specific):</i> Horizontal and vertical tapping with 0.05 and 0.12 m targets. Distance between circuit boards was 0.303 m.</p>	For each task the mean movement time was calculated in seconds.	<p><i>Reciprocal tasks:</i> Participants were significantly faster ($p = 0.003$) in the second visit for the unilateral task with 0.05 m target on the dominant side.</p> <p>ICC from repeat visits ranged from 0.54-0.93. Lowest ICC was for unilateral task with 0.05 m target (0.54) on the non-dominant side, for all other tasks ICC was greater than 0.74.</p> <p>Standard error of measurement ranged from 0.006-0.021 s.</p> <p><i>Discrete tasks:</i> ICC ranged from 0.85-0.92.</p> <p>Standard error of measurement ranged from 0.010-0.015 s.</p>
Deuble et al. 2016	To investigate if Fitts' Law could detect submaximal performance during tapping tasks.	N = 10 (5 male, 5 female; 24 ± 4 years).	Non-disabled individuals who regularly participated in sport or physical activity at least 3 times a week.	<p>Tapping tasks were performed using pairs of custom-made 17.5x12 cm fiberglass printed circuit boards. One the four pairs of boards the targets were 2.5, 5, 7.5 and 10 cm wide. Boards were connected to a Musclelab unit sampling at 100 Hz.</p> <p>Participants sat on a stool at a 72.5 cm high bench with feet on a 7.5 cm high footrest. Participants completed 14 trials in 7 different conditions on 3 occasions:</p> <p>i) Index of difficulty (ID) = 3; 10 cm wide plate with 40.1 cm gap between. ii) ID = 4.01; 7.5 cm wide plate with 60.6 cm gap.</p>	<p>The number of taps in 15 s was recorded for each trial. This was then used to calculate the mean movement time (s).</p> <p>During each trial, for each individual the R^2 was calculated for the fastest mean movement time of each of the 7 IDs, for both maximal and submaximal efforts.</p> <p>For the 4 equal IDs, the difference between the fastest and slowest mean movement time was calculated for maximal and submaximal trials.</p>	<p>The R^2 score was significantly greater in maximal trials compared to submaximal trials ($p < 0.001$).</p> <p>The difference between fastest and slowest mean movement time was significantly greater in submaximal compared to maximal trials ($p = 0.021$).</p> <p>In maximal trials there was no change in the R^2 value ($p = 0.537$) or difference between fastest and slowest times in the four equal IDs ($p = 0.767$) across repeat trials.</p>

				<p>iii) ID = 4.6; 2.5 cm wide plate with 30.4 cm gap.</p> <p>iv) ID = 3.6a; 10 cm wide plate with 60.6 cm gap.</p> <p>v) ID = 3.6b; 7.5 cm wide plate with 45.4 cm gap.</p> <p>vi) ID = 3.6c; 5 cm wide plate with 30.4 cm gap.</p> <p>vii) ID = 3.6d; 2.5 cm wide plate with 15.2 cm gap.</p> <p>Participants completed each task in a randomised order with maximal effort and then submaximal effort at least 20% slower.</p>		
Hogarth et al. 2019	To examine validity of coordination tasks in Para-swimmers with brain injury.	<p>N = 51</p> <p>Para-swimmers: n = 21 (16 male, 28 ± 7 years; 5 female, 20. ± 5 years).</p> <p>Non-disabled: n = 30 (15 male, 24 ± 4 years; 15 female, 23 ± 5 years).</p>	<p>i) Para-swimmers who had a national or international classification and were undertaking planned training regimes and competing at a national or international level.</p> <p>ii) Non-disabled participants who were healthy and recreationally active.</p>	<p><i>IMPAIRMENT:</i></p> <p>Tapping tasks used custom-made wireless pads with a 0.195x0.10 m target. Pad centres were placed 0.195 m apart. Trials were 15 s. Bilateral tapping was performed with the arms extended and hand in a fist with index finger extended. Participants alternately tapped the target on the two pads with right and left fingers as quickly and accurately as possible.</p> <p>Unilateral tapping with dominant and dominant hand was performed with the pads in the same position as for the bilateral task. Participants used one hand to alternate tapping between the two pads as quickly and accurately as possible.</p> <p><i>PERFORMANCE (Para-swimmers only)</i></p> <p><i>Maximal swim speed:</i></p> <p>Using the freestyle stroke, participants accelerated to maximal speed, maintained it for a 10 m period between 2 video cameras.</p>	<p>Mean movement time was calculated in milliseconds.</p> <p>Symmetry ratio was calculated between dominant and non-dominant limb for the unilateral task.</p>	<p><i>Validity:</i></p> <p>Mean movement time was faster, and symmetry score greater in non-disabled compared to Para-swimmers.</p> <p>Random forest algorithm correctly classified 96% of participants as non-disabled or Para-swimmer.</p> <p>Dominant (r = -0.72, p < 0.01) and non-dominant (r = -0.54, p = 0.01) unilateral tapping performance significantly correlated with maximal swim speed.</p> <p>Bilateral tapping (r = -0.21, p = 0.37) and symmetry score (r = -0.36, p = 0.15) did not significantly correlate with maximal swim speed.</p> <p><i>Reliability (non-disabled only):</i></p> <p>ICC was 0.85, 0.91, 0.85 and 0.42; coefficient of variation 5.4, 4.2, 5.2 and 4.1%; and standard error of the measurement 5, 8, 11 N and 0.04 for bilateral, dominant and non-dominant tapping and symmetry score, respectively.</p>
Roldan et al. 2017	To design new sport-specific tests of manual dexterity and intralimb coordination in	N = 73 Boccia players with cerebral palsy (42 male, 31 female).	Boccia players classified as BC1 or BC2 competing in regional or national competitions.	<p><i>Box and block test:</i></p> <p>Participants have to transfer 2.54 cm³ blocks from one section of a box to another. Participants used their throwing hand and performed two trials of 1 min.</p>	<p><i>Box and block test:</i></p> <p>Number of blocks moved in 1 min.</p> <p><i>Box and ball test:</i></p> <p>Number of balls moved in 1</p>	<p>Large, significant (r = 0.80, p < 0.001) correlation between the Box and block and Box and ball test.</p> <p>Moderate to very large correlation (r = -0.30 to -0.75, p < 0.05) between discrete</p>

Boccia players.	BC1: n = 33, 34 ± 16 years; BC2: n = 40, 34 ± 14 years. N = 19 non- disabled controls (28 ± 7 years).	Adults without any physical impairment.	<p><i>Box and ball test:</i> Same procedure as Box and block test but using Boccia balls instead of blocks.</p> <p><i>Tapping tasks:</i> Using metal plates 30 x 20 cm with target area of 18 x 5 cm. Participants crossed their non-throwing arm across their chest and arranged throwing hand into a fist with index finger extended.</p> <p><i>Discrete horizontal:</i> Wheelchair placed parallel to a table, 10 cm from the tapping plates. Participant's shoulder was aligned with the rear plate. Centre of the plates were 30 cm apart. On a verbal command, participants moved their index finger from the rear to forward plate as quickly as possible, to the target area. Participants completed 10 cycles.</p> <p><i>Discrete vertical:</i> Arranged in a "L" shape at 90° with 30 cm between plate centres. Participants started with their finger on the horizontal plate and moved on the command to the vertical plate.</p> <p><i>Discrete vertical with ball:</i> Using 14 x 7 cm plates loaded on springs to register contact. Contact could be made anywhere on the plate. Replicated the other discrete vertical task but performed whilst holding a ball, rather than with their finger.</p> <p><i>Reciprocal vertical tapping with ball:</i> As with the discrete task, but participants continually tapped alternately between plates.</p>	<p>minute.</p> <p><i>Discrete tapping tasks:</i> Average time (s) to move between plates across 10 trials.</p> <p><i>Reciprocal tapping task:</i> Number of successful contacts made in 1 min.</p>	<p>tapping tasks and Box and block test.</p> <p>The non-disabled control group performed significantly better than Boccia players on all tests.</p> <p>There was significant differences between BC1 and BC2 Boccia players for i) Box and block, ii) Box and ball and iii) reciprocal vertical tapping task with ball.</p> <p>Intrasession reliability was excellent for the discrete (ICC = 0.87) and reciprocal (ICC = 0.88) tapping tasks using the ball.</p>
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Non-Para sport studies

Artilheiro et al. 2014	To analyse the performance of adults with dyskinetic cerebral palsy during an upper	N = 16 adults with dyskinetic cerebral palsy (10 males, 6 females; 30 ±	Adults with dyskinetic cerebral palsy and age-matched controls.	<p><i>Coordination during upper limb movement:</i> Sat on a chair with hips, knees and ankles at 90°. Task was to raise a mug (350 g) from a position of 75% maximum passive elbow extension, to</p>	<p><i>Spatiotemporal variables:</i> Time (s) to execute lifting mug to mouth; adjusting phase, returning mug to initial position.</p> <p>Ratio of lifting to returning.</p>	<p><i>Spatiotemporal variables:</i> Execution of lifting, adjusting and returning the mug was significantly slower (p < 0.05) in adults with dyskinetic cerebral palsy. The ratio between lifting and returning was not different between</p>
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	limb movement task.	4 years). N = 11 age-matched controls (2 males, 9 females; 24 ± 4 years)		the mouth, adjust the movement and return it to the original position. This was repeated six times, consecutively, at a comfortable velocity and without releasing the mug between repetitions.	Peak and mean velocity ($\text{m}\cdot\text{s}^{-1}$) during movement, as well as time to peak velocity (s). Smoothness of movement was assessed using i) the number of movement units, the number of velocity peaks over 10% of peak velocity; ii) mean index of curvature, ratio of trajectory of 3 rd finger to straight line connecting start and end of movement; iii) jerk, the rate of change in acceleration of the position.	groups. Peak and mean velocity were lower and time to reach peak velocity longer, in the group with dyskinetic cerebral palsy. All measures of smoothness were significantly higher in the group with dyskinetic cerebral palsy.
Bui et al. 2017	To investigate if a computer-based Archimedes spiral test can assess coordination performance.	N = 49 (25 ± 7 years); n = 13 patients with autosomal recessive spastic ataxia of Charlevoix-Saguenay (29 ± 9 years); n = 36 non-disabled (24 ± 6 years).	Patients with autosomal recessive spastic ataxia of Charlevoix-Saguenay (ARSACS) and non-disabled controls.	Archimedes spiral test. This was performed on a 56 cm optical touch computer screen, using MATLAB sampling at 100 Hz. The spiral was 15 cm wide and 15 cm tall, with 2.5 cm between each loop. Participants traced the spiral with the index finger of their preferred hand at a self-paced speed. Screen positioned at arm's length with slight elbow flexion.	<i>Execution time:</i> Recorded in seconds, the total time to complete the spiral. <i>Spatial displacement:</i> Distance (in pixels) between the traced and reference spiral calculated at 100 Hz. This is used to calculate the mean error and maximum error. <i>Smoothness of movement:</i> Summation of frequency analysis from 0.1 to 2.9 Hz using fast Fourier transform.	No difference in execution time between groups ($p = 0.81$). Mean error ($p = 0.001$, ES = 1.80) and maximum error ($p = 0.004$, ES = 1.40) significantly greater in ARSACS patients. Significant difference in smoothness of movement ($p < 0.002$) between groups. Logistic regression correctly classified people based on mean error (95.9%) and maximum error (89.8%). Analysis considering frequency from 1.2 to 1.7 Hz correctly classified 100% of cases.
Corben et al. 2010	Compared performance in three upper limb function tests in Friedrich Ataxia.	N = 38 (17 male, 19 female; 32 ± 13 years).	Individuals with Friedrich Ataxia.	<i>9-hole peg test:</i> A timed measure of finger dexterity, where individuals have to place and remove nine pegs in a pegboard as quickly as possible. Both limbs are tested three times and the mean time calculated. <i>Box and block test</i> <i>Jebsen Taylor hand function test:</i> A test of arm and hand function representing everyday function. Participants must 1) write a short sentence; 2) turn over five 3x5" cards;	<i>9-hole peg test:</i> Time in seconds averaged over the 3 repeat trials, for both limbs. <i>Box and block test:</i> Number of blocks moved recorded as $1\cdot\text{min}^{-1}$. <i>Jebsen Taylor hand function test:</i> Time recorded for both limbs.	All test performances significantly negatively correlated with disease duration ($r = -0.41$ to -0.54) and Friedrich Ataxia Rating Scale ($r = -0.73$ to -0.82). Significant decrease in non-dominant limb 9-hole peg test ($p = 0.02$) and box block test ($p = 0.01$) at 12 month follow-up. No other test showed significant change over course of 12 months.

				3) pick up six small items and place them in a container; 4) simulate feeding; 5) stack four checkers; 6) lift five large, empty cans; 7) lift five large, weighted cans. This is repeated using both limbs.		
Gagnon et al. 2004	To examine the construct validity of the Standardised Finger to Nose test with upper extremity function tests and to examine the effect of age on performance.	N = 24 (12 male, 12 female; 37.5% less than 40 years).	Patients confirmed with ARSACS.	<p><i>Standardised finger to nose test:</i> Using their index finger, participants must alternately touch the end of their nose and a horizontal target 45 cm away. This was performed using the preferred limb.</p> <p><i>Box and block test</i></p> <p><i>Purdue pegboard:</i> Used to measure unilateral and bilateral dexterity, participants have to place pins, washers and collars on a board in 30 or 60 s.</p>	<p><i>Standardised finger to nose test:</i> Performance recorded as the number of targets hit in 20 s and averaged over two trials.</p> <p><i>Box and block test:</i> Number of blocks moved recorded as 1·min⁻¹.</p> <p><i>Purdue pegboard:</i> Recorded as the number of completed arrangements in 1 minute.</p>	<p>Standardised finger to nose test showed moderate-strong correlation with Box block test and Purdue pegboard ($r = 0.82$, $p = 0.01$).</p> <p>Performance on the Standardised finger to nose test was significantly greater in those younger than 40 years (12.7 ± 2.2) compared to older than 40 years (6.7 ± 3.4).</p>
Gagnon et al. 2018 (Orphanet)	To examine the effect of disease severity on dexterity and coordination in adults with ARSACS.	N = 28 (16 male, 12 female; 38 ± 13 years)	<p>Patients confirmed with ARSACS.</p> <p>Participants were split into i) those with no walking difficulty, ii) those who used a walking aid and iii) permanent wheelchair users.</p>	<p><i>Purdue pegboard</i></p> <p><i>9-hole peg test</i></p> <p><i>Standardised finger to nose test</i></p>	<p><i>Purdue pegboard:</i> Recorded as the number of pegs places on the board in 30 s.</p> <p><i>9-hole peg test:</i> Time recorded in seconds and averaged over two trials for both limbs.</p> <p><i>Standardised finger to nose test:</i> Performance recorded as the number of targets hit in 20 s and averaged over two trials.</p>	<p>Performance in all tests was significantly greatest in those who could walk and worst in those who were wheelchair users.</p>
Gagnon et al. 2018 (Archives)	To examine validity and reliability of measures of coordination and strength in spastic ataxia.	<p><i>Intra-rater group:</i> N = 42 (21 male, 21 female; 39 ± 11 years).</p> <p><i>Inter-rater group:</i> N = 33 (15 male, 18 female; 40 ± 11 years).</p>	Patients confirmed with ARSACS.	<p><i>9-hole peg test</i></p> <p><i>Standardised finger to nose test</i></p> <p><i>Archimedes spiral test:</i> Participants drew a spiral over a printed spiral without lifting the pen off the page. This was repeated twice.</p> <p><i>Fast alternating hand movements:</i> 10 cycles of alternate pronation and supination of the hand on their thigh, completed as quickly as possible and using both limbs.</p>	<p><i>9-hole peg test:</i> Time recorded in seconds and averaged over two trials for both limbs.</p> <p><i>Standardised finger to nose test:</i> Performance recorded as the number of targets hit in 20 s and averaged over two trials.</p> <p><i>Archimedes spiral test:</i> Time take to draw spiral in seconds combined with precision of drawing: i) normative or</p>	<p><i>Intra-rater reliability:</i> ICC for 9-hole peg test and standardised finger to nose test range from 0.93-0.97. Standard error of measurement was 6.5 and 7.1 s for right and left limbs for 9-hole peg test, and were 0.9 and 0.6 for the standardised finger to nose test.</p> <p><i>Inter-rater reliability:</i> ICC for 9-hole peg test and standardised finger to nose test ranged from 0.903-0.981.</p> <p><i>Validity:</i></p>

slightly irregular, > 1 cm traced outside line, < 30 s; ii) slightly irregular, > 1 cm traced outside line, > 30 s; iii) irregular, tracing touches or crosses 2 lines or spiral unrecognised or incomplete.

Fast alternate hand movements:
Time recorded in seconds. Mean of both limbs used to categorise as i) normative or slightly irregular, < 10 s; ii) clearly irregular but < 10 s; iii) very irregular, > 10 s or unable to complete.

Males were significantly better performers than females at the 9-hole peg test ($p < 0.037$), but not standardised finger to nose test ($p > 0.161$).

9-hole peg test and standardised finger to nose test were able to significantly ($p < 0.001$) discriminate participants according to their performance in Archimedes spiral and Fast alternate hand movements tests.

Both 9-hole peg test and finger to nose test could discriminate according to disease stage ($p < 0.001$) and age ($p < 0.001$).

ARSACS: autosomal recessive spastic ataxia of Charlevoix-Saguenay

Table 3: Data extracted from the eligible studies regarding range of motion impairment.

Authors	Objective	Sample size	Population	Assessment tool	Outcome measures	Results
Para sport studies						
Bjerkefors et al. 2019	To examine differences in joint angles and range of motion in able-bodied and para-kayak athletes.	<p>N = 51 (34 male, 17 female)</p> <p>Para-kayak: n = 41 (28 male, 13 female; 35 ± 9 years).</p> <p>Able-bodied: n = 10 (6 male, 4 female; 20 ± 1 years).</p>	<p>Para-kayak athletes competing at national or international level with over 1 year experience.</p> <p>Elite able-bodied kayak athletes.</p>	<p>Kinematic analysis of kayak performance on a kayak ergometer during 20 paddle cycles of the greatest intensity that could be maintained for the 20 cycles. If para-athletes used adaptive seats or straps when competing these were used on the ergometer also.</p> <p>Kinematic data were collected throughout the paddle cycle which was defined as the time from catch to catch for each side.</p>	<p><i>Range of motion:</i></p> <p>Shoulder: flexion-extension, abduction-adduction, internal-external rotation.</p> <p>Elbow: flexion-extension.</p> <p>Wrist: dorsal-palmar flexion, ulnar-radial deviation.</p> <p>Trunk: flexion-extension, rotation.</p> <p>Variables were recorded for maximum and minimum angle values and range of motion in degree.</p>	<p>Able-bodied athletes showed greater maximal trunk flexion angle and trunk rotation range of motion. The most impaired Para-kayak athletes showed greater trunk extension.</p> <p>Able-bodied and the least impaired Para-kayak athletes showed greater maximal shoulder flexion, but more impaired Para-kayak athletes had greater should extension and range of motion.</p> <p>Significant positive correlations were found between maximum shoulder flexion, maximum trunk flexion and trunk and pelvis range of motion with power output during paddling.</p>
Fung et al. 2013	To examine how the supporting bar on trunk function during wheelchair fencing.	N = 14 (8 male, 6 female; 30 ± 6 years).	Elite wheelchair fencers competing at the international level (6.6 ± 3.8 years).	<p>Digital video camcorder (50 Hz) captured participants performing i) lunge and ii) fast-return with and without a supporting bar held by the non-fencing arm.</p> <p>Video camera was placed 10 m away and calibrated using a 1 x 1 m calibration board.</p>	<p>Maximum trunk angle: calculated as the angle between the line of the shoulder and iliac crest of the fencing arm with the vertical line perpendicular to the ground through the hip joint.</p>	<p>Maximum trunk angle was significantly greater in the lunge and fast-return with the use of the supporting bar ($p < 0.05$).</p> <p>Without the supporting bar, maximal lunge and fast-return trunk angle were significantly different based on wheelchair fencing classification.</p> <p>There were no differences based on wheelchair fencing classification with the use of the supporting bar.</p>
Hyde et al. 2017	To examine how assistive pole and strength impacted seated throwing performance.	N = 10 (8 male, 2 females; 32 ± 10 years).	Athletes with spinal cord injury (C6-L1). All participants were eligible for classification in Paralympic seated throwing, but participated in either seated throwing,	<p>Kinematic analysis of seated throwing with and without an assistive pole in both a standardised and self-selected condition. The standardised position had a seat angle of 30° and backrest height of 18% of athlete's sitting height. In the self-selected condition these could be individually altered by the participant.</p> <p>Kinematic data were collected for start of forward movement; cocking to throw;</p>	<p>Range of motion was measured in degrees.</p> <p>Angular velocity was measured in °·s⁻¹.</p>	<p>Use of an assistive pole led to significantly greater hand release speed, elbow flexion at the start of the throw and shoulder external rotation angular velocity during cocking.</p> <p>Seat configuration had no effect on any kinematic variable.</p>

			wheelchair basketball or wheelchair rugby.	arm-acceleration; and release phases and analysed for range of motion and angular velocity of elbow flexion, shoulder rotation, trunk rotation, trunk flexion.		
Nicholson et al. 2018	To evaluate test-retest reliability of tests of range of motion for Para-swimming.	<p>N = 66</p> <p>Impaired muscle power: n = 13 (8 male, 5 female; 30 ± 6 years).</p> <p>Hypertonia: n = 11 (9 male, 2 female; 27 ± 6 years).</p> <p>Non-disabled: n = 42 (20 male, 22 female; 23 ± 5 years).</p>	<p>i) Para-swimmers who had a national or international classification and were undertaking planned training regimes and competing at a national or international level.</p> <p>ii) Non-disabled participants who were healthy and recreationally active.</p>	<p>Upper limb active range of motion was assessed using a digital inclinometer and goniometer.</p> <p>i) bilateral shoulder flexion, ii) shoulder abduction, iii) elbow flexion/extension were performed seated in a chair with feet flat on the ground.</p> <p>v) shoulder internal/external rotation at 90° shoulder abduction and elbow flexion were performed lying on their back.</p> <p>vi) shoulder extension (with elbow flexed and extended), vii) shoulder abduction and viii) shoulder flexion were performed prone.</p> <p>ix) trunk functional reach forwards, backwards, left and right were performed sat on a plinth with hips and knees at 90°, feet on a stool and arms crossed over chest.</p>	<p>Range of motion was measured in degrees.</p>	<p><i>Validity:</i></p> <p>No significant difference in shoulder flexion or abduction between disabled and non-disabled groups. Para-swimmers with impaired muscle power had significantly reduced ($p < 0.05$) elbow flexion and extension compared to non-disabled.</p> <p>Shoulder internal rotation was significantly reduced ($p < 0.01$) in Para-swimmers with hypertonia, and shoulder internal and external rotation ($p < 0.01$) in Para-swimmers with impaired muscle power, compared to non-disabled.</p> <p>Functional reach in all directions was significantly reduced ($p < 0.01$) in Para-swimmers compared to non-disabled.</p> <p><i>Intra-rater reliability (non-disabled only):</i></p> <p>For all measures, other than left arm elbow extension ($p = 0.04$) there was no significant difference ($p > 0.14$) between repeat trials.</p> <p>ICCs ranged from 0.68 to 0.96, and standard error of measurement from 1.42 to 4.60 degrees.</p> <p><i>Inter-rater reliability (non-disabled only):</i></p> <p>All measures, other than elbow flexion and shoulder internal rotation ($p < 0.01$) left were not significantly different ($p > 0.05$) between raters.</p> <p>ICCs ranged from 0.62 to 0.98 and standard error of measurement from 1.42 to 6.52 degrees.</p>
Reina et al. 2018	To investigate the effect of Boccia classification and throwing distance	N = 5 (35 ± 5 years).	Elite Boccia players who had competed at the Paralympic	Kinematic analysis of 10 throws in 4 conditions: i) short distance (2 m), ii) middle distance (5 m), iii) long distance (9 m) and iv) maximum speed throw as	Angles in degrees were calculated for elbow flexion, elbow extension and trunk inclination.	Elbow flexion and extension were significantly greater with each increment in throwing distance, and for maximum throwing speed ($p < 0.001$).

	on kinematics of throwing.		Games and classified as BC1 or BC2.	if to dislodge an opponent's ball.	Ball release speed was calculated in $\text{m}\cdot\text{s}^{-1}$.	<p>Trunk inclination was significantly greater in medium versus short throw ($p = 0.006$); medium versus long ($p = 0.002$) and long versus maximum speed throw ($p < 0.05$).</p> <p>BC2 players had significantly greater elbow flexion, trunk inclination and ball release speed ($p < 0.001$) than BC1 players.</p> <p>There was a moderate positive correlation between elbow extension and ball release speed ($r = 0.525$, $p < 0.001$).</p>
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Non-Para sport studies

Artilheiro et al. 2014	To analyse the performance of adults with dyskinetic cerebral palsy during an upper limb movement task.	<p>N = 16 adults with dyskinetic cerebral palsy (10 males, 6 females; 30 ± 4 years).</p> <p>N = 11 age-matched controls (2 males, 9 females; 24 ± 4 years)</p>	Adults with dyskinetic cerebral palsy and age-matched controls.	<p><i>Range of motion during upper limb movement:</i></p> <p>Sat on a chair with hips, knees and ankles at 90°. Task was to raise a mug (350 g) from a position of 75% maximum passive elbow extension, to the mouth, adjust the movement and return it to the original position. This was repeated six times, consecutively, at a comfortable velocity and without releasing the mug between repetitions.</p>	<p><i>Range of motion:</i></p> <p>Shoulder: flexion-extension, abduction-adduction, internal-external rotation; elbow flexion-extension; forearm pronation-supination.</p> <p>Measured variables were starting position; minimum and maximum angular values; and range of motion in degrees.</p>	<p><i>Range of motion:</i></p> <p>At the start position, the dyskinetic cerebral palsy group had decreased shoulder flexion and increased elbow flexion and forearm pronation.</p> <p>Minimum angle for shoulder flexion was lower in dyskinetic cerebral palsy, but minimum angle for shoulder abduction, elbow flexion and forearm pronation.</p> <p>Maximum angle of shoulder and elbow flexion were decreased in dyskinetic cerebral palsy, but forearm pronation was increased.</p> <p>Range of motion for shoulder flexion, elbow flexion and forearm pronation were lower in dyskinetic cerebral palsy.</p>
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Table 4: Quality assessment for each study using a modified appraisal tool for cross-sectional studies.

Authors	1	2	3	4	5	6	8	9	10	11	12	15	16	17	18	19	20
Para sport studies investigating strength impairment																	
Altmann et al. 2016	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	NR	Y
Altmann et al. 2018	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	NR	Y
Beckman et al. 2014	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	NR	Y
Connick et al. 2018	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
Hogarth et al. 2019	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
Hyde et al. 2017	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
Rosso et al. 2019	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
Santos et al. 2017	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	N	Y
Vanlandewijck et al. 2011	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y
Non-Para sport studies investigating strength impairment																	
Gagnon et al. 2018	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	NR	Y
Para sport studies investigating coordination impairment																	
Connick et al. 2016	Y	Y	N	Y	Y	UD	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y
Deuble et al. 2016	Y	Y	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y
Hogarth et al. 2019	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y
Roldan et al. 2017	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
Non-Para sport studies investigating coordination impairment																	

Artilheiro et al. 2014	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
Bui et al. 2017	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y
Corben et al. 2010	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y
Gagnon et al. 2004	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	N	N	Y
Gagnon et al. 2018 (Orphanet)	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
Gagnon et al. 2018 (APMR)	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	NR	Y

Para sport studies investigating ROM impairment

Bjerkefors et al. 2019	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
Fung et al. 2013	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	NR	Y
Hyde et al. 2017	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
Nicholson et al. 2018	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
Reina et al. 2018	Y	Y	N	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	N	NR	Y

Non-Para sport studied investigating ROM impairment

Artilheiro et al. 2014	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
TOTAL, n (%)	26	26	3	25	25	24	26	26	26	25	24	26	26	26	18	19	26
	(100)	(100)	(12)	(96)	(96)	(92)	(100)	(100)	(100)	(96)	(92)	(100)	(100)	(100)	(69)	(73)	(100)

Modified appraisal tool for cross-sectional studies developed by Downes et al. (2016): 1) Were the study aims/objectives clear?; 2) Was the study design appropriate for the stated aim(s)?; 3) Was the sample size justified?; 4) Was the target population clearly identified?; 5) Was the sample frame taken from an appropriate population base so that it closely represented the target population?; 6) Was the selection process likely to select participants that were representative of the target population?; 7) Were the outcome variables measured appropriate to the aims of the study?; 8) Were the risk factor and outcome variables measured correctly using instruments that had been trialled or published previously?; 9) Was it clear what was used to determine statistical significance and/or precision estimates?; 10) Were the methods sufficiently described to enable them to be repeated?; 11) Were the basic data adequately described?; 12) Were the results internally consistent?; 13) Were the results for the analyses described in the methods, presented?; 14) Were the authors' discussions and conclusions justified by the results?; 15) Were the limitations of the study discussed?; 16) Were there any funding sources or conflicts of interest that may affect the authors' interpretation of the results?; 17) Was ethical approval or consent of participants attained?

PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	3-5
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	5
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	5
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	6-7
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	5-6
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	5-6
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	6-7
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	7
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	7
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	7-8
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	N/A
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	N/A

PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	7-8
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	N/A
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	8, Fig. 1
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	Tables 1-3
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	Table 4
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	9-16, Table 1-3
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	9-16
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	9-16
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	N/A
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	17-23
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	23-24
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	25
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	26

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

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