Journal Pre-proof

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PII: S1360-8592(24)00100-1

DOI: https://doi.org/10.1016/j.jbmt.2024.02.043

Reference: YJBMT 2825

To appear in: *Journal of Bodywork & Movement Therapies*

Received Date: 5 May 2023

Revised Date: 5 December 2023

Accepted Date: 25 February 2024

INTRINSIC AND EXTRINSIC VARIABLES IMPACTING UPPER QUARTER Y-BALANCE TEST SCORES IN SPORTING COHORTS: A SYSTEMATIC REVIEW

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No funding was received for this work.

Declarations of interest: none.

ABSTRACT

Introduction: The upper quarter y-balance test (YBT-UQ) is a functional screening tool used to detect musculoskeletal injury risk, aid rehabilitation, and monitor dynamic function, strength and control, yet little is currently known about intrinsic and extrinsic factors that influence reach scores. **Objectives:** This systematic review aimed to determine if age, sex, or interventions influenced reach scores and whether between-limb differences were common in non-injured sporting populations, with a secondary aim to identify if sport impacted YBT-UQ reach. **Methods:** Web of Science, PubMed, and SportDiscus were systematically searched from January 2012 to 16/11/2023, revealing twenty-three studies satisfying inclusion criteria of published in English between 2012-2023, healthy participants of any age including both males and females, athletic populations, YBT-UQ use to assess upper limb mobility/stability, report normalised reach scores, and peer-reviewed full-texts. Methodological quality was evaluated via National Institutes of Health (NIH) quality assessment tools for controlled interventions, observational cohort and cross-sectional designs, and pre-post with no control group. **Results:** Age, sex, sport, and fatigue were influencing factors; greater reach scores were achieved in older athletes (i.e. >18 years), males, and in a well-rested state. Between-limb differences were not common in sporting populations; therefore, asymmetries may be useful for practitioners to aid injury risk identification. **Conclusion:** This is the first systematic review investigating YBT-UQ influencing factors and thereby provides context for clinicians regarding characteristics that impact reach scores in sporting populations, from which normative values could be determined and further aid clinical decisions or areas to improve regarding injury risk.

Key words: stability, mobility, functional screening, performance, athletic populations

TEXT

Introduction

Upper extremity injuries have a high prevalence in sport, particularly in overhead athletes; for example, the shoulder accounts for 12-19% of baseball injuries and 23-38% of swimming injuries in one year (Tooth et al 2020). These injuries often lead to time-loss, performance reductions, and incur medical costs creating a burden for health services (Ryan et al 2019; Lambert et al 2022). Deficits in dynamic balance (ability to maintain whole-body stability over the centre of mass during movement) are known to contribute to a greater injury risk (Teyhen et al 2014b), thus functional screening tools including a proprioceptive element are crucial to identify those at greater risk of injury, monitor rehabilitation after injury, and inform clinician return-to-play decisions.

The upper quarter y-balance test (YBT-UQ) is a screening tool which assesses upper limb dynamic mobility and stability unilaterally in a closed-kinetic chain setting (Westrick et al 2012). The standardized YBT-UQ apparatus consists of three reach directions (inferolateral, superolateral, and medial), with posterior directions positioned 135° from the anterior and 90° between the posterior directions (Gorman et al 2012). The direction of reach is named relative to the static limb (Westrick et al 2012). In order to perform the test, individuals are required to assume a 3-point plank position whereby the feet are shoulder-width apart and one hand on the stance platform. The static limb is considered to be the testing limb during trials (Christian & Moran 2021). Individuals then simultaneously slide the reach indicator with the contralateral, free limb to their end range of motion without losing balance, return to the center stance, and reach in the other directions (Gorman et al 2012; Westrick et al 2012; Stapleton et al 2021). A successful trial is completed once an individual has reached in all three directions without loss of balance, pushing the indicator away, lifting feet off the floor, or failing to maintain contact with the reach indicator (Gorman et al 2012). Typically, practice trials or demonstrations are provided beforehand to eliminate a learning effect and three recorded trials are performed, from which the average can be used for analysis (Westrick et al 2012). The sum of the three directions is then used to calculate a total excursion score which can further assist with the calculation of a composite score relative to limb length (Westrick et al 2012; Dittmer et al 2021; Stapleton et al 2021).

In comparison to other upper limb functional tests, the YBT-UQ has demonstrated high test-retest reliability (ICC: 0.80-0.99) and high inter-rater reliability (ICC: 1.00) using both commercialised and modified kits (Gorman et al 2012; Cramer et al 2017; Williamson et al 2019). Therefore, the YBT-UQ is well established to highlight musculoskeletal imbalances and potentially aid injury risk predictions.

Postural control and balance are a multifaceted characteristic that may be influenced by various factors including anthropometric characteristics, sex, and limb dominance (Fusco et al 2020). Various studies utilising the lower quarter y-balance test (YBT-LQ) have reported sex, age, and sport to be influencing factors on reach outcomes (Teyhen et al 2014a; Chimera et al 2015; Miller et al 2017; Slater et al 2020) which may also translate to the test's upper limb counterpart. Several factors have been evaluated within YBT-UQ literature through cross-sectional studies including age (Bullock et al 2017), sex (Butler et al 2014a; Butler et al 2014b; Ruffe et al 2019) and between-limb differences (Bauer et al 2020b), however data on YBT-UQ reach is conflicting and divergent findings may arise from variance across the populations investigated, such as military recruits (Westrick et al 2012; Teyhen et al 2014a) and healthy adults (Gorman et al 2012). Neither a comprehensive summary of intrinsic (e.g., age, sex) and extrinsic (e.g., interventions, type of sport) factors which may influence reach outcomes, nor a normative dataset exists for the YBT-UQ. Availability of such data would allow for effective comparisons between individuals of similar characteristics and provide greater understanding of those who may be predisposed to injury (Taylor et al 2016), particularly in sport rehabilitation settings and as a prehabilitation screening assessment (Stapleton et al 2021).

At present, there are no systematic reviews which have evaluated the factors influencing YBT-UQ outcomes. As such, the primary aims of this systematic review were to identify whether age, sex, or interventions (e.g. strengthening programmes, fatigue protocols) influence YBT-UQ reach distances and whether between-limb differences are common in sporting populations. The review's secondary aim was to determine if sport influenced reach scores achieved, as it is important to contextualise reach scores for athletic populations by sports, particularly those with considerable differences in their physical demands e.g., boxing versus gymnastics.

Methods

Literature Search

A literature search was conducted in three databases: SportDiscus, PubMed, and Web of Science from January 2012 to 16/11/2023. The search protocol was performed adhering to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement guidelines (Page et al 2020). The following search strategy was employed: [(y balance test) OR (ybt) AND (upper quarter) OR (upper extremity) OR (upper limb) AND (athlete)]. Database limiters (year, language, publication type) were applied within each database, increasing search specificity prior to exporting results.

Inclusion criteria

The following inclusion criteria were used to select and screen studies to determine their eligibility for inclusion: (a) published in English between 2012-2023 due to YBT-UQ research first emerging in 2012 (Gorman et al 2012; Westrick et al 2012); (b) healthy participants of any age, including both males and females, with no current upper extremity pathologies; (c) athletic populations; (d) use of the YBT-UQ; (e) report normalised scores as a percentage of limb length using the commonly accepted approach of ((absolute reach distance/limb length)*100) for directional reach, and ((sum of 3 directions/3*limb length)*100) for composite score (CS) (Cramer et al 2017; Schwiertz et al 2020; Dittmer et al 2021), to allow for comparable inferences; (f) full-text, peer-reviewed studies.

Exclusion criteria

The following exclusion criteria were used to screen studies ineligible for inclusion: (a) published in another language; (b) non-sporting population e.g., military recruits; (c) participants with current injury; (d) no numerical reach values either as CS, or by directional reach and CS; (e) reach scores which were not normalised by percentage limb length; (f) conference abstracts or reviews.

Study selection

The study selection process is outlined in Figure 1. After retrieving the search results, all studies were exported, and duplicates were removed. Titles, then abstracts were screened by both authors independently and those which clearly did not meet inclusion criteria were eliminated. Studies deemed to have uncertain relevance were included for full text review to confirm eligibility. Final inclusion eligibility was carried out via retrieval of the full texts which were read in full and tested against inclusion/exclusion criteria independently by both authors. Any uncertainties were discussed between authors and resolved by agreement. Hand searching of reference lists was then conducted to identify any additional studies of relevance.

[Figure 1 about here]

Data extraction

The following data were extracted from the final list of included studies: (a) general information (author(s), year, publication); (b) aims and objectives; (c) participant characteristics (sample size, age, sex, sport); (d) study findings/conclusions (directional reach distances, composite scores, and effects of interventions where applicable).

Quality assessment

Due to the current review encompassing a range of experimental and observational approaches, methodological quality was determined using three distinct quality assessment tools relative to each study's design. To assess the quality of included randomised controlled trials, the full 14-item National Institutes of Health (NIH) Quality Assessment of Controlled Intervention Studies was used (National Institutes of Health 2021a). Similarly, to assess the quality of observational studies, the 14-item NIH Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies was utilised (National Institutes of Health 2021b). Questions pertaining to exposures were removed due their lack of relevance for the nature of the included studies, therefore quality was assessed using 9 items (items 1-5 and 11-14); this is a similar approach used by others (Pol et al 2021). Lastly, to assess the methodological quality of included pre-post intervention studies, the full 12-item NIH Quality Assessment Tool for Before-After (Pre-Post) Studies with No Control Group was employed (National Institutes of Health 2021c). Items within each tool were scored yes, no, cannot determine, not recorded, or not applicable, with overall quality being rated poor, fair, or good. Scoring of methodological quality was carried out to specify the quality of included studies and was not conducted in view of excluding studies. Both researchers independently conducted quality screening with any disagreements being resolved through discussion and consensus.

Results

Study selection

The initial search yielded 18,660 results. Once duplicates were removed, 14,262remained for further evaluation. After title screening, 14,022 articles were removed with 240 to undergo abstract screening, from which 88 full-texts were screened. From this, 23 studies were included in the review. The primary reasons for exclusion included absence of a specific sport and no YBT-UQ used.

General characteristics

A total of 1790 participants were included across 23 studies. A detailed description of study characteristics is presented in Table 1. Of the 23 studies, 20 used the official Y Balance Test Kit (Functional Movement Systems, Inc., Chatham, VA, USA), two used an unofficial Y Balance Test Kit (Beyranvand et al 2017; Dittmer et al 2020) and one used tape with inferolateral and superolateral angles measured 135° from the medial line (Arora et al 2021). All studies normalised to upper limb length. Nineteen studies recorded three trials per reach direction whilst the number of recorded trials was unclear in four (Bauer et al 2020a, Norambuena et al 2021; Bauer et al 2022; Jha et al 2022). Sixteen studies recorded measurements as the best of three attempts, three recorded via the average across reach trials, whilst three did not report how measurements prior to analysis were noted. Of the included studies, ten reported measurements were taken barefoot, two reported participants wore shoes and ten did not report on footwear. Furthermore, ten studies investigated several factors potentially influencing reach scores, whilst the other thirteen investigated one factor. The findings for each factor are presented below and study characteristics are presented in Table 1:

[Table 1 about here]

Age

Four studies explored the influence of age on reach performance, with all including at least two age groups; one investigated differences between three groups (Borms & Cools 2018) and another between six groups (Bauer et al 2021). Three studies found a significant age-effect on reach and variance was found across studies regarding age groupings. Singla, Hussain and Bhati (2018) reported their older group (18-25 years) to have significantly greater CS than those aged 14-17, however this effect was only observed on the non-dominant limb. Conversely, Bullock et al (2017) found age effects on medial, inferolateral, and superolateral reach for those aged 20.5 ± 1.2 years compared to those aged 17.0 ± 1.1 years. Bauer et al (2021) reported some significant age effects but this varied by reach direction; younger athletes (13 and 14 years) achieved greater medial reach than 17 year-old athletes, and superolateral reach was greater in 18 year-old athletes compared to 13 year-old athletes. No age effects were observed for superolateral or CS reach (Bauer et al 2021). Borms & Cools (2018) found no differences in reach when age was considered as an isolated variable, however they identified a three-way interaction for gender, sport and age in superolateral reach.

Sex

Seven studies investigated the impact of sex on reach performance. Six studies found significant differences between males and females; one study identified males outperformed females in all reach directions and CS (Borms & Cools 2018), and another reported males reaching significantly further in the medial and superolateral directions (Bullock et al 2017). Three studies found males to have significantly greater scores for medial, inferolateral and CS (Butler et al 2014a; Taylor et al 2016; Ruffe et al 2019), whilst one study found males to achieve greater inferolateral reach and CS (Stapleton et al 2021). The remaining study found no sex differences in any direction or CS (Butler et al 2014b).

Between-limb difference

Over half of the studies (n = 12) examined differences between limbs; eight compared dominant and non-dominant limbs, three studies compared left and right (Myers et al 2017;

Ruffe et al 2019; Norambuena et al 2021), whilst the remaining study investigated throwing and non-throwing limbs (Bauer et al 2023). All studies defined the stabilising limb as the limb being assessed. Eight studies found no significant differences in reach performance between limbs, five of which compared dominant and non-dominant, and one study provided descriptive statistics on between-limb difference only (Bauer et al 2023). Contrastingly, one study found a difference between limbs favouring the non-dominant for CS only (Borms & Cools 2018), whilst another reported significantly greater distances when assessing the non-dominant limb for inferolateral reach only (Christian & Moran 2021). Finally, one study (Bauer et al 2021) identified differences between limbs in varying directions depending on age (13 years: inferolateral, superolateral, CS; 15 years: medial; 16 years: CS; 18 years: superolateral).

Effects of interventions

A total of seven studies investigated the influence of interventions on subsequent YBT-UQ reach performance; two explored the impact of fatigue interventions (Salo & Chaconas 2017; Bauer et al 2020a), three investigated the influence of core activation/strength/stability training (Arora et al 2021; Bauer et al 2022, Jha et al 2022), a further study looked at the impact of suspension training (Norambuena et al 2021), whilst the final study researched the influence of kinesiotape on reach scores (Dittmer et al 2020). Both studies investigating fatigue's impact found significant effects, with one reporting fatigue resulted in significant reductions in all reach directions and CS for both limbs (Salo & Chaconas 2017), whilst the other highlighted only superolateral reach and CS were reduced (Bauer et al 2020a). Norambuena et al (2021) identified significant increases in CS for both limbs as a result of a 5-week TRX suspension training protocol in youth judokas. Two studies found 5- to 6-week core strength/stability training demonstrated favourable improvements in CS (Bauer et al 2022, Jha et al 2022), all reach directions in the dominant limb, and IL for the non-dominant limb (Bauer et al 2022).

However, the final two studies reported no differences in CS as a result of core activation (Arora et al 2021) or CS and directional reach due to kinesiotape use (Dittmer et al 2020).

Type of sport

A total of six studies directly compared sports. Two of these compared contrasting sports e.g., baseball and wrestling (Taylor et al 2016; Myers et al 2017); three compared sports of a very similar nature e.g., predominantly overhead movements (Butler et al 2014b; Borms & Cools 2018; Stapleton et al 2021); and one compared swimmers with untrained controls (Schwiertz et al 2020). Five studies found a significant sport-effect and of those, two identified a significant sport effect in all reach directions and CS (Taylor et al 2016; Schwiertz et al 2020). One study identified significantly greater performances in handball compared to volleyball players in medial reach only, and highlighted a three-way interaction with sport, side and sex (inferolateral reach) in addition to sport, sex and age (superolateral reach) (Borms & Cools 2018). Furthermore, one study highlighted a significant sport influence for medial reach, inferolateral reach, and CS (Myers et al 2017), whilst another identified meaningful differences between similar sports (baseball and softball) for inferolateral reach and CS only (Stapleton et al 2021). The remaining study found no differences between sports (Butler et al 2014b).

[Table 2 about here]

Methodological quality analysis

Quality assessment of included studies is displayed in supplementary tables 1 to 3. The majority of studies (n = 22) were scored fair, with only one being rated poor (Arora et al 2021). Regarding observational cohort and cross-sectional studies, participation rate, blinding, loss to follow-up, and statistical adjustments for confounding variables often could not be determined or were not reported. All clearly defined the study population and outcome measures were applied uniformly across all individuals. Three studies (Butler et al 2014a; Butler et al 2014b;

Bauer et al 2023) justified their sample size through a-priori power calculations. Furthermore, all controlled intervention studies were randomised with prespecified outcomes (Salo & Chaconas 2017; Dittmer et al 2020; Arora et al 2021; Bauer et al 2022, Jha et al 2022) but only two studies adequately reported their randomisation method (Bauer et al 2022; Jha et al 2022).With the exception of one study (Jha et al 2022), all reported similar groups at baseline for characteristics that could impact outcomes. However, no study reported whether group allocation was concealed or reported adequately on drop-out rates. One study reported blinding of assessors (Norambuena et al 2021).

Discussion

The primary purpose of this review was to determine if age, sex, or interventions influence reach distances and whether between-limb differences are common on the YBT-UQ in sporting populations. Additionally, the secondary aim was to determine if type of sport impacted on reach scores. Twenty-three studies were included (22 of fair quality, 1 of poor quality). To our knowledge, this is the first review within YBT-UQ assessment to identify factors which may influence reach outcomes.

Age

Previous literature pertaining to the YBT-LQ identified age as an influencing factor on reach scores, whereby older athletes (i.e., >18 years) often attain greater reach scores than younger athletes (Breen et al 2016; Plisky et al 2021; Schedler et al 2021). Similar findings are reported for the Star Excursion Balance Test (Gribble et al 2012), and the Modified Star Excursion Balance Test (Gonzalo-Skok et al 2017) assessing dynamic stability of the lower limb. Therefore, it was pertinent that a primary aim of this review was to determine if age was an important consideration for YBT-UQ reach scores. For the purpose of this review, studies were only included for evaluation of age if age sub-group analysis was performed. Age appears to be an influencing factor as 3 of the 4 studies reported differences between age groups, particularly when comparing adult to adolescent athletes, suggesting that older athletes (i.e., 18+ years vs under 18s) performed better. However, the reach directions this finding applied to was inconsistent, and with the small number of studies included here, identifying normative data by age is somewhat limited. This poses potential uncertainty from a practitioner's perspective when determining whether reach scores for certain age categories are considered sufficient. It should be noted that the age ranges for sub-groups did vary across the studies which adds a complexity to data synthesis, and furthermore, age is likely to be related to other factors. For example, those studies which identified differences by age groups declared participants to be part of school, collegiate or professional teams, suggesting that level of competition and age are likely inter-related as older athletes with more advanced competition levels possess greater dynamic balance (Bullock et al 2017). This may be due to greater exposure to sport-specific training, which enhances dynamic stability/mobility (Butler et al 2014b), or maturation status which has been shown to potentially influence YBT-LQ outcomes (Schedler et al 2021). Interestingly, those which did not identify an age effect, did not highlight the level at which their participants competed (Borms & Cools 2018).

Despite the complexity of potential confounders on the relationship between age and YBT-UQ reach outcomes, lower scores appeared to be seen in younger athletes (<18 years), perhaps suggesting they possess poorer neuromuscular control and thus are at a greater risk of future injury. This would suggest that adolescent athletes may require more attention to upper limb mobility and stability training programmes to reduce their potential risk. As the test requires reach to the end range of motion (Bauer et al 2023), younger/adolescent athletes may not currently possess the strength or training load required to achieve higher scores. It has recently been suggested that population-specific cut points are needed for injury screening tools to provide a more accurate determination of injury risk in athletes based on population characteristics e.g., age, sex, sport (Plisky et al 2021). Currently, an accepted asymmetry value of >4cm indicates increased risk, however this value was determined using the YBT-LQ. A previous prospective observational study (Ruffe et al 2019) highlighted this asymmetry value for YBT-UQ superolateral reach distance resulted in a greater risk of lower limb injury by seven times. Population-specific cut points (e.g., by age) would be beneficial to clinicians to interpret reach scores and predict injury risk (Plisky et al 2021). Additionally, practitioners should be cautious when comparing younger individuals with normative values obtained in older athletes (Breen et al 2016).

Sex

The findings from this review demonstrate sex appears to influence reach on the YBT-UQ within sporting populations. Of seven studies, six identified males achieving significantly greater reach than females, however, there are inconsistencies regarding the reach directions in which these differences were observed. The studies agree that males have significantly greater reach distances in medial and CS whilst superolateral and inferolateral was shown to be varied (Butler et al 2012; Taylor et al 2016; Bullock et al 2017; Borms & Cools 2018; Ruffe et al 2019; Stapleton et al 2021). These differences may be a result of comparatively greater core stability and strength, as previous research highlighted females display poorer performance on core stability tests such as the modified Biering-Sorensen test and seated flexor endurance test (Leetun et al 2004; Brophy et al 2009). Although the YBT-UQ assesses the shoulder, the remainder of the kinetic chain will play a considerable role in providing support (Karandikar & Vargas 2011), particularly at the end of reach. As current upper extremity closed-kinetic chain (CKC) tests require performance in a press-up position, it is reasonable to suggest the core must play a larger role than currently researched (Butler et al 2012; Bullock et al 2017; Savkin et al 2018).

Similarly, sex has been identified as a factor potentially influencing scores achieved on the YBT-LQ and the Closed Kinetic Chain Upper Extremity Stability Test, with males often attaining greater scores than females (Plisky et al 2021; Teixeria et al 2022), although the reasons for this were not clear. Prior research has also identified a difference in results between males and females regarding the aforementioned >4cm cut point. Ruffe et al (2019) reported male runners had an increased risk of running-related injuries with >4cm posteromedial reach (YBT-LQ) and YBT-UQ superolateral reach. Conversely, females with an asymmetry of >4cm for YBT-UQ inferolateral reach were 75% less likely to become injured. However, practitioners should be aware that females achieving lower scores than males may not necessarily be indicative of low risk and caution should be applied to assess the risk relative to each sex. At present, further evaluation using a battery of tools and injury monitoring may be most appropriate to determine injury risk (Bauer et al 2023). Similar to the relationship between age and YBT-UQ reach scores, the effect of sex on reach distances may be as a result of a combination of factors including age, anthropometric characteristics, neuromuscular control, and core strength (Leetun et al 2004; Brophy et al 2009).

Between-limb differences

Sports utilising the upper quarter often have different requirements for each limb, therefore, it is important to identify if these performance asymmetries also impact upon general limb stability and mobility (Butler et al 2014b; Borms & Cools 2018). It is accepted that limb asymmetry >4cm in reach score increases risk of incurring future injury (Plisky et al 2006; Butler et al 2012; Chimera et al 2015). Of 11 studies which compared limbs, eight studies found no differences suggesting that symmetry (rather than asymmetry) is more commonly reported. Of note, eight of the twelve studies compared the dominant versus non-dominant limb, whereas three studies compared the left versus right limb without reporting limb dominance within their study population and the final study compared throwing versus non-throwing limbs. These differences in limb categorisation between studies create complex comparisons, however those three studies reporting differences exclusively used dominant/non-dominant comparison suggesting that limb dominance may be a factor for asymmetry in reach scores and it should be considered in relation to the demands of the sport.

Of the three studies that reported differences, two favoured the non-dominant limb as supporting limb, however one identified greater reach for inferolateral (Christian & Moran 2021) whilst the other reported differences in CS only (Borms et al 2016). Another study reporting differences identified the dominant limb (as supporting limb) to display greater reach performances across various age groups (Bauer et al 2021). Although differences were present, the significant differences in two studies were not clinically meaningful; Borms & Cools (2018) reported limb asymmetry was below the 4cm cut-off, at 1.1cm, whilst the difference of 4.4% reported by Christian & Moran (2021) is unclear in relation to the absolute (cm) cut-off. A potential explanation for these differences may be attributed to the included sports (softball, volleyball, tennis and handball) which require critical movements (e.g., spike in volleyball) with the dominant limb, therefore testing the non-dominant arm as the stabilising limb may allow for greater trunk rotation than the dominant limb permits due to greater stability (Christian & Moran 2021). The aforementioned sports were also represented within a selection of studies which did not identify any differences between dominant and non-dominant limbs (Butler et al 2014b ; Borms et al 2016; Bauer et al 2020b; Stapleton et al 2021), therefore differences across these studies may be a result of additional factors e.g., age, sex, or competition level. This idea has been recently supported by Bauer et al (2023) who determined the relationship between reach scores and future injury occurrence may be a result of subject-related variables, suggesting reach scores may be multifactorial. Additionally, Bauer et al (2021) reported 15-18 year-old athletes were below their predetermined maximum asymmetry cut-off value of 7.75%LL, a threshold previously reported by Teyhen et al (2020) in warrior athletes and military personnel, whereby values >7.75%LL increases an individual's likelihood of future musculoskeletal injury by 1.2x. More recently, Bauer et al (2023) has reported that an asymmetry score >7.75%LL was associated with a moderate increase in injury risk for inferolateral reach only. However, the 13 and 14 year-old participants were above this cut-off value (Bauer et al 2021). This finding may be a result of maturation status and growth development (Schedler et al 2021); therefore, practitioners should aim to improve symmetry in younger athletes as it may reduce their risk of future upper limb injury.

Overall, the current findings suggest that between-limb differences are not common during YBT-UQ assessment in sporting populations, including sports typically regarded as asymmetrical. Therefore, practitioners can use asymmetry scores to identify which athletes may possess a greater risk of injury, allowing them to target individuals requiring further mobility/stability training and create plans to improve their dynamic function. Asymmetry scores can also be used as a monitoring tool to highlight changes over time.

Effects of interventions

At present, there is evidence to show that fatigue reduces YBT-UQ directional reach and CS (Salo & Chaconas 2017; Bauer et al 2020a), although the reach directions impacted are somewhat contentious. Similar findings were demonstrated on the YBT-LQ (Johnston et al 2018), whereby all reach directions were negatively affected by maximal aerobic fatigue. The findings of this review highlight a wide range of reductions in achieved scores (~1-12%LL), thereby demonstrating the importance of sufficient rest prior to functional testing to enable accurate determination of upper limb dynamic function (Savkin et al 2018; Bauer et al 2020a).

Furthermore, upper limb (TRX suspension) training can improve reach performance across both limbs, although it is important to note that participants were international-level athletes in a predominantly CKC sport, therefore clinicians should be cautious when transferring results to OKC sports (Norambuena et al 2021). Similarly, chronic core strengthening and stability interventions over 5- to 6-weeks improved directional reach and CS (Bauer et al 2022; Jha et al 2022), although findings were limited to young adults. However, this suggests that upper limb mobility/stability can be significantly improved within 5- to 6-weeks, which may allow clinicians to construct relevant programmes to induce improvements in dynamic function for rehabilitation purposes (Dittmer et al 2020). In contrast, acute interventions implemented during functional testing have shown no impact on performance (core activation and kinesiotape). Despite five of seven interventions demonstrating improvements, generalised findings should be applied with caution as the small and heterogeneous literature pool currently limits extrapolating to wider populations and settings.

Type of sport

The findings suggest the sport is an influencing factor on reach, as five studies found a difference in YBT-UQ scores by sport, whereas only one study did not (Butler et al 2014b). However, in that one study the lack of effect might have been due to the similarities between the sports compared (baseball and softball), which require similar movement patterns and thus a similar degree of upper limb functionality to perform. In contrast, one study which did report a difference in YBT-UQ scores by sport also compared baseball and softball (Stapleton et al 2021). This contrasting finding may be attributable to authors investigating older athletes (~19-20 years old) competing at Division 1 level, compared to younger athletes (~15 years old) competing at high school level. However, most studies identified differences between sports which were not of a similar nature e.g., wrestling and baseball (Myers et al 2017). Although athletes will have similar athletic attributes, sport-specific requirements will vary. Sports with greater CKC movements (e.g., wrestling) appear to achieve greater YBT-UQ reach distances than those of predominantly open-kinetic chain (OKC), e.g., running, suggesting that the type of sport influences reach due to greater CKC demands of the shoulder and core (Taylor et al

2016). This aligns with that of Chimera et al (2015) and Barrera-Domínguez et al (2021) who identified sport influenced dynamic ability during the YBT-LQ with sports requiring regular movement outside the base of support achieving greater distances.

Teyhen et al (2020) previously used a multifactorial model in military personnel/warrior athletes where YBT-LQ anterior reach <72% limb length was a risk factor for injury. The generation and implementation of cut points in various populations e.g., by sport(s) would enable practitioners to differentiate individual's injury risk based upon the demands of their sport. This review highlighted athletes in sports requiring a higher degree of CKC movements achieved greater reach scores than OKC sports; however, upper limb OKC sports (e.g., running) do not carry the same inherent risk of upper limb injury. Therefore, caution should be applied when generalising reach scores across sport populations and making clinical decisions (Plisky et al 2021).

Limitations

There are several important limitations to acknowledge in this systematic review. Firstly, the scope of the literature considered for inclusion was limited to English, which may have introduced bias by potentially excluding relevant studies. Moreover, the sample population included was strictly limited to individuals in sport, therefore, results may be confined to athletic individuals only and may not be generalisable to the wider population. Furthermore, the quality of included studies was vastly categorised as 'fair' which may be a consequence of questions relating to blinding of participants/assessors in each of the NIH tools utilised, therefore study bias may have influenced findings. However, it should be noted that due to the nature of included studies, whereby exercise methods of intervention/assessment are used, it is often difficult to blind study participants and/or assessors. Lastly, due to specific inclusion criteria relating to the calculation of relative reach scores as a proportion of limb length, there is a possibility that several relevant studies were excluded.

Conclusion

This review is the first to report on the factors influencing reach performance on the YBT-UQ. Age, sex, sport, and fatigue are influencing factors; however, results pertaining to age and core strength/stability interventions should be interpreted with caution due to the small number of studies included, whilst acute interventions (e.g., kinesiotape) warrant a greater number of high-quality studies to definitively determine their impact. Between-limb differences were not common among sporting populations and therefore asymmetries of the upper extremity may be useful to aid injury risk identification and return-to-play decisions. By acknowledging factors that influence reach performance, practitioners may be better placed to identify those with a potentially greater injury risk and create actionable plans to improve upper limb dynamic function. At present, the YBT-UQ may be most useful for injury risk identification when used alongside a battery of tests. Consideration should also be given to further evaluate the neuromuscular demands of the YBT-UQ e.g., using electromyography to quantify muscle activity.

Clinical relevance

- Age, sex, sport, and fatigue influence YBT-UQ reach scores.
- Normative YBT-UQ reach scores should be devised to enable clinicians/practitioners to identify those at potential risk of injury and advise on return to play.
- Early evidence suggests neuromuscular interventions > 5 weeks can improve YBT-UQ reach scores.
- The YBT-UQ may identify musculoskeletal injury risk, however it may be most useful within a battery of functional tests with injury monitoring for accurate prediction.

- Future work should generate population-specific cut points to allow clinicians to assess injury risk via a larger predictive model.

Future research

More data on the effect of modifiable factors (e.g., neuromuscular activity) on YBT-UQ scores from high-quality studies are needed to build a larger predictive model with normative scores and population-specific cut-points. This would consider the multifactorial nature of injury risk prediction and guide practitioners on neuromuscular training needs in their clients and upper limb control, thereby enhancing dynamic function. Bias may be limited in future studies through the provision and justification for sample sizes to ensure adequate power as this review included twenty studies that failed to report on this. Further, studies in future should adequately report their randomisation method where applicable to enhance confidence in outcome measures. Future research should also consider the implications of footwear on reach scores achieved. This review included studies with and without footwear, with a large proportion of studies failing to report if participants performed the test barefoot, therefore its impact was outside of the scope for this review.

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Table 1. Characteristics of included studies

First author and year	Purpose	Participants			
		Total sample size (n=)	Age mean±SD	Sex	Sport
Arora, 2021	Influence core activation on UE performance in basketball players	36	17-25 (range)	M	Basketball
Bauer, 2020a	Pre- to post-fatigue differences in UE mobility and stability	24	14.8 ± 0.7	M	Handball
Bauer, 2020b	Differences between throwing/non-throwing arms	56	F = 13 M = 14-15	14 F 42 M	Handball
Bauer, 2021	Assess differences between throwing/non-throwing arms in handball players of varying ages	190	13-18 (range)	80 F 110 M	Handball
Bauer, 2022	6-week core strengthening training with handball training versus handball training only on muscular endurance, shoulder stability/mobility and throwing velocity	26	INT(16.9 ± 0.6) C(17.2 ± 0.8)	M	Handball
Bauer, 2023	Determine if pre-season reach scores are associated with sport-related injury occurrence	133	15.7 ± 1.7	42 F 91 M	Handball
Beyranvand, 2017	Compare stability in healthy & rounded shoulder gymnasts	30	9-12 (range)	M	Gymnastics
Borms, 2016	Compare strength and SMBT/YBT-UQ performance in overhead athletes	29	21.6 ± 2.5	15 F 14 M	Volleyball, Basketball, Badminton, Handball, Tennis
Borms, 2018	Age, gender and sport reference values for UE tests	206	18-50 (range)	100 F 106 M	Volleyball Tennis Handball

Table 1. Characteristics of included studies

First author and year	Purpose	Participants			
		Total sample size (n=)	Age mean±SD	Sex	Sport
Bullock, 2017	Differences on YBT-UQ and FMS in swimmers	140	HS: M = 17.0 ± 1.1 F = 16.7 ± 0.7 COL: 20.8 ± 1.2 20.5 ± 1.2	63 F 77 M	Swimming
Butler, 2014a	Compare sex on YBT-UQ reach in swimmers	97	M 19.3 ± 1.2 F 19.1 ± 0.7	54 F 43 M	Swimming
Butler, 2014b	Limb differences in UE function in HS baseball and softball	65	B(15.8 ± 1.2) SB(15.1 ± 1.1)	M/F	Baseball, Softball
Christian, 2021	Compare limb differences in collegiate softball players	22	18-23 (range)	F	Softball
Dittmer, 2021	Effectiveness of Kinesio tape application on closed kinetic chain shoulder proprioception and ROM in athletes with rounded shoulder posture	19	19.8 ± 1.9	M	American football, Baseball, Soccer, Rodeo
Jha, 2022	Effects of 5-week core stability training on UE performance measures	70	INT(22.1 ± 1.6) C(21.5 ± 1.5)	48 M 22 F	Rowing
Myers, 2017	Compare core and shoulder closed kinetic chain functional performance via YBT-UQ in wrestlers versus baseball players	48	W(16.12 ± 1.24) B(15.79 ± 1.25)	M	Wrestling, Baseball
Norambuena, 2021	Determine changes in physical performance traits after a 5-week suspension-training programme	10	15.4 ± 2.8	8 F 2 M	Judo

Table 1. Characteristics of included studies

First author and year	Purpose	Participants			
		Total sample size (n=)	Age mean±SD	Sex	Sport
Ruffe, 2019	Determine if the YBT could predict running related injuries in cross-country runners	148	15.6 ± 1.2	80 F 68 M	Cross-country running
Salo, 2017	Fatigue on YBT-UQ performance in recreational weightlifters	24	25.7 ± 2.67	7 F 17 M	Weightlifting
Schwiertz, 2020	Determine discriminative validity of the YBT-UQ by comparing age- and sex-matched trained vs. untrained youth	74	S(12.3 ± 2.1) C(12.5 ± 2.0)	44 F 30 M	Swimming
Singla, 2018	Assess correlation between UE balance, strength, and power in cricketers of various age groups	48	Adolescent (16.42 ± 0.99) Adult (20.91 ± 1.74)	M	Cricket
Stapleton, 2021	Identify associations between movement competency, UE dynamic stability, and athletic performance in baseball and softball athletes	38	B(20 ± 1.38) SB(19.93 ± 1.28)	M/F	Baseball, Softball
Taylor, 2016	Establish normative values for YBT-UQ/CKCUEST and compare by sex and sport	257	M(19.3 ± 1.2) F(19.2 ± 1.2)	139 F 118 M	Baseball, Basketball, Lacrosse, Cross-country running, Soccer, Volleyball & Track & Field

B = baseball; C = control group; CKCUEST = closed kinetic chain upper extremity test; COL = collegiate; F = female; FMS = functional movement screen; H = healthy; HS = high school; I = injury history; INT = intervention group; L = left; M = male; MS = middle school; PRO = professional; R = right; ROM = range of motion; S = swimming; SMBT = seated medicine ball throw; SB softball; UE = upper extremity; V = volleyball; W = wrestling; YBT-UQ = y balance test upper quarter

Table 2. Study findings

First author and year	Study findings				
	Inferolateral (%LL)	Medial (%LL)	Superolateral (%LL)	Composite Score (%LL)	Results
Arora, 2021				Group 1: 89.36 ± 3.10 Group 2: 89.39 ± 6.94 Group 3: 89.99 ± 4.93 Group 4: 88.97 ± 6.42	• Participants assigned to groups based on outcomes of the Sahrmann Core Stability Test, conducted during pre-testing • No differences between core activation groups: (1) high core strength group with core activation, (2) high core strength group without core activation, (3) low core strength group with core activation, (4) low core strength group without core activation
Bauer, 2020a	Fatigue: D (108.2 ± 12.28), ND (110.1 ± 9.3) Non-fatigue: D (109.2 ± 11.6) ND (110.5 ± 10.6)	Fatigue: D (107.6 ± 8.0) ND (110.2 ± 8.5) Non-fatigue: D (109.5 ± 8.9) ND (111.6 ± 9.5)	Fatigue: D (80.4 ± 10.8) ND (79.9 ± 11.2) Non-fatigue: D (84.8 ± 11.8) ND (89.1 ± 10.20)	Fatigue: D (98.7 ± 7.5) ND (100.0 ± 7.3) Non-fatigue: D (101.2 ± 8.3) ND (103.7 ± 7.2)	• Fatigue significantly reduced SL and CS in both D and ND limbs • Fatigue did not impact on ME or IL reach scores on either limb
Bauer, 2020b	13yrs: D (98.9 ± 11.0) ND (98.2 ± 12.8) 14yrs: D (108.8 ± 12.1) ND (106.9 ± 12.2) 15yrs: D (106.0 ± 10.6) ND (104.8 ± 8.1)	13yrs: D (111.8 ± 10.0) ND (111.8 ± 7.3) 14yrs: D (112.4 ± 7.6) ND (112.7 ± 6.9) 15yrs: D (111.2 ± 10.6) ND (110.6 ± 10.6)	13yrs: D (79.4 ± 8.6) ND (78.1 ± 7.3) 14yrs: D (82.5 ± 8.8) ND (79.9 ± 9.4) 15yrs: D (79.1 ± 11.6) ND (80.0 ± 10.0)	13yrs: D (96.7 ± 7.1) ND (96.1 ± 7.5) 14yrs: D (101.1 ± 7.5) ND (99.7 ± 7.1) 15yrs: D (98.7 ± 8.5) ND (98.3 ± 7.3)	• No consistent differences between D and ND limbs • Only SL in 14y/o M demonstrated significant difference between limbs
Bauer, 2021	13yrs: D (99.1 ± 10.6) ND (98.3 ± 14.0) 14yrs: D (108.1 ± 11.7) ND (104.5 ± 13.1) 15yrs: D (99.3 ± 11.8) ND (99.5 ± 13.0) 16yrs: D (109.1 ± 17.9) ND (107.2 ± 18.2)	13yrs: D (109.2 ± 11.5) ND (108.3 ± 8.5) 14yrs: D (110.6 ± 9.0) ND (109.5 ± 8.7) 15yrs: D (107.7 ± 9.4) ND (105.6 ± 9.9) 16yrs: D (106.6 ± 18.4) ND (105.3 ± 17.1)	13yrs: D (77.8 ± 11.0) ND (78.4 ± 12.9) 14yrs: D (83.5 ± 8.8) ND (80.4 ± 9.8) 15yrs: D (84.7 ± 11.6) ND (83.2 ± 11.6) 16yrs: D (87.0 ± 10.9) ND (85.2 ± 11.4)	13yrs: D (95.4 ± 8.8) ND (95.0 ± 10.0) 14yrs: D (100.6 ± 8.2) ND (98.0 ± 8.4) 15yrs: D (97.2 ± 8.4) ND (96.1 ± 9.4) 16yrs: D (100.9 ± 8.9) ND (99.2 ± 10.0)	• Significant age effect for ME – 13 and 14 year old players achieve greater reach than 17 year old players. • Significant age effect for SL – 18 year old players achieve greater reach score than 13 year old players. • No age effect regarding IL reach. • Significant between-limb differences in 13 year old players (IL, SL, CS), 15 year old players (ME), 16 year old players (CS) and 18 year old players (SL). • No age x side interaction effects observed. • Directional reach scores here are presented for 13, 14, 15, and 16 year old athletes, readers are referred to the original article for 17 and 18 year old results.

Table 2. Study findings

First author and year	Study findings				
	Inferolateral (%LL)	Medial (%LL)	Superolateral (%LL)	Composite Score (%LL)	Results
Bauer, 2022	**Pre** Intervention: D (111.9 ± 15.1) ND (111.0 ± 14.1) Control: D (100.2 ± 9.5) ND(101.7 ± 11.0) **Post** Intervention: D (113.5 ± 11.9) ND (111.2 ± 12.6) Control: D (100.8 ± 11.8) ND (99.5 ± 14.6)	**Pre** Intervention: D (116.7 ± 6.5) ND (115.4 ± 8.2) Control: D (108.6 ± 9.1) ND (108.1 ± 7.5) **Post** Intervention: D (117.2 ± 10.6) ND (116.1 ± 8.6) Control: D (105.9 ± 7.7) ND (107.7 ± 9.2)	**Pre** Intervention: D (82.5 ± 9.9) ND (80.6 ± 11.7) Control: D (85.0 ± 13.5) ND (81.2 ± 12.7) **Post** Intervention: D (91.3 ± 8.6) ND (91.2 ± 9.7) Control: D (84.9 ± 13.7) ND (81.1 ± 14.1)	**Pre** Intervention: D (103.7 ± 8.8) ND (102.3 ± 8.9) Control: D (97.9 ± 8.8) ND (97.0 ± 9.2) **Post** Intervention: D (107.3 ± 8.3) ND (106.2 ± 8.4) Control: D (97.2 ± 9.2) ND (96.1 ± 9.1)	• D (throwing arm) reach showed significant differences between means, favouring intervention group. • ND (non-throwing arm) reach showed significant differences between means for IL and CS, favouring intervention group.
Bauer, 2023	Non-injured TA (105.6 ± 14.0) NTA (104.9 ± 14.5)	Non-injured TA (110.2 ± 11.3) NTA (108.1 ± 9.8)	Non-injured TA (85.8 ± 11.7) NTA (83.6 ± 12.8)	Non-injured TA (100.5 ± 10.0) NTA (98.9 ± 9.8)	• No statistical analysis for between-limb differences reported. • Reach distance and asymmetry not confirmed as factors indicating increased injury risk in current group.
Beyranvand, 2017	H: D (85.07 ± 2.25) ND (85.73 ± 3.73) RS: D (82.80 ± 3.36) ND (83.13 ± 3.09)	H: D (94.73 ± 2.40) ND (95.72 ± 2.57) RS: D (92.13 ± 3.42) ND (92.67 ± 2.49)	H: D (71.60 ± 3.29) ND (72.13 ± 3.11) RS: D (68.53 ± 4.05) ND (69.07 ± 3.63)	H: D (83.80 ± 2.52) ND (84.37 ± 2.49) RS: D (81.15 ± 3.54) ND (81.62 ± 2.32)	• No consistent differences between D and ND limbs within either group • Results significantly higher in H group for all reach directions and CS on both limbs
Borms, 2016	D (96.09 ± 12.07) ND (96.35 ± 10.17)	D (101.22 ± 7.32) ND (101.07 ± 6.16)	D (73.12 ± 10.24) ND (71.54 ± 10.26)	D (90.14 ± 7.56) ND (89.65 ± 6.02)	• No differences between D and ND limbs for any reach direction

Table 2. Study findings

First author and year	Study findings				
	Inferolateral (%LL)	**Medial (%LL)**	**Superolateral (%LL)**	**Composite Score (%LL)**	**Results**
Borms, 2018	Volleyball – M (D): 18-25y/o: (93.65 ± 12.93) 26-33y/o: (95.19 ± 10.10) 35-50y/o: (90.84 ± 7.80) Volleyball – M (ND): 18-25y/o: (93.47 ± 10.20) 26-33y/o: (95.68 ± 10.84) 35-50y/o: (91.71 ± 10.34) Volleyball – F (D): 18-25y/o: (84.28 ± 12.42) 26-33y/o: (82.13 ± 16.67) 35-50y/o: (63.47) Volleyball – F (ND): 18-25y/o: (86.07 ± 12.54) 26-33y/o: (82.51 ± 11.28) 35-50y/o: (77.02)	Volleyball – M (D): 18-25y/o: (104.21 ± 5.30) 26-33y/o: (101.12 ± 3.62) 35-50y/o: (100.39 ± 2.15) Volleyball – M (ND): 18-25y/o: (104.67 ± 5.08) 26-33y/o: (102.21 ± 2.74) 35-50y/o: (102.83 ± 4.46) Volleyball – F (D): 18-25y/o: (96.37 ± 8.81) 26-33y/o: (93.23 ± 11.87) 35-50y/o: (91.90) Volleyball – F (ND): 18-25y/o: (96.65 ± 7.89) 26-33y/o: (91.02 ± 10.94) 35-50y/o: (92.01)	Volleyball – M (D): 18-25y/o: (72.14 ± 9.58) 26-33y/o: (73.34 ± 7.40) 35-50y/o: (65.58 ± 11.95) Volleyball – M (ND): 18-25y/o: (73.08 ± 11.46) 26-33y/o: (71.52 ± 9.12) 35-50y/o: (66.23 ± 8.49) Volleyball – F (D): 18-25y/o: (66.73 ± 13.59) 26-33y/o: (52.81 ± 12.07) 35-50y/o: (34.46) Volleyball – F (ND): 18-25y/o: (68.57 ± 11.11) 26-33y/o: (56.38 ± 15.46) 35-50y/o: (43.13)	Volleyball – M (D): 18-25y/o: (90.00 ± 7.48) 26-33y/o: (89.89 ± 5.27) 35-50y/o: (85.60 ± 2.21) Volleyball – M (ND): 18-25y/o: (90.41 ± 6.91) 26-33y/o: (89.80 ± 5.74) 35-50y/o: (86.92 ± 4.77) Volleyball – F (D): 18-25y/o: (82.46 ± 10.59) 26-33y/o: (76.06 ± 11.49) 35-50y/o: (63.28) Volleyball – F (ND): 18-25y/o: (84.43 ± 9.04) 26-33y/o: (77.49 ± 9.23) 35-50y/o: (70.87)	• Significant effect in ME - sport • M significantly higher than F in all sport, both limbs and CS • Significant difference for ND compared to D limb for CS • Directional reach and CS values reported here are volleyball only, readers are referred to the original article for further results by age and sex for tennis and handball • F IL score is mean only (no standard deviation) as only one participant constituted this category (volleyball, 34-50y/o) • No significant age effects on any reach direction or CS
Bullock, 2017	Competition level average: HS (97.76 ± 13.72) COL (99.46 ± 13.97)	Competition level average: HS (97.95 ± 9.02) COL (103.17 ± 7.73) Competition level by sex averages: HS: M (101.63 ± 7.45) F (92.06 ± 8.23) COL: M (105.15 ± 7.89) F (101.30 ± 7.19)	Competition level average: HS (75.28 ± 1.16) COL (78.95 ± 1.13) Average by sex: M (78.86 ± 9.73) F (75.46 ± 9.24)		• COL significantly greater reach in ME, IL, and SL reach than HS (age/competition effect) – limb was not stated • Significant sex effects in ME and SL reach • CS not reported • Data by sex for IL, sex x competition level for IL and SL not available, and only data for significant values reported
Butler, 2014a	M (89.8 ± 10.8) F (85.6 ± 10.3)	M (100 ± 8.8) F (92.5 ± 8.1)	M (74.9 ± 9.7) F (72.1 ± 11.2)	M (88.3 ± 8.9) F (83.4 ± 8.3)	• Significant sex difference for CS, ME and IL (M>F) • No sex differences in SL reach

Table 2. Study findings

First author and year	Study findings				
	Inferolateral (%LL)	**Medial (%LL)**	**Superolateral (%LL)**	**Composite Score (%LL)**	**Results**
Butler, 2014b				D (86.6 ± 8.1) ND (87.2 ± 8.9) M (87.1 ± 8.6) F (86.3 ± 8.4)	• No consistent differences between D and ND limbs for any reach direction or CS • No significant difference between M (B) and F (S) for any reach direction or CS • Numerical values for directional reach data not provided
Christian, 2020	D (80.1 ± 10.5) ND (83.7 ± 12.2)	D (88.7 ± 10.7) ND (88.0 ± 10.9)	D (62.5 ± 10.1) ND (61.1 ± 11.0)	D (76.4 ± 8.1) ND (78.3 ± 8.7)	• Significant difference in ND limb for IL • No significant differences between D and ND limb for ME, SL, or CS
Dittmer, 2019	Kinesio tape: BA (91.9 ± 13.6) PI (95.2 ± 12.9) Non-kinesio tape: BA (97.9 ± 12.7) PI (99.7 ± 12.2)	Kinesio tape: BA (96.0 ± 7.2) PI (96.2 ± 5.7) Non-kinesio tape: BA (97.8 ± 7.0) PI (96.7 ± 7.7)	Kinesio tape: BA (67.0 ± 8.1) PI (68.2 ± 6.7) Non-kinesio tape: BA (71.6 ± 7.0) PI (72.7 ± 7.5)	Kinesio tape: BA (85.0 ± 7.7) PI (86.2 ± 6.7) Non-kinesio tape: BA (89.1 ± 7.3) PI (89.3 ± 7.1)	• No difference between conditions (kinesio tape vs. non-kinesio tape) for any reach direction • Only assessed D limb
Jha, 2022				Intervention: Pre (76.8 ± 9.4) Post (92.0 ± 11.2) Control: Pre (82.2 ± 13.4) Post (81.8 ± 12.1)	• Intervention group demonstrated ~19% improvement in CS (mean change = 15.2, p<0.001) • Control did not show any statistically significant improvement in reach
Myers, 2017	W: R (93.98 ± 11.68) L (96.89 ± 13.08) B: R(85.29 ± 8.39) L (85.59 ± 7.45)	W: R (106.99 ± 10.54) L (107.59 ± 11.04), B: R (97.04 ± 7.10) L (87.05 ± 5.89)	W: R (73.92 ± 15.14) L (71.93 ± 12.08) B: R (73.08 ± 8.76) L (70.90 ± 8.26)	W: R (91.63 ± 9.70) L (92.14 ± 9.60) B: R (84.51 ± 5.40) L (85.14 ± 6.30)	• W significantly greater CS, ME and IL than B • No difference on SL • No consistent differences between L and R limbs

Table 2. Study findings

First author and year	Study findings				
	Inferolateral (%LL)	Medial (%LL)	Superolateral (%LL)	Composite Score (%LL)	Results
Norambuena, 2021				Pre-intervention: R (80.9 ± 9.2) L (81.4 ± 8.6) Post-intervention: R (89.3 ± 8.4) L (90.0 ± 9.6)	• Suspension training elicited significant improvements in CS on both R and L limbs • Numerical values for directional reach data not provided • No consistent differences between limbs
Ruffe, 2019	M: R (89.7 ± 9.9) L (90.6 ± 11.3) F: R (85.5 ± 10.3) L (87.3 ± 9.0)	M: R (91.3 ± 9.2) L(90.9 ± 8.8) F: R (85.5 ± 9.8) L (87.3 ± 9.0)	M: R (68.5 ± 68.9) L (68.9 ± 9.9) F: R (65.4 ± 9.3) L (66.7 ± 9.9)	M: R (92.7 ± 9.1) L (92.5 ± 9.6) F: R (92.4 ± 8.0) L (92.2 ± 9.7)	• M significantly greater reach scores in ME, IL and CS than F for both R and L limbs • No sex differences for SL reach • No consistent differences between limbs
Salo, 2017	**Pre-test** Non-fatigue: R (92.37 ± 8.22) L (85.84 ± 10.80) Fatigue: R (95.56 ± 7.51) L (87.48 ± 6.35) **Post-test** Non-fatigue: R (94.72 ± 11.40) L (87.05 ± 9.54) Fatigue: R (87.55 ± 8.75) L (79.98 ± 8.57)	**Pre-test** Non-fatigue: R (97.05 ± 8.22) L (99.76 ± 8.04) Fatigue: R (100.74 ± 4.83) L (100.50 ± 5.69) **Post-test** Non-fatigue: R (98.10 ± 8.84) L (101.51 ± 8.65) Fatigue: R (96.11 ± 5.86) L (98.51 ± 7.59)	**Pre-test** Non-fatigue: R (68.33 ± 10.78) L (69.60 ± 11.39) Fatigue: R (65.58 ± 5.86) L (67.18 ± 7.06) **Post-test** Non-fatigue: R (68.38 ± 9.97) L (70.89 ± 10.93) Fatigue: R (55.50 ± 8.54) L (55.02 ± 8.32)	**Pre-test** Non-fatigue: R (85.92 ± 9.06) L (85.07 ± 9.45) Fatigue: R (87.29 ± 3.85) L (86.72 ± 4.89) **Post-test** Non-fatigue: R (87.09 ± 86.48) L (86.48 ± 9.09) Fatigue: R (79.72 ± 4.65) L (77.83 ± 6.10)	• Fatigue caused significant reductions in ME, IL, SL reach and CS, post-test (2.04-12.16cm) for both R and L limbs • No statistical comparison of R and L limbs within groups provided
Schwiertz, 2020	Swimmers: R (102.2 ± 13.5) L (101.8 ± 12.9) Untrained: R (87.2 ± 16.6) L (88.3 ± 17.5)	Swimmers: R (104.0 ± 8.4) L (102.3 ± 6.8) Untrained: R (94.5 ± 11.9) L (92.7 ± 10.4)	Swimmers: R (83.3 ± 9.3) L (79.0 ± 9.4) Untrained: R (67.0 ± 12.6) L (65.8 ± 13.8)	Swimmers: R (96.0 ± 8.1) L (94.8 ± 9.0) Untrained: R (82.9 ± 12.1) L (82.3 ± 12.3)	• Significant difference between swimmers and untrained controls for ME, IL, SL, and CS for R and L limbs • Absolute values (cm) showed significant differences between swimmers and untrained controls in ME, IL, and SL directions for R and L limbs • Significant differences between reach directions (ME > IL > SL)

Table 2. Study findings

First author and year	Study findings				
	Inferolateral (%LL)	Medial (%LL)	Superolateral (%LL)	Composite Score (%LL)	Results
Singla, 2018				D: Adolescents (87.3 ± 7.66) Adults (90.52 ± 9.48) ND: Adolescents (86 ± 8.4) Adults (91.38 ± 8.73)	• Adults achieved significantly greater CS than adolescents – ND only • Only provide CS, no numerical values for directional reach data provided
Stapleton, 2021	B (99.63 ± 14.76) S (87.81 ± 17.13)	B (108.08 ± 32.65) S (92.35 ± 16.56)	B (68.17 ± 9.94) S (63.18 ± 14.94)	B (91.96 ± 13.17) S (81.11 ± 14.35)	• Significant difference for IL and CS between M/F and B/S, data provided as mean scores for each group and not separated by L/R limbs
Taylor, 2016	M: D (110.1 ± 13.1) ND (110.7 ± 13.8) F: D (97.9 ± 16.2) ND (98.5 ± 14.6)	M: D (111.4 ± 9.4) ND (110.5 ± 9.0) F: D (99.1 ± 10.5) ND (100.4 ± 10.9)	M: D (82.8 ± 11.9) ND (84.2 ± 12.1) F: D (78.1 ± 13.0) ND (77.5 ± 12.9)	M: D (101.4 ± 9.1) ND (101.8 ± 8.7) F: D (91.7 ± 10.8) ND (92.1 ± 9.7)	• No consistent differences between D and ND limbs • Significant effect for sex on CS, ME and IL • Significant effect for sport on CS, ME, IL and SL • Results reported here are sex only, readers are referred to the original paper for reach distances by sport

B = baseball; BA = baseline; COL = collegiate; CS = composite score; D = dominant; F = female; H = healthy; HS = high school; I = injury history; IL = inferolateral; L = left limb; LL = limb length; M = male; ME = medial; MS = middle school; ND = non-dominant; PI = post-intervention; PRO = professional; R = right limb; RS = rounded shoulders; S = softball; SL = superolateral; TA = throwing arm; NTA = non-throwing arm; W = wrestling.

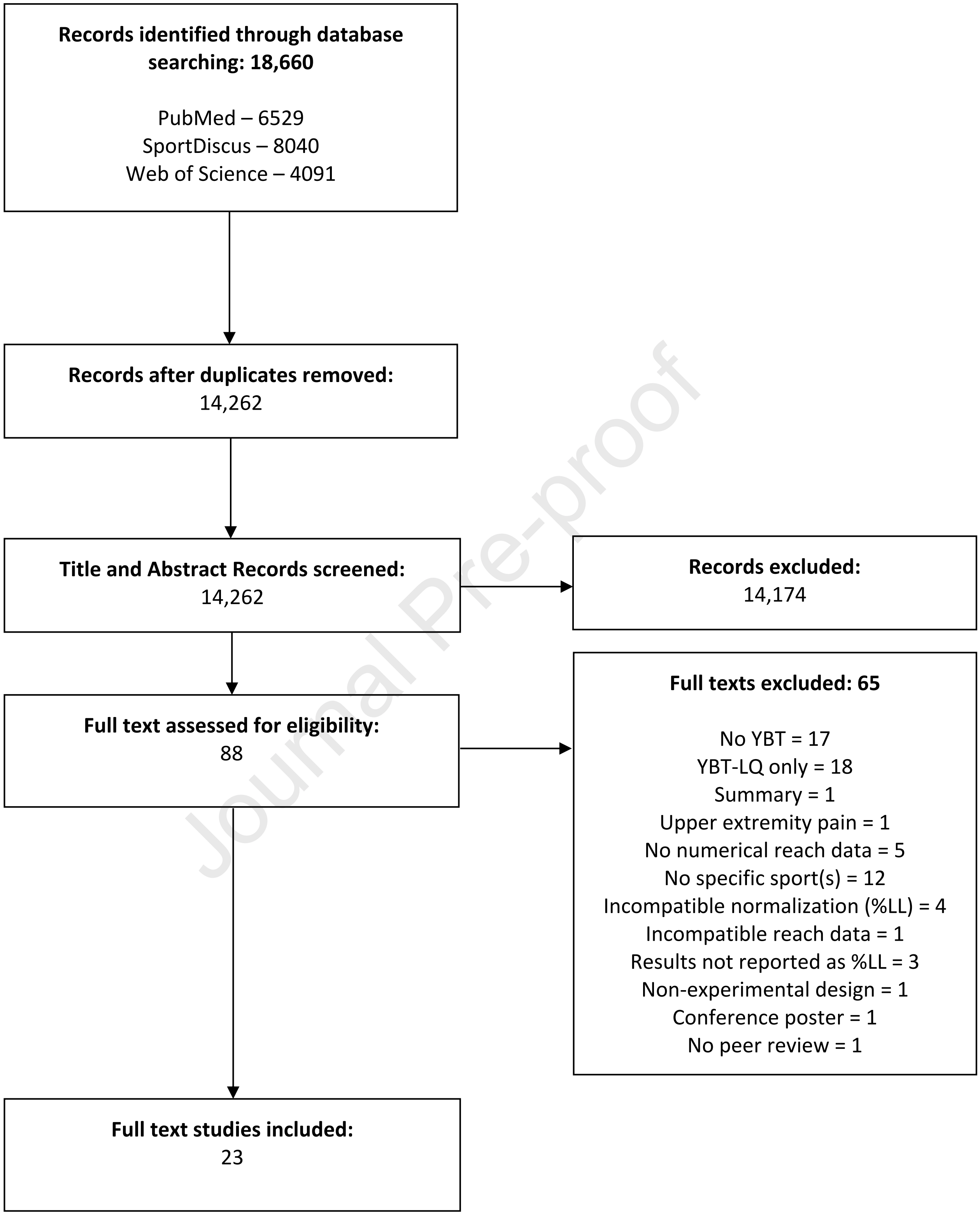

Figure 1. PRISMA flow diagram of systematic literature search

The authors have no competing interests or conflicts of interest to declare.

Declarations of interest: none.