


Please cite the Published Version

Richardson, Eleanor, Lewis, Jeremy S, Gibson, Jo, Morgan, Chris, Halaki, Mark, Ginn, Karen and Yeowell, Gillian  (2020) Role of the kinetic chain in shoulder rehabilitation: does incorporating the trunk and lower limb into shoulder exercise regimes influence shoulder muscle recruitment patterns? Systematic review of electromyography studies. *BMJ Open Sport & Exercise Medicine*, 6. e000683-e000683.

DOI: <https://doi.org/10.1136/bmjsem-2019-000683>

Publisher: BMJ

Version: Published Version

Downloaded from: <https://e-space.mmu.ac.uk/625604/>




Usage rights:  [Creative Commons: Attribution-Noncommercial 4.0](https://creativecommons.org/licenses/by-nc/4.0/)

Additional Information: This is an Open Access article published in *BMJ Open Sport & Exercise Medicine*, published by BMJ, copyright The Author(s).

Enquiries:

If you have questions about this document, contact openresearch@mmu.ac.uk. Please include the URL of the record in e-space. If you believe that your, or a third party's rights have been compromised through this document please see our Take Down policy (available from <https://www.mmu.ac.uk/library/using-the-library/policies-and-guidelines>)

Role of the kinetic chain in shoulder rehabilitation: does incorporating the trunk and lower limb into shoulder exercise regimes influence shoulder muscle recruitment patterns? Systematic review of electromyography studies

Eleanor Richardson ^{1,2} Jeremy S Lewis ^{3,4,5} Jo Gibson,^{6,7} Chris Morgan,⁸ Mark Halaki,⁹ Karen Ginn,⁹ Gillian Yeowell ²

To cite: Richardson E, Lewis JS, Gibson J, *et al*. Role of the kinetic chain in shoulder rehabilitation: does incorporating the trunk and lower limb into shoulder exercise regimes influence shoulder muscle recruitment patterns? Systematic review of electromyography studies. *BMJ Open Sport & Exercise Medicine* 2020;**6**:e000683. doi:10.1136/bmjsem-2019-000683

▶ Additional material is published online only. To view, please visit the journal online (<http://dx.doi.org/10.1136/bmjsem-2019-000683>).

Accepted 8 March 2020



© Author(s) (or their employer(s)) 2020. Re-use permitted under CC BY-NC. No commercial re-use. See rights and permissions. Published by BMJ.

For numbered affiliations see end of article.

Correspondence to
Eleanor Richardson;
ellierichardson44@hotmail.com

ABSTRACT

Objective To investigate the influence of trunk and lower limb motion on electromyography (EMG) muscle activity and recruitment patterns around the shoulder.

Design Systematic review.

Data sources MEDLINE, CINAHL, PEDro, AMED, PubMed, Cochrane Central Register of Controlled trials, Cochrane Database of Systematic reviews, SportsDiscuss and PROSPERO.

Eligibility criteria Studies investigating both multiregional kinetic chain (KC) shoulder exercises *and* localised non-kinetic chain (nKC) shoulder exercises in healthy subjects under the same experimental conditions were included in this review.

Results KC exercises produced greater EMG activation levels in 5 of 11 studies for the lower trapezius. Of the remaining studies, five found no difference between the exercise types and one favoured nKC exercises. KC exercises produced greater EMG activation levels in 5 of 11 studies for the serratus anterior. Of the remaining studies, three reported the opposite and three found no significant difference between the exercise types. nKC exercises produced greater EMG activation in infraspinatus in three of four studies. KC exercises produced the lowest trapezius muscle ratios in all studies. Studies investigating the upper trapezius, middle trapezius, supraspinatus, subscapularis, biceps brachii, latissimus dorsi, pectoralis major, deltoid, and trapezius and serratus anterior ratios showed inconsistency.

Conclusion This review found evidence that integrating the KC during shoulder rehabilitation may increase axio-shoulder muscle recruitment, produce lower trapezius muscle ratios and reduce the demands on the rotator cuff. Stepping appears preferable to squatting.

PROSPERO registration number CRD42015032557, 2015.

INTRODUCTION

During sporting and non-sporting activities, the shoulder complex works as an integral part of the whole musculoskeletal system and

What is already known?

- ▶ Kinetic chain (KC) exercises are often advocated over an isolated local shoulder exercise approach during the rehabilitation of the shoulder, but its relevance is not well understood.
- ▶ This review suggests that integrating the KC into shoulder rehabilitation exercises may enhance axio-shoulder muscle recruitment, produce lower trapezius muscle ratios and reduce the demands on the rotator cuff when compared with non-kinetic chain (nKC) exercises.

What are the new findings?

- ▶ How the KC is integrated is key: stepping appears preferable to squatting.
- ▶ KC exercises using lower quadrant weight transfer may reduce the demands on the rotator cuff. nKC exercises may be preferable when the rehabilitation goal is to isolate and strengthen the rotator cuff.

not in isolation.¹⁻⁶ The term kinetic chain (KC) refers to the sequential task specific activation of body segments during functional movement patterns.^{1 3} An efficient KC will generate, summate and permit efficient mechanical energy transfer throughout the whole chain contributing to function.^{1 4} Inefficiency within the KC at any 'link' has the potential to detrimentally affect force transfer to adjacent segments,^{1 3 4} which may require other components of the chain to increase their contribution to accommodate the energy loss.^{1 4} This has been postulated as a predisposing factor that increases the risk of shoulder injury and pain in overhead athletes.^{1 3 7-9}

In tennis, the leg and the trunk generate 50%–55% of the total kinetic energy required for the serve.^{3 4} Lumbopelvic–hip stability and gluteal muscle activation are essential requirements for an efficient baseball pitch.^{10–14} Reduced hip abduction strength and hip range of motion have also been associated with increased risk of shoulder and elbow injury in throwing athletes.^{1 7–9 15–17} In addition, substantially higher rates of energy transfer through the shoulder complex have been observed during a tennis serve in injured players compared with their uninjured counterparts.⁴ Overhead athletes with lower limb injuries also appear to have an increased risk of upper limb injuries and pain,^{1 4 7–9 15–19} as well as reduced performance.^{4 20–22} Lower limb peak power has been found to be the primary determinant of throwing velocity in elite handball players²¹ and also strongly correlated with sprint-swim speed in freestyle swimmers.²³ In addition, maximum velocity and muscle mass of the lower limb have been reported to be significantly correlated with javelin throwing performance in elite athletes.²⁰

Isolated shoulder exercises may not address the altered global muscle activation patterns observed in those with shoulder injuries.^{1–3 6} Isolated shoulder exercises may address local strength deficits, yet local strength deficits are not definitively associated with shoulder injury.^{24–30} Consequently, clinicians frequently advocate the inclusion of lower extremity and trunk motion into shoulder rehabilitation programmes to optimise efficient energy transfer throughout the whole KC.^{1–3 5 6 31}

The relevance of a KC approach over an isolated local shoulder exercise approach during the rehabilitation of the shoulder is not well understood. Therefore, the primary aim of this study was to investigate the influence of trunk and lower limb activity on the electromyography (EMG) and muscle recruitment patterns around the shoulder in a non-symptomatic population. A secondary aim was to identify deficits in current knowledge that would provide guidance for future research to better understand the relevance of the KC in normal function and rehabilitation.

METHODS

The principles of the participants, interventions, comparisons, outcomes and study design (PICOS) criteria were followed and conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines.³²

Eligibility criteria

Studies

Preliminary searching identified the need to include non-randomised studies in the review to ensure that all studies relevant to the research question were evaluated. Studies considered level 3 and above on the 2011 Oxford Centre for Evidence-Based Medicine (OCEBM)³³ were eligible for inclusion. Only studies published in English were evaluated, and no publication date or status restrictions were imposed. Only

studies interpreting original data with ethical approval were included.

Participants

Studies conducted on healthy adults (or with a healthy subject cohort group) over 16 years of age were included. Studies investigating wheelchair users were excluded as the aims were to assess the role of leg and trunk motion on shoulder function.

Intervention

Studies investigating the use of *both* KC shoulder exercises and local non-kinetic chain (nKC) shoulder exercises under the same experimental conditions were included. KC exercises investigated in studies were not required to be exclusively direct movement comparisons of their nKC counterparts. Additionally, both open KC and closed KC were included, assuming they also involved activating the muscles of the trunk or the lower limb and/or the motion of these segments.

Outcomes

Studies evaluating EMG activity using both surface and indwelling electrodes were included.

Search strategy

Studies were identified by searching the following databases: MEDLINE (in-process and other non-indexed citations and OVID MEDLINE), CINAHL, PEDro, AMED, PubMed, Cochrane Central Register of Controlled trials, Cochrane Database of Systematic reviews, SportsDiscuss and PROSPERO. Searches were conducted on 10 May 2018 and reran on 7 September 2019.

Abstract and subject heading search phrases were developed and finalised jointly by three reviewers (ER, CM and GY) following extensive background research (table 1).

The outcome of interest in this study was EMG, and to ensure all relevant studies were considered, such as those where EMG did not appear in the title or abstract but was used as an outcome measure, it was necessary to broaden the terms used. Similarly, while the intervention of interest in this study was the KC, to ensure the inclusion of all relevant studies, broader search terms in relation to exercise therapy were used (table 1). Titles and abstracts were independently reviewed for eligibility, and any discrepancies were discussed. Disagreements on inclusion of articles were resolved through discussion between ER and CM and, when necessary, a third reviewer (JG). Only studies meeting the full eligibility criteria were considered for review. Manual searching of the reference lists of included articles to identify any additional studies meeting the inclusion criteria was also conducted (figure 1).

METHODOLOGICAL QUALITY ASSESSMENT

Methodological quality of included studies was independently assessed by two reviewers (ER and CM) using the modified Downs and Black tool (mD&B).^{34–41} The tool

Table 1 PICOS abstract and subject heading search phrases

PICOS abstract and subject heading search phrases

Population: anatomical region	(shoulder) OR (Glenohum*) OR (scapula) OR (shoulder girdle) OR (shoulder function) OR (shoulder joint)
Intervention	(exercise*) OR (rehabil*) OR (kinetic chain) OR (resistance train*) OR (strength*) OR (muscle train*) OR (lower limb train*) OR (core stab*) OR (trunk exercises) OR (trunk rotation) OR (gym) OR (Physio*) OR (physical therapy) OR (kinetic link-model) OR (proprioceptive neuromuscular facilitation) OR (PNF) OR (non-operative) OR (conservative) OR (kinesiotherapy)
Comparison	(no treat*) OR (placebo) OR (global rehab*) OR (local rehab*) OR (other intervention) OR (conventional rehab*)
Outcome	(EMG) OR (EMG activity) OR (ROM) OR (range of motion) OR (neuromuscular control) OR (control) OR (proprioception) OR (strength) OR (muscular endurance) OR (co-contraction) OR (performance) OR (function) OR (ADLS) OR (injury recurrence) OR (injury risk)
Study design	Studies considered level three and above on the OCEBM ³³ were eligible for inclusion.

ADLS, activities of daily living; EMG, electromyography; OCEBM, Oxford Centre for Evidence-based Medicine; PICOS, participants, interventions, comparisons, outcomes and study design; PNF, proprioceptive neuromuscular facilitation; ROM, range of motion.

constitutes a 27-point checklist split across the following subsections: reporting, external validity, internal validity (bias) and internal validity (confounding). The total score for this tool ranges from 0 to 28, with a higher score

indicating higher methodological quality.^{35 39 40} Disagreement among the reviewers was resolved by consensus. Each paper was assigned a quality grade of 'excellent' (24–28 points), 'good' (19–23 points), 'fair' (14–18

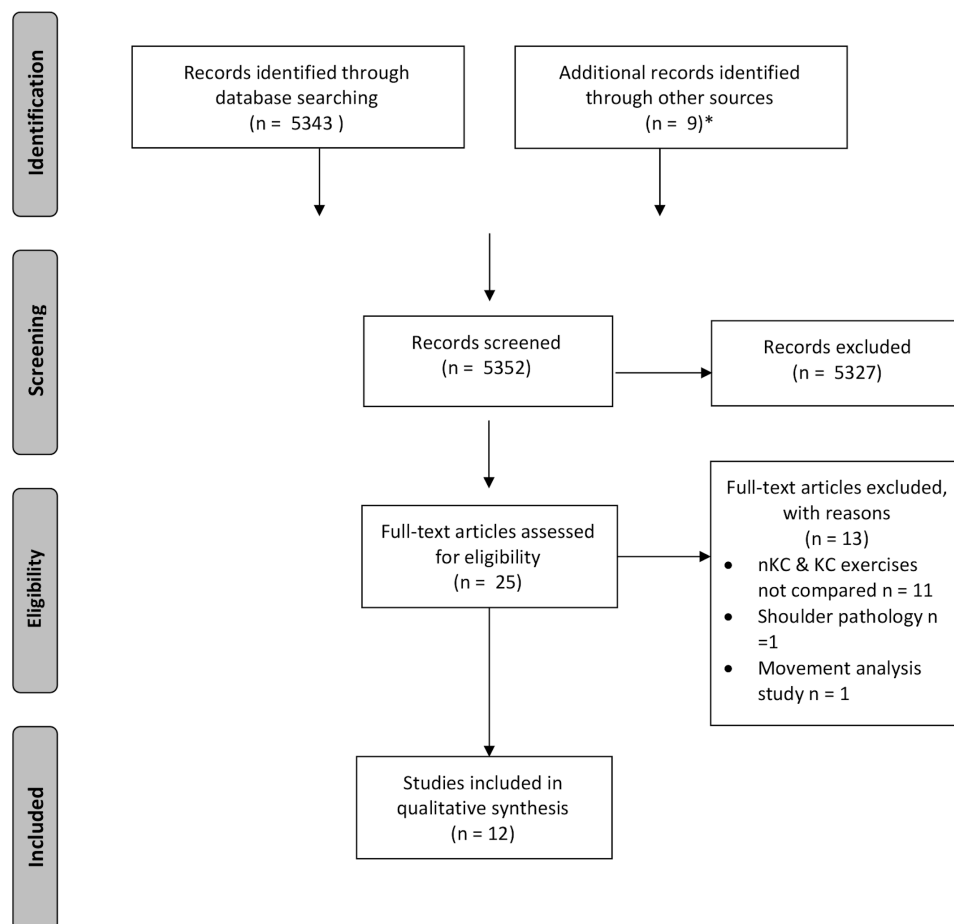


Figure 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram²⁴ illustrating the systematic process of inclusion and exclusion criteria application, which generated the final number for analysis in this systematic review. *Manual searching through reference lists/bibliographies, consultation with JG and discussion with other clinical experts regarding unpublished research. KC, kinetic chain; nKC, non-kinetic chain.

points) or 'poor' (<14 points), as documented previously.⁴²

RISK OF BIAS (ROB)

O'Connor *et al*⁴² have challenged the use of the mD&B tool, suggesting it may fail to identify ROB in all studies. Therefore, specific ROB assessment was also undertaken through the application of a dedicated ROB tool: ROBINS-1.⁴³ Two reviewers (ER and CM) applied this tool independently with 100% agreement.

ELECTROMYOGRAPHY

EMG has been suggested to be the most reliable tool researchers have to evaluate the complex activation patterns of muscles during movement.⁴⁴ However, cross talk may influence the validity of EMG through the contamination of signals.^{45–48} Surface electrodes are more susceptible to cross talk contamination than indwelling electrodes.⁴⁵ Recent evidence indicates that surface electrode recordings overestimate infraspinatus and latissimus dorsi activity due to pick up from surrounding muscles.^{45–49} Surface electrodes are also susceptible to geometric displacement. When placed on the area overlying the inferior slips of serratus anterior it has been shown that activity levels in this muscle during shoulder movements are underestimated compared with that recorded using indwelling electrodes due to this type of displacement.⁵⁰

In light of these known limitations, a scoring tool to evaluate EMG methodological quality was developed for this study (online supplementary file 1).

The evaluation tool was applied to five articles by ER, and the results were discussed with two other reviewers (KG and MH) with extensive EMG experience until there was full agreement. The evaluation tool was then applied to the remaining seven articles by ER.

EMG METHODOLOGICAL QUALITY SCORING TOOL

The EMG methodological quality scoring tool was developed based on the Standards for Reporting EMG data as endorsed by the International Society of Electrophysiology and Kinesiology.⁵¹ It was divided into six domains with a maximum number of points available in each: *EMG detection of signal* (five points), *processing signal* (two points), *EMG levels/patterns* (two points), *EMG timing* (one point), *procedures* (two points) and *analysis* (one point). A percentage quality score was generated for each study based on the total number of points earned divided by the total number of points available. All domains were scored using a simple 'yes' equals one point and 'no' equals zero points, with the exception of the first domain, EMG detection of signal. The first subsection in this domain relates to electrode type and asks, 'Was the selection of electrode (surface or indwelling) appropriate?' If all the electrode types used were appropriate for each muscle under investigation, then yes would be ticked and a score of 1 awarded. However, for studies in which both yes and no answers were recorded for different muscle groups,

a score between 0 and 1 was awarded based on the total number of muscle groups listed under yes divided by the total number of muscle groups listed under both yes and no columns. For example, if three of four muscle groups investigated scored yes, then a score of 0.75 would be awarded for this section and added to the remainder of the points earned in this domain.

For ease of between-study ranking only, overall percentages were awarded to each study.

DATA ANALYSIS

Data relating to the research question was extracted by ER and CM and inputted into a Microsoft Excel V.16.10 spreadsheet. Data extraction was piloted by ER and CM, and any misunderstandings and disagreements were addressed through consultation. A third reviewer (GY) was available to arbitrate any unresolved issues but was not required. Of the 12 studies included in the review, disagreement between the reviewers (ER and CM) with data extracted occurred in one study.⁵² This was resolved by contacting the author to clarify EMG amplitudes to ensure accurate data extraction.

Due to the small sample sizes and the heterogeneity of the outcomes assessed, a meta-analysis or statistical assessment of the outcomes was not performed, and a narrative analysis was undertaken.

RESULTS

Twelve articles met the inclusion criteria for this review (online supplementary file 2).^{52–63} Seventeen muscle groups were investigated in 204 participants without symptoms.

Study characteristics

Studies were assessed to be either level 2 or 3 OCEBM evidence.³³ All EMG results were expressed as a percentage of maximal voluntary contraction (MVC). Two studies also provided additional information for axio-shoulder muscle ratios.^{57–63} All studies used surface EMG with two also using fine wire intramuscular electrodes in supraspinatus and infraspinatus.^{60–62} Smith *et al*⁶⁰ also investigated the upper subscapularis. A total of 85 exercises were investigated: 45 individual KC exercises and 40 nKC exercises.

The muscles investigated in each study varied, with lower trapezius (n=11), serratus anterior (n=11) and upper trapezius (n=10) comprising the muscles most commonly evaluated. Less commonly evaluated were infraspinatus (n=4), supraspinatus (n=2) and latissimus dorsi (n=2), with the remaining muscle groups investigated only in individual studies.

Methodological quality

Ten out of the 12 studies were rated 'fair',^{52–59 61 62} with the remaining 2 rated 'poor',^{60 63} on the mD&B (table 2).

The ROB was scored as 'low' across all studies, with only one domain, bias due to confounding, showing a moderate ROB (online supplementary file 3).



Table 2 Downs and black methodological quality assessment results

Article reference		De Mey et al ⁶³	Hardwick et al ⁶⁴	Kaur et al ⁶⁵	Kibler et al ⁶⁶	Maenhout et al ⁶⁷	Maenhout ⁶⁸	Nagai et al ⁶⁹	Nakamura et al ⁶²	Smith et al ⁶⁰	Tsuruike and Ellenbecker ⁶¹	Uhl et al ⁶²	Yamauchi et al ⁶³
Criteria													
Criteria 1–10		1	1	1	1	1	1	1	1	1	1	1	1
Reporting		1	1	1	1	1	1	1	1	1	1	1	1
	3	1	1	1	1	1	1	X	1	X	X	1	X
	4	1	1	1	1	X	1	1	1	1	1	1	1
	5 (2)	X	X	X	X	X	X	X	X	X	X	X	X
	6	1	1	1	1	1	1	1	X	X	1	1	1
	7	1	1	1	1	1	1	1	1	X	1	1	1
	8	X	X	1	X	X	X	X	X	X	X	X	X
	9	1	1	1	1	1	1	1	1	1	1	1	1
	10	1	1	1	1	1	1	1	1	X	X	X	1
Criteria 11–13		UTD	UTD	UTD	UTD	UTD	UTD	UTD	UTD	UTD	UTD	UTD	UTD
External validity		UTD	UTD	UTD	UTD	UTD	UTD	UTD	UTD	UTD	UTD	UTD	UTD
	13	UTD	1	UTD	UTD	UTD	UTD	UTD	UTD	1	UTD	UTD	UTD
Criteria 14–20		1	1	1	1	1	1	1	1	1	1	1	1
Internal validity bias		UTD	UTD	UTD	UTD	UTD	UTD	UTD	UTD	UTD	UTD	UTD	UTD
	16	1	1	1	1	1	1	1	1	1	1	1	1
	17	1	1	1	1	1	1	1	1	1	1	1	UTD
	18	1	1	1	1	1	1	1	1	UTD	1	1	1
	19	1	1	1	1	1	1	1	1	1	1	1	1
	20	1	1	1	1	1	1	1	1	1	1	1	1
Criteria 21–26		1	1	UTD	UTD	UTD	UTD	UTD	1	1	1	1	UTD
Internal validity		UTD	UTD	UTD	UTD	UTD	UTD	UTD	UTD	UTD	UTD	UTD	UTD
Selection bias		X	X	1	X	X	X	X	X	X	X	X	X
	24	X	X	X	X	X	X	X	X	X	X	X	X
	25	X	X	X	X	X	X	X	X	X	X	X	X
	26	1	1	1	1	1	1	1	1	1	1	1	1
Criteria 27		1	1	1	0	0	0	0	0	0	0	0	0
Modified power		16	18	18	15	14	15	14	15	12	14	15	13
% Agreement		100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Quality grade		Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Poor	Fair	Fair	Poor

For article scoring: 1=score given; X=no score given; [redacted], items deemed less pertinent to the quality of investigatory EMG studies; [redacted], items deemed most pertinent to the quality of investigatory EMG studies. EMG, electromyography; UTD, unable to determine.



With respect to EMG methodological quality, 7 of the 12 studies were awarded greater than 80%,^{52 53 55 57-59 63} two between 70% and 79%^{56 61} and three studies less than 70%^{54 60 62} (table 3), with a mean percentage score of 78% (SD=10%).

COMPARATIVE EMG ACTIVITY BETWEEN KC AND NKC EXERCISES

Axioscapular muscles

The results suggest that KC exercises may preferentially activate and produce higher EMG amplitudes in the whole trapezius and lower trapezius when compared with their nKC counterparts. Conflicting results exist in relation to upper trapezius and middle trapezius (online supplementary file 2 and table 4). Removal of studies with the lowest methodological quality for both the mD&B and EMG methodological quality assessment did not add clarity to these conflicting results.

Trapezius

Of the studies investigating the upper trapezius (n=10),^{52-54 56-60 62 63} four found no significant difference in activation levels between KC and nKC exercises^{52 53 58 60}; four found KC exercises elicited greater EMG activation than nKC exercises^{54 56 59 62}; one study⁶³ found nKC exercises elicited greater EMG activation than KC exercises; and one study did not provide a direct KC versus nKC comparison.⁵⁷ Of the studies investigating the middle trapezius (n=4),^{57 58 60 63} one showed no significant difference in activation levels between KC and nKC exercises⁶⁰; one did not provide enough comparative data to determine the presence of any significant difference⁵⁷; and two studies provided conflicting results.^{58 63} Of the 11 studies investigating the lower trapezius,^{52-54 56-63} 5 demonstrated consistently higher EMG activation levels during KC exercises compared with nKC exercises.^{56-58 62 63} Five studies showed no difference,^{52-54 59 60} and one study found nKC exercises elicited greater EMG activation than KC exercises.⁶¹ One study investigated the whole trapezius⁵³ and found the KC exercise ‘high scapula retraction in static unipedal squat’ elicited higher EMG activation than nKC ‘high scapula retraction in sitting’ (online supplementary file 2). Removal of studies with the lowest methodological quality score for both the mD&B and EMG methodological quality assessment saw seven studies remaining. Of these, three favoured KC exercises in eliciting the highest EMG activation levels⁵⁶⁻⁵⁸; one favoured nKC exercises⁶¹; and three reported no significant difference between the two.^{52 53 59}

Serratus anterior

Of the studies investigating the serratus anterior (n=11),^{52 54-63} five reported KC exercises produced significantly higher EMG activation levels compared with nKC exercises^{55 57-60}; three studies reported the opposite^{52 61 63}; two studies found no significant differences^{54 56}; and one study found an equal total number of KC exercises produced greater EMG activity than nKC exercises and

Table 3 EMG methodological quality evaluation

Article reference	De Mey et al ⁵³	Hardwick et al ⁵⁴	Kaur et al ⁵⁵	Kibler et al ⁵⁶	Maenhout et al ⁵⁷	Maenhout et al ⁵⁸	Nagai et al ⁵⁹	Nakamura et al ⁶²	Smith et al ⁶⁰	Tsuruike and Ellenbecker ⁶¹	Uhl et al ⁶²	Yamauchi et al ⁶³
Domain												
EMG detection of signal	4.00	3.50	4.00	3.75	4.75	4.75	4.80	4.75	3.75	3.75	3.75	4.50
Processing signals	1.0	1.0	1.0	1.0	1.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0
Evaluation of EMG levels/ patterns	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Evaluation of EMG timing	N/A	N/A	N/A	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Procedures	2.0	0.0	2.0	1.0	2.0	2.0	2.0	2.0	1.0	1.0	1.0	2.0
Analysis	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Total scores	10.00	7.50	10.00	9.75	10.75	10.75	9.8	10.75	7.75	8.75	7.75	10.50
% Quality scores	83%	62%	83%	75%	90%	90%	82%	90%	64%	73%	64%	88%

Shades of grey for visual between-study comparison only: ■, ≤70%; ■, ≥70%–79%; ■, ≥80%. EMG, electromyography; N/A, not assessed.

Table 4 To show whether studies favoured nKC or KC exercise for overall EMG activation levels

Study	UT	MT	LT	WT	SA	PD	MD	AD	Inf	Sup	USSC	PM	LD	BB	ExOb	cGMax	iGmax	FAd
Nakamura <i>et al</i> ⁶²	ND	-	ND	-	nKC	-	-	nKC	nKC	-	-	-	-	-	-	-	-	-
Nagai <i>et al</i> ⁵⁹	KC	-	ND	-	KC	-	-	KC	-	-	-	ND	-	-	-	-	-	-
Uhl <i>et al</i> ⁶²	KC	-	KC	-	ND	-	-	KC	nKC	nKC	-	-	-	-	-	-	-	-
De Mey <i>et al</i> ⁵³	ND	-	ND	KC	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Kaur <i>et al</i> ⁵⁵	-	-	-	-	KC	-	-	-	-	-	-	-	ND	-	KC	KC	KC	KC
Kibler <i>et al</i> ⁵⁶	KC	-	KC	-	ND	nKC	-	nKC	-	-	-	-	-	-	-	-	-	-
Smith <i>et al</i> ⁶⁰	ND	ND	ND	-	KC	ND	ND	ND	ND	ND	ND	-	-	ND	-	-	-	-
Tsuruike and Ellenbecker ⁶¹	-	-	nKC	-	nKC	ND	-	-	nKC	-	-	-	-	-	-	-	-	-
Yamauchi <i>et al</i> ⁶³	nKC	KC	KC	-	nKC	-	-	-	-	-	-	-	-	-	-	-	-	-
Maenhout <i>et al</i> ⁵⁸	ND	nKC	KC	-	KC	-	-	-	-	-	-	-	-	-	-	-	-	-
Maenhout <i>et al</i> ⁵⁷	-	-	KC	-	KC	-	-	-	-	-	-	-	-	-	-	-	-	-
Hardwick <i>et al</i> ⁵⁴	KC	-	ND	-	ND	-	-	-	-	-	-	-	ND	-	-	-	-	-
KC versus nKC overall	KC	ND	KC	KC	KC	nKC	ND	ND	nKC	nKC	ND	ND	ND	ND	KC	KC	KC	KC

"ND" = no difference in overall KC and nKC exercises.

"-" = not investigated or investigated but not assessed comparatively. KC exercises are written in blue text and nKC exercises are written in red text as a visual aid to interpretation.

AD, anterior deltoid; BB, biceps brachii; cGMax, contralateral gluteus maximus; ExOb, external oblique; FAd, femoral adductor; iGMax, ipsilateral gluteus maximus; Inf, infraspinatus; KC, kinetic chain; LD, latissimus dorsi; MD, middle deltoid; MT, middle trapezius; ND, no difference in overall KC and nKC exercises; nKC, non-kinetic chain; PD, posterior deltoid; PM, pectoralis major; SA, serratus anterior; Sup, supraspinatus; USSC, upper subscapularis; UT, upper trapezius; WT, whole trapezius.

vice versa (online supplementary file 2 and table 4).⁶² Removal of studies with the lowest methodological quality score for both the mD&B and EMG methodological quality assessment saw seven studies remaining. Of these, four favoured KC exercises for eliciting the highest EMG activation levels^{55 57-59}; two favoured nKC exercises^{52 61}; and one found no difference between the two.⁵⁶

Rotator cuff

Non-KC exercises produced higher EMG amplitudes in the infraspinatus when compared with their KC counterparts in three of four studies,^{52 61 62} with the remainder showing no significant difference between exercise types.⁶⁰ One study investigating the upper subscapularis⁶² reported no significant difference in EMG activation levels between the two exercise types. Two studies investigated the supraspinatus^{60 62} and found no significant difference in EMG amplitudes between KC and nKC exercises⁶⁰ and an equal total number of KC exercises producing greater EMG activity than nKC exercises and vice versa (online supplementary file 2 and table 4).⁶² Removal of studies with the lowest methodological quality score for both the mD&B and EMG methodological quality assessment saw two studies remaining, both favouring nKC in eliciting the highest EMG activation levels.^{52 61}

Glenohumeral joint prime movers

The results from this review show an unclear picture in relation to whether KC or nKC exercises preferentially activate muscles considered prime movers of the glenohumeral joint. No significant differences in EMG activity

was found for biceps brachii⁶⁰ latissimus dorsi,^{54 55} pectoralis major⁵⁹ or the middle deltoid.⁶⁰

Of the studies investigating the anterior deltoid (n=5),^{52 56 59 60 62} an equal total number of KC exercises produced greater EMG activity than nKC exercises and vice versa (online supplementary file 2 and table 4). Removal of studies with the lowest methodological quality score for both the mD&B and EMG methodological quality assessments saw three studies remaining, two of which favoured nKC exercises for eliciting highest EMG activation levels^{52 56} and one favouring KC exercises.⁵⁹

Trunk, pelvis and lower limb

One study investigated the external oblique, ipsilateral gluteus maximus, contralateral gluteus maximus and the femoral adductor muscles⁵⁵ and found KC exercises produced significantly greater EMG activity in each muscle group compared with that elicited during nKC exercises (online supplementary file 2 and table 4). This study was of fair methodological quality on the mD&B and scored in the highest category (greater than 80%) on our EMG methodological quality assessment.

Muscle ratio comparisons

Upper trapezius:lower trapezius ratio (UT:LT)

KC exercises produced lower UT:LT ratios when compared with their nKC counterparts in one study.⁶³ Ratios were less than 1 for all exercises except nKC standing scaption. KC standing external rotation plus trunk and hip rotation produced the lowest ratio (0.2) (table 5).

Table 5 To show whether studies favoured nKC or KC exercises for axioscapula muscle ratios

Study	UT:LT ratio	UT:SA ratio	UT:MT ratio	Lowest ratios
Yamauchi <i>et al</i> ⁶³	KC 1.1 (0.8) <nKC 1 (1.3)	KC 2.1 (1.4)<nKC 2 (3.1)	KC 1.1 (2.4)<nKC 1 (3.6)	UT/LT=KC 2.1 (0.2)
	KC 2.1 (0.2)<nKC 2 (0.3)	nKC 3 (0.5)<KC 3.1 (1.5)	KC 3.1 (1.0)<nKC 3 (1.1)	UT/SA=nKC 3 (0.5)
	KC 5.1 (0.4)<nKC 5 (0.5)	KC 4.1 (4.9)<nKC 4 (10.2)	KC 5.1 (0.6)<nKC 5 (0.9)	UT/MT=KC 2.1 (0.3)
	KC 6.1 (0.4)<nKC 6 (0.7)	KC 5.1 (9.3)<nKC 5 (18.7) nKC 6 (2.5)<KC 6.1 (4.2)	KC 6.1 (1.0)<nKC 6 (1.5)	
Maenhout <i>et al</i> ⁵⁷	N/A	nKC 1 (0.52)<KC 2 (1) & KC 5 (1.56)	N/A	UT/LT=KC 2 (1.03) UT/SA=KC 3 (0.4) UT/MT=KC 5 (1.44)
KC versus nKC overall	KC	ND	KC	KC

Ratio of <1=muscle more active than UT.

Ratio of >1=UT more active.

KC, kinetic chain; LT, lower trapezius; MT, middle trapezius; N/A, not assessed; ND, no difference in overall KC and nKC exercises; nKC, non-kinetic chain; SA, serratus anterior; UT, upper trapezius.

Maenhout *et al*⁵⁷ did not provide information regarding a direct KC versus nKC ratio comparison. KC exercise 'kneeling push-up plus (KPP) with heterolateral leg extension' produced the lowest ratio (1.03).

Upper trapezius:serratus anterior ratio

Maenhout *et al*⁵⁷ reported varied ratios across all exercises but found nKC exercise 'KPP' to be significantly lower than KC exercise 'KPP with heterolateral leg extension' and 'KPP with heterolateral leg extension on a wobble board'. KC exercise 'KPP with homolateral leg extension' produced the lowest overall ratio (0.4).

Yamauchi *et al*⁶³ found KC exercises produced significantly lower ratios than nKC exercises in three out of five comparisons, with nKC exercises producing significantly lower ratios in the remaining two. Non-KC exercise 'standing external rotation at 90 degrees abduction' produced the lowest ratio (0.5) (table 5).

Upper trapezius:middle trapezius ratio (UT:MT)

Yamauchi *et al*⁶³ found KC exercises produced lower UT:MT ratios when compared with their nKC counterparts. The mean ratio for all exercises regardless of type or category was 1.15 (SD=0.9), with KC exercise 'standing external rotation plus hip and trunk rotation' producing the lowest ratio (0.3). During direct KC and nKC comparisons, only KC exercise 'prone scapula retraction at 90 degrees abduction plus trunk rotation' (0.6) and nKC 'prone scapular retraction at 90 degrees abduction' (0.9) recorded a ratio of less than 1 (table 5).

Maenhout *et al*⁵⁷ did not provide information regarding a direct KC versus nKC comparison. However, the mean ratio for all exercises regardless of type or category was 1.54 (SD=1.5), with KC exercise 'KPP with heterolateral leg extension on a wobble board' producing the lowest ratio (1.44).

Yamauchi *et al*⁶³ study scored poor on the mD&B methodological quality assessment but scored in the

highest category (greater than 80%) on our EMG methodological quality assessment.

DISCUSSION

This review aimed to investigate whether the addition of lower limb and trunk motion into shoulder exercises influenced EMG activity and recruitment patterns around the shoulder complex. Overall, the findings suggest that integrating the KC into shoulder exercises may enhance axioscapular muscle recruitment, produce lower trapezius muscle ratios and reduce the demands on the rotator cuff.

KC and the axioscapular muscles

Lower trapezius

A preferential effect favouring motion in the form of lateral weight transference as a KC integration strategy compared with movements such as bipedal squatting was observed in this review. Of the five studies^{56–58 61–63} that favoured KC exercises, 4 involved significant weight transference through the lower limb^{57 58 61–63} and 1 combined hip and knee extension with trunk and thoracic rotation.⁵⁸ The results in the remaining six studies suggest that sequential lateral weight transference may be key to eliciting higher lower trapezius activation levels.

Tsuruke & Ellenbecker⁶¹ elicited higher activation levels in the lower trapezius during nKC quadruped shoulder flexion compared with the 'lawn-mower'. Closer inspection of the techniques employed during these two commonly prescribed KC exercises reveals a disparity between exercise execution and the recommendations within the literature.^{1–5} In Tsuruke & Ellenbecker,⁶¹ the 'lawn-mower' appears to have been without any lateral weight transference through the lower limb.^{1–5} However, when evaluating this comparison in isolation it is not possible to infer whether this difference relates to

suboptimal KC sequencing or the inherent differences in gross movement patterns between each exercise.

A direct movement comparison between lateral rotation of the shoulder in standing with and without the addition of trunk rotation, was assessed by Yamauchi *et al.*⁶³ The end position during this latter exercise is similar to the end position of the 'lawn-mower' described by Tsuruke & Ellenbecker.⁶¹ In Yamauchi *et al.*'s⁶³ study the arm was supported with a towel, the head is observed to follow the movement and although the feet remain facing forwards, weight transfer towards the ipsilateral leg can be observed. This method of sequencing is arguably more in keeping with the frameworks that exist in the literature¹⁻⁵ and suggests that the order in which the KC is integrated may affect lower trapezius activation levels. However, it is not clear whether contributions from a particular KC component lead to the higher lower trapezius activation levels observed.

The components of KC sequencing may be evaluated further if the findings from Tsuruike *et al.*⁶¹ and Yamauchi *et al.*⁶³ are combined with the findings of Nagai *et al.*⁵⁹ In Nagai *et al.*,⁵⁹ no significant difference was found in lower trapezius activation levels between bilateral shoulder flexion in sitting with or without the addition of trunk rotation. Unlike Yamauchi *et al.*,⁶³ the lower quadrant was omitted from this sequencing pattern. Exercise instructions also differed with Yamauchi *et al.*⁶³ requesting subjects maximally rotate the trunk and hips during shoulder rotation and Nagai *et al.*⁵⁹ instructing a more segmented approach of rotation followed by shoulder flexion. These findings reinforce the potential importance of fluid proximal-to-distal lateral weight transference through the lower quadrant during KC integration.

The preferential effects of lateral weight transference as a KC integration strategy on lower trapezius is also observed in studies where differences were reported but not deemed statistically significant.^{52-54 60} Studies that employed a KC exercise variant that involved stepping all yielded higher activation levels in the lower trapezius than their nKC counterparts.^{54 60} Conversely, studies employing a static bipedal stance without dynamic lateral weight transference did not yield higher lower trapezius activation levels than their nKC counterpart.^{52 53 59} One study⁶⁰ investigated the effect of an attempted overhead 'reach' in bipedal stance and during a stepping motion as well as an attempted cross body 'reach' in bipedal stance and during a stepping motion. Arm immobilisation removed glenohumeral joint motion as a variable rendering the 'reach' a shoulder girdle shrugging motion. The addition of stepping revealed a trend of higher lower trapezius activation levels in all exercises, although this was not deemed statistically significant. Although clinical and statistical significance do not always equate, no data exist to report whether this observed trend was clinically relevant.

When this narrative analysis is examined in conjunction with the results from the methodology quality assessments, more studies (n=3) favour KC exercises⁵⁶⁻⁵⁸

over nKC exercises⁶¹ (n=1) for eliciting highest EMG activation level in the lower trapezius. Of the three studies that did not show consistent differences between either KC and nKC exercises, the KC exercises investigated all involved static bipedal postures and did not involve any fluid lateral weight transference through the lower quadrant during EMG data collection.

Serratus anterior

Unless surface electrodes are placed at the angle of testing during isometric contractions, they weakly correlate with intramuscular electrodes from 90 degrees of elevation upwards during activities where serratus anterior would be expected to be active.⁵⁰ It is notable that studies in this review favouring nKC exercises over KC exercises, or finding no significant difference between the two, investigated exercises from 90 degrees elevation upwards using surface electrodes.^{54 56 61}

One study⁶³ found nKC exercises produced higher serratus anterior activation levels than KC exercises in 2 out of 3 comparisons. Standing external rotation at 90 degrees abduction and prone retraction at 145 degrees abduction were evaluated with and without the addition of trunk rotation. Given the potential for geometric electrode displacement during trunk rotation, coupled with Hackett's *et al.*'s⁵⁰ findings, the validity of this comparison is challenged. Furthermore, the comparison which favoured KC inclusion involved lateral rotation with the arm in neutral with and without thoracic rotation.⁶³ With the arm below 90 degrees and serratus anterior activity expected to be low during both exercises, this comparison is arguably more valid.⁵⁰

Of the studies that favoured KC exercises,^{55 57 58 60} all involved significant weight transference or unilateral loading through the lower quadrant. As geometric displacement was likely in 3 of these four studies,^{55 57 58} it could be argued that the differences noted in favour of KC exercises were actually under-estimated.⁵⁰ The results from Smith *et al.*'s⁶⁰ study, where the addition of stepping with the arm immobilised increased serratus anterior activation to the highest level seen across all 12 studies (199% MVC) when compared with bipedal stance, further supports the notion that KC integration enhances serratus anterior activation levels.

KC and axioscapular muscle ratios

Restoration of balanced co-activation of the axioscapular muscles is considered an important component of shoulder rehabilitation programmes.⁶⁴ A lack of activity in lower trapezius, middle trapezius and serratus anterior in combination with excessive upper trapezius activity has been described.^{57 64} As such, UT/LT, UT/MT and UT/SA ratios have been frequently evaluated in the literature with ratios of less than one being deemed desirable.^{57 63 64}

One study in this review investigated trapezius muscle ratios across all exercises.⁶³ KC exercises consistently produced lower UT/LT and MT/LT muscle ratios than their nKC counterparts. Standing external rotation of



the shoulder at 0 degrees abduction with the addition of trunk and hip rotation produced the lowest UT/LT ratio (0.2) whereas prone shoulder retraction at 90 degrees abduction plus trunk rotation produced the lowest UT/MT ratios (0.6). This is partly in keeping with Cools *et al*⁶⁴ who found favourable UT/MT and UT/LT muscle ratios during side lying external shoulder rotation at 0 degrees and prone horizontal shoulder abduction with external rotation at 90 degrees.

Cools *et al*⁶⁴ concluded that eliminating the effect of gravity on upper trapezius lead to these favourable ratios. The findings of this review partly support this conclusion with the only two exercises to produce an UT/MT ratio of less than one being in the prone position. However, this inference does not explain why the most favourable UT/LT ratio in Yamauchi *et al*'s⁶³ study was noted during standing. Nor does it explain the significant decrease in UT/LT ratios noted when scaption through full range in standing (1.3) was compared with scaption with the addition of trunk and hip rotation (0.8). The addition of trunk and hip rotation, plus the observed lateral weight transfer that coupled this movement, appears to have enhanced recruitment of the lower trapezius.

Two studies investigated UT/SA ratios^{57 63} but only one directly compared ratios between KC and nKC exercises.⁶³ Although Yamauchi *et al*⁶³ found KC exercises produced lower ratios than nKC exercises in three out of five comparisons, two of the five favoured nKC exercise variants. During one of these comparisons, arm abduction angle was 90 degrees for both KC and nKC exercise variants and serratus anterior activation levels were expected to be high – criteria that render surface EMG most likely to under-report serratus anterior activation levels.⁵⁰ The remaining comparison evaluated the addition of thoracic rotation to arm elevation at 145 degrees in prone. Where arm elevation angles were below 90 degrees and serratus anterior not expected to be overly active, KC exercises produced more favourable ratios.

The pitfalls of surface EMG as a valid outcome measure for serratus anterior might explain why UT/SA ratios of less than one were infrequent (table 5). Clinicians must therefore interpret any muscle ratio where surface electrodes were used for serratus anterior activity with caution. The limitations of surface EMG as a valid outcome measure for serratus anterior may also explain why Cools *et al*⁶⁴ were unable to find any exercise for optimising UT/SA ratios.

KC and the rotator cuff

Findings from this review suggest that reduced contribution from the KC has the potential to influence force transfer to distal segments,¹⁻⁴ with nKC exercises preferentially activating the infraspinatus and supraspinatus.^{52 60-62} However, only four studies investigated the infraspinatus with three of these considered to be of poor methodological quality.^{52 60 61} In addition to this, two studies used surface EMG during movements where infraspinatus would be expected to be both active

and inactive at different phases of the movement,^{52 61} a scenario where intramuscular electrodes are required to give valid infraspinatus measures.⁴⁵ If this is taken into consideration, only two studies that investigated both infraspinatus and supraspinatus remain,^{60 62} one of which found no difference between KC and nKC exercises.⁶⁰ Furthermore, overall activity in the remaining study was consistently low for infraspinatus (2%–14% MVC) and low to moderate to supraspinatus (4%–29% MVC).⁶⁵

STRENGTHS & LIMITATIONS OF REVIEW

The strength of recommendations made by a systematic review relates directly to the quality of the studies evaluated.³² There was a moderate ROB due to confounding for all studies. However, the pitfalls of EMG as an objective measure render eliminating ROB for this domain unlikely.

Studies in this review were considered of 'fair' to 'poor' quality on the mD&B scale. However, it was considered that all domains in the mD&B tool were not equally pertinent to the quality of investigatory studies solely evaluating EMG amplitudes among healthy subjects. Consequently, items deemed most and least pertinent were highlighted as dark grey and light grey, respectively (table 2). If the items deemed least pertinent are excluded, this would theoretically increase all but one study⁶⁵ to a quality grade rating of 'good' based on O'Connor *et al*'s⁴² classification system. It is acknowledged, however, that this postulation adds a subjective element to an otherwise systematic process.

We acknowledge that no studies exist regarding the validity and reliability of our novel EMG methodology quality assessment method, and therefore caution must be taken when attaching meaning to these results. It is therefore recommended that readers use the percentages generated as a means of quality comparison between studies only until such time as this scoring method is evaluated further. In addition, as only studies written in English were included in this review, the authors are uncertain of the number or quality of any non-English language publications related to the research question. Consequently, a future systematic review that does not have this limitation may produce different results or conclude with different findings.

Not all studies included in this review investigated KC exercises where the KC segment involved provided a direct movement comparison of their nKC counterpart exercise. The authors acknowledge that in these circumstances, direct conclusions from the data cannot be drawn but instead use these comparisons to inform the narrative discussion around the interpretation of the collective results across all studies.

No meta-analysis was performed in this review, which may be considered as a limitation. However, due to heterogeneity among studies in relation to the exercises undertaken, the electrode type, placement and protocol followed, as well as the variations of ROB among the

included studies a meta-analysis was not performed, as recommended in the Cochrane guidelines.³⁷

CONCLUSION

This review found evidence that may suggest integrating the KC into shoulder rehabilitation exercises may enhance axio-shoulder muscle recruitment, produce lower trapezius muscle ratios and reduce the demands on the rotator cuff. The manner in which the KC is integrated may be key in eliciting these potentially clinically favourable outcomes, with consistent evidence favouring lateral lower quadrant weight transference methods, such as stepping, over common KC integration strategies such as squatting. Conflicting evidence suggests that nKC exercises are preferable when the rehabilitation goal is to isolate and strengthen the rotator cuff, whereas KC exercises may be more suited when targeting enhanced efficiency. Caution is needed when the results of studies using surface EMG as an outcome measure are used to inform exercise selection, especially in relation to serratus anterior and ratios where the serratus anterior forms part of the formula. Further investigations are required to explore the role of lower quadrant weight transference in relation to optimising shoulder muscle recruitment patterns in both healthy and injured cohorts. Future research investigating the validity and reliability of our peer reviewed EMG methodological quality assessment tool is also warranted.

Author affiliations

¹Department of Physiotherapy, BMI The Alexandra Hospital, Cheadle, UK

²Faculty of Health Psychology and Social Care, Manchester Metropolitan University, Didsbury, UK

³School of Health and Social Work, University of Hertfordshire, Hatfield, UK

⁴Therapy Department London, Central London Community Healthcare NHS Trust, London, UK

⁵Department of Physical Therapy and Rehabilitation Sciences, Qatar University, Doha, Qatar

⁶Department of Physiotherapy, Royal Liverpool and Broadgreen Hospitals NHS Trust, Liverpool, UK

⁷The School of Health Sciences, University of Liverpool, Liverpool, UK

⁸High Performance Unit, Medical Department, Arsenal Football Club, London, UK

⁹Faculty of Health Sciences, The University of Sydney, Sydney, New South Wales, Australia

Twitter Eleanor Richardson @Els_Richardson, Jeremy S Lewis @JeremyLewisPT, Jo Gibson @Shouldergeek1, Chris Morgan @ChrisMorgan10 and Mark Halaki @HalakiMark

Contributors All those involved in this systematic review met the criteria for coauthorship, and therefore no Contributorship statement was required.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Patient and public involvement statement Patients were not involved in this research.

Patient consent for publication Not required.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement All data relevant to the study are included in the article or uploaded as supplementary information.

Open access This is an open access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which

permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited, appropriate credit is given, any changes made indicated, and the use is non-commercial. See: <http://creativecommons.org/licenses/by-nc/4.0/>.

ORCID iDs

Eleanor Richardson <http://orcid.org/0000-0002-4330-2020>

Jeremy S Lewis <http://orcid.org/0000-0001-7870-9165>

Gillian Yeowell <http://orcid.org/0000-0003-3872-9799>

REFERENCES

- 1 Chu SK, Jayabalan P, Kibler WB, *et al*. The kinetic chain revisited: new concepts on throwing mechanics and injury. *Pm R* 2016;8:S69–77.
- 2 Cools AM, Johansson FR, Borms D, *et al*. Prevention of shoulder injuries in overhead athletes: a science-based approach. *Braz J Phys Ther* 2015;19:331–9.
- 3 Ben Kibler W, McMullen J, Uhl T, *et al*. Shoulder rehabilitation strategies, guidelines, and practice. *Oper Tech Sports Med* 2000;8:258–67.
- 4 Martin C, Bideau B, Bideau N, *et al*. Energy flow analysis during the tennis serve: comparison between injured and noninjured tennis players. *Am J Sports Med* 2014;42:2751–60.
- 5 Sciascia A, Cromwell R. Kinetic chain rehabilitation: a theoretical framework. *Rehabil Res Pract* 2012;2012:1–9.
- 6 Wilk KE, Arrigo CA, Hooks TR, *et al*. Rehabilitation of the overhead throwing athlete: there is more to it than just external Rotation/Internal rotation strengthening. *Pm R* 2016;8:S78–90.
- 7 Andersson SH, Bahr R, Clarsen B, *et al*. Preventing overuse shoulder injuries among throwing athletes: a cluster-randomised controlled trial in 660 elite handball players. *Br J Sports Med* 2017;51:1073–80.
- 8 Beckett M, Hannon M, Ropiak C, *et al*. Clinical assessment of scapula and hip joint function in preadolescent and adolescent baseball players. *Am J Sports Med* 2014;42:2502–9.
- 9 Endo Y, Sakamoto M. Correlation of shoulder and elbow injuries with muscle tightness, core stability, and balance by longitudinal measurements in junior high school baseball players. *J Phys Ther Sci* 2014;26:689–93.
- 10 Kibler WB, Press J, Sciascia A. The role of core stability in athletic function. *Sports Med* 2006;36:189–98.
- 11 Oliver GD, Keeley DW. Gluteal muscle group activation and its relationship with pelvis and torso kinematics in high-school baseball pitchers. *J Strength Cond Res* 2010;24:3015–22.
- 12 Oliver GD, Weimar WH, Plummer HA. Gluteus medius and scapula muscle activations in youth baseball pitchers. *J Strength Cond Res* 2015;29:1494–9.
- 13 Oliver GD, Weimar W. Hip range of motion and scapula position in youth baseball pitching pre and post simulated game. *J Sports Sci* 2015;33:1447–53.
- 14 Plummer HA, Oliver GD. The relationship between gluteal muscle activation and throwing kinematics in baseball and softball catchers. *J Strength Cond Res* 2014;28:87–96.
- 15 Laudner K, Wong R, Onuki T, *et al*. The relationship between clinically measured hip rotational motion and shoulder biomechanics during the pitching motion. *J Sci Med Sport* 2015;18:581–4.
- 16 Pontillo M, Spinelli BA, Sennett BJ. Prediction of in-season shoulder injury from preseason testing in division I collegiate football players. *Sports Health* 2014;6:497–503.
- 17 Robb AJ, Fleisig G, Wilk K, *et al*. Passive ranges of motion of the hips and their relationship with pitching biomechanics and ball velocity in professional baseball pitchers. *Am J Sports Med* 2010;38:2487–93.
- 18 Scher S, Anderson K, Weber N, *et al*. Associations among hip and shoulder range of motion and shoulder injury in professional baseball players. *J Athl Train* 2010;45:191–7.
- 19 Lintner D, Noonan TJ, Kibler WB. Injury patterns and biomechanics of the athlete's shoulder. *Clin Sports Med* 2008;27:527–51.
- 20 Bouhlel E, Chelly MS, Tabka Z, *et al*. Relationships between maximal anaerobic power of the arms and legs and javelin performance. *J Sports Med Phys Fitness* 2007;47:141–6.
- 21 Chelly MS, Hermassi S, Shephard RJ. Relationships between power and strength of the upper and lower limb muscles and throwing velocity in male handball players. *J Strength Cond Res* 2010;24:1480–7.
- 22 Gabbett TJ, Jenkins DG, Abernethy B. Correlates of tackling ability in high-performance rugby League players. *J Strength Cond Res* 2011;25:72–9.
- 23 Hawley JA, Williams MM, Vickovic MM, *et al*. Muscle power predicts freestyle swimming performance. *Br J Sports Med* 1992;26:151–5.

- 24 Rio E, Kidgell D, Moseley GL, *et al.* Tendon neuroplastic training: changing the way we think about tendon rehabilitation: a narrative review. *Br J Sports Med* 2016;50:209–15.
- 25 Brox JI, Gjengedal E, Uppheim G, *et al.* Arthroscopic surgery versus supervised exercises in patients with rotator cuff disease (stage II impingement syndrome): a prospective, randomized, controlled study in 125 patients with a 2 1/2-year follow-up. *J Shoulder Elbow Surg* 1999;8:102–11.
- 26 Bang MD, Deyle GD. Comparison of supervised exercise with and without manual physical therapy for patients with shoulder impingement syndrome. *J Orthop Sports Phys Ther* 2000;30:126–37.
- 27 Ludewig PM, Borstad JD. Effects of a home exercise programme on shoulder pain and functional status in construction workers. *Occup Environ Med* 2003;60:841–9.
- 28 McClure PW, Bialker J, Neff N, *et al.* Shoulder function and 3-dimensional kinematics in people with shoulder impingement syndrome before and after a 6-week exercise program. *Phys Ther* 2004;84:832–48.
- 29 Walther M, Werner A, Stahlschmidt T, *et al.* The subacromial impingement syndrome of the shoulder treated by conventional physiotherapy, self-training, and a shoulder brace: results of a prospective, randomized study. *J Shoulder Elbow Surg* 2004;13:417–23.
- 30 Ginn KA, Cohen ML. Exercise therapy for shoulder pain aimed at restoring neuromuscular control: a randomized comparative clinical trial. *J Rehabil Med* 2005;37:115–22.
- 31 Magarey ME, Jones MA. Dynamic evaluation and early management of altered motor control around the shoulder complex. *Man Ther* 2003;8:195–206.
- 32 Harris JD, Quatman CE, Manring MM, *et al.* How to write a systematic review. *Am J Sports Med* 2014;42:2761–8.
- 33 Howick J, Chalmers I, Glasziou P, *et al.* The 2011 Oxford levels of evidence (introductory document). Oxford centre for evidence-based medicine. Available: <https://www.cebm.net/2009/06/oxford-centre-evidence-based-medicine-levels-evidence-march-2009/> [Accessed 10 Jan 2018].
- 34 Sanderson S, Tatt ID, Higgins JPT. Tools for assessing quality and susceptibility to bias in observational studies in epidemiology: a systematic review and annotated bibliography. *Int J Epidemiol* 2007;36:666–76.
- 35 Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *J Epidemiol Community Health* 1998;52:377–84.
- 36 Deek JJ, Dinnes J, D'Amico R. *Evaluating non-randomised intervention studies.* International Stroke Trial Collaborative Group; European Carotid Surgery Trial Collaborative Group, 2003: 2003. 1–173.
- 37 Higgins JPT, Green S, eds. *Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0.* The Cochrane Collaboration, 2011. <http://handbook.cochrane.org>
- 38 Chudyk AM, Jutai JW, Petrella RJ, *et al.* Systematic review of hip fracture rehabilitation practices in the elderly. *Arch Phys Med Rehabil* 2009;90:246–62.
- 39 Eng JJ, Teasell R, Miller WC, *et al.* Spinal cord injury rehabilitation evidence: methods of the SCIRE systematic review. *Top Spinal Cord Inj Rehabil* 2007;13:1–10.
- 40 Grigoriu A-I, Dinomais M, Rémy-Néris O, *et al.* Impact of Injection-Guiding techniques on the effectiveness of botulinum toxin for the treatment of focal spasticity and dystonia: a systematic review. *Arch Phys Med Rehabil* 2015;96:2067–78.
- 41 Samoocha D, Bruinvels DJ, Elbers NA, *et al.* Effectiveness of web-based interventions on patient empowerment: a systematic review and meta-analysis. *J Med Internet Res* 2010;12:e23.
- 42 O'Connor SR, Tully MA, Ryan B, *et al.* Failure of a numerical quality assessment scale to identify potential risk of bias in a systematic review: a comparison study. *BMC Res Notes* 2015;8:224–32.
- 43 Sterne JA, Hernán MA, Reeves BC, *et al.* ROBINS-I: a tool for assessing risk of bias in non-randomised studies of interventions. *BMJ* 2016;355:i4919.
- 44 Basmajian JV, De Luca CJ. *Muscles alive: their functions revealed by electromyography.* 5th edn. Baltimore: Lippincott Williams & Wilkins Company, 1985.
- 45 Johnson VL, Halaki M, Ginn KA. The use of surface electrodes to record infraspinatus activity is not valid at low infraspinatus activation levels. *J Electromyogr Kinesiol* 2011;21:112–8.
- 46 Oberg T, Sandsjö L, Kadefors R, *et al.* Electromyographic changes in work-related myalgia of the trapezius muscle. *Eur J Appl Physiol Occup Physiol* 1992;65:251–7.
- 47 Pery J, Easterday CS, Antonelli DJ. Surface versus intramuscular electrodes for electromyography of superficial and deep muscles. *Phys Ther* 1981;61:7–15.
- 48 Stokes IAF, Henry SM, Single RM. Surface EMG electrodes do not accurately record from lumbar multifidus muscles. *Clin Biomech* 2003;18:9–13.
- 49 Ginn KA, Halaki M. Do surface electrode recordings validly represent latissimus dorsi activation patterns during shoulder tasks? *J Electromyogr Kinesiol* 2015;25:8–13.
- 50 Hackett L, Reed D, Halaki M, *et al.* Assessing the validity of surface electromyography for recording muscle activation patterns from serratus anterior. *J Electromyogr Kinesiol* 2014;24:221–7.
- 51 Merletti R, di Torino P. Standards for reporting EMG data. *J Electromyogr Kinesiol* 1999;9.
- 52 Nakamura Y, Tsuruike M, Ellenbecker TS. Electromyographic activity of scapular muscle control in free-motion exercise. *J Athl Train* 2016;51:195–204.
- 53 De Mey K, Danneels L, Cagnie B, *et al.* Kinetic chain influences on upper and lower trapezius muscle activation during eight variations of a scapular retraction exercise in overhead athletes. *J Sci Med Sport* 2013;16:65–70.
- 54 Hardwick DH, Beebe JA, McDonnell MK, *et al.* A comparison of serratus anterior muscle activation during a wall slide exercise and other traditional exercises. *J Orthop Sports Phys Ther* 2006;36:903–10.
- 55 Kaur N, Bhanot K, Brody LT, *et al.* Effects of lower extremity and trunk muscles recruitment on serratus anterior muscle activation in healthy male adults. *Int J Sports Phys Ther* 2014;9:924–37.
- 56 Kibler WB, Sciascia AD, Uhl TL, *et al.* Electromyographic analysis of specific exercises for scapular control in early phases of shoulder rehabilitation. *Am J Sports Med* 2008;36:1789–98.
- 57 Maenhout A, Van Praet K, Pizzi L, *et al.* Electromyographic analysis of knee push up plus variations: what is the influence of the kinetic chain on scapular muscle activity? *Br J Sports Med* 2010;44:1010–5.
- 58 Maenhout A, Benzoor M, Werin M, *et al.* Scapular muscle activity in a variety of plyometric exercises. *J Electromyogr Kinesiol* 2016;27:39–45.
- 59 Nagai K, Tateuchi H, Takashima S, *et al.* Effects of trunk rotation on scapular kinematics and muscle activity during humeral elevation. *J Electromyogr Kinesiol* 2013;23:679–87.
- 60 Smith J, Dahm DL, Kotajarvi BR, *et al.* Electromyographic activity in the immobilized shoulder girdle musculature during ipsilateral kinetic chain exercises. *Arch Phys Med Rehabil* 2007;88:1377–83.
- 61 Tsuruike M, Ellenbecker TS. Serratus anterior and lower trapezius muscle activities during multi-joint isotonic scapular exercises and isometric contractions. *J Athl Train* 2015;50:199–210.
- 62 Uhl TL, Muir TA, Lawson L. Electromyographic assessment of passive, active assisted, and active shoulder rehabilitation exercises. *Am J Phys Med Rehabil* 2010;2:132–41.
- 63 Yamauchi T, Hasegawa S, Matsumura A, *et al.* The effect of trunk rotation during shoulder exercises on the activity of the scapular muscle and scapular kinematics. *J Shoulder Elbow Surg* 2015;24:955–64.
- 64 Cools AM, Dewitte V, Lanszweert F, *et al.* Rehabilitation of scapular muscle balance: which exercises to prescribe? *Am J Sports Med* 2007;35:1744–51.
- 65 McCann PD, Wootten ME, Kadaba MP, *et al.* A kinematic and electromyographic study of shoulder rehabilitation exercises. *Clin Orthop Relat Res* 1993;288:179–88.