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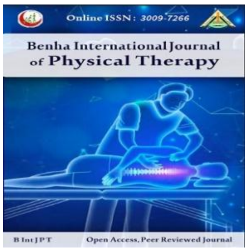

Original research

Influence of Induced Shoulder Complex Muscles Fatigue on Sensorimotor Functions of The Upper Extremity: A systematic review.

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Abstract

Background: Induced fatigue of the shoulder muscles can significantly impact the kinematics and muscle power of the upper extremity, potentially leading to musculoskeletal injuries. Understanding these effects is crucial for developing effective interventions and rehabilitation protocols. **Purpose**: This systematic review investigated the impact of induced fatigue of the shoulder muscles on the sensorimotor functions of the upper extremity. **Methods**: The review followed PRISMA guidelines. A comprehensive search was conducted in five databases for clinical trials examining the effects of shoulder muscles fatigue on sensorimotor functions of the upper extremity. Inclusion criteria included various study designs. Data extraction covered participant characteristics, intervention details, outcome measures, and results. Data synthesis involved meta-analysis using MedCalc software. **Results**: A total of 25 clinical trials were included in this systematic review of which five studies went through meta-analysis. Induced fatigue significantly impacts the arthrokinematics of the glenohumeral joint, affecting the dispersion of the helical axis of rotation and altering the position of the humeral head within the glenoid cavity. Fatigue also alters humeral head migration. However, pooled statistical analysis of five studies showed no statistically significant difference in proprioceptive acuity (Z= 0.875, 95%CI [-1.037 - 2.708], P = 0.382) with significant heterogeneity among the included studies (I2 97.05%, P < 0.0001). **Conclusion**: Induced fatigue of the shoulder complex musculature may influence the kinematics and muscle power of the upper extremity. However, the low methodological quality of the included trials and significant heterogeneity in the investigated variables hinder drawing definitive conclusions. More high-quality RCTs are required to reach a definitive conclusion regarding the effects of induced fatigue on upper extremity sensorimotor functions.

Keywords: induced fatigue; shoulder; kinematics; strength; proprioception.

INTRODUCTION

Fatigue is one of the most common clinical problem that can be seen in both sports and work environment contributing to injury rate and decrease the stability of the shoulder complex[1]. Muscle fatigue can be defined as the reduction in the highest amount of force or power that muscles can produce during sustained activity [2]. Fatigue decrease muscle strength, affect shoulder range of motion and proprioception that could contribute to overuse injuries [1].

The prevalence of fatigue worldwide was discussed in a recent systematic review including 91 studies with more than 623000 participants with a prevalence of 20.4% in adults which raise an alarm regarding this phenomenon that represents one of the top presented healthcare complaints in primary care settings [3].

The shoulder complex consists of four articulations which are the glenohumeral joint, acromioclavicular joint, sternoclavicular joint and scapulothoracic joint which is not a true bony articulation [4].

The articulations of the shoulder complex are mechanically linked and work in a coordinated manner to produce a specific kinematic that provides stability for the whole upper limb during functional tasks [5]. For instance, to reach full range of motion of the glenohumeral joint in the sagittal or frontal plane i.e., flexion or abduction, the scapula has to perform upward rotation, backward tilt and slight external rotation, additionally, the acromioclavicular joint rotates upward, the sternoclavicular joint retracts and rotates posteriorly, and the humerus rotates externally [6].

These coordinated motions provide an optimal alignment of the scapular glenoid fossa with the head of the humerus playing an extensive and essential role in maintaining and providing stability in activities that demand a great deal of mobility of the shoulder joint in both sports activities such as volleyball, basketball, handball etc. and work environments such as carpentry, truck driving etc. [7].

The muscular activity of the shoulder complex relies heavily on the afferent impulses reaching the central nervous system (CNS) from the variable sensory organs that exist in this area including the muscle spindles, the Golgi tendon organs and mechanoreceptors. These structures deliver sensory signals to the CNS such as the joint position sense, the forces applied to articular structures and tension develop within the muscles, these data are integrated by the CNS to perform the desired movements efficiently [8, 9].

In shoulder complex, fatigue has an effect on normal shoulder kinematics including exacerbating scapular motions and decreasing shoulder elevation which may be attributed to delay in muscle activation, variation of muscle force production and reduced accuracy of the proprioceptive input [10].

The effect of fatigue on proprioception can influence the motor control ability of the CNS on the shoulder complex's movement and jeopardize the joint stability and movement patterns [11]. Also, fatigue affects the neuromuscular pathways and alter motor unit firing, motoneuron excitability, and motor cortical excitability [12]. In addition, as muscles are the main stabilizers of the shoulder joint, fatigue could lead to disruption of the proximal stability of the shoulder joint leading to risks of shoulder instability [13].

The current systematic review will discuss and investigate the impact of induced fatigue of the shoulder complex muscles to highlight its consequences such as shoulder complex and proximal shoulder instability and address them properly in order to reduce the possible risks of fatigue-related musculoskeletal injuries of the upper extremity.

METHODS

This systematic review adhered to the Preferred Reporting Items of Systematic Reviews and Meta-analysis (PPRISMA) [14]. The protocol was registered in PROSPERO database on 27th October 2024 (CRD42024602256).

Systematic Search

PubMed, Web of Science, Scopus, Cochrane Central and Physiotherapy Evidence Database (PEDro) were searched for clinical trials investigating the impact of shoulder girdle muscles fatigue on sensorimotor functions of the upper extremity using the terms fatigue and shoulder in the title and abstract or title, abstract and keywords from inception till October 2024. The detailed search strategy is available in **Appendix (1).**

The inclusion criteria included single group pre-test post-test studies, controlled trails, randomized controlled trails or crossover trails investigation the effect of induced fatigue of the shoulder complex musculature confirmed by valid objective or subjective measure on the sensorimotor functions of the upper extremity. Articles were excluded if they were not peer reviewed such as conference papers, theses or dissertation or articles written in any language other than English.

Screening and Filtration

Relevant records were imported into Mendeley software (Elsevier, Amsterdam, The Netherlands) and assessed against the predefined eligibility criteria through two phases; first through title and abstract then the remaining studies were assessed through their full text.

Quality of Research and Risk of Bias Assessment

Two independent authors used the PEDro scale to assess randomized controlled trails and controlled trails while methodological index for non-randomized studies (MINORS) scale will be used to assess non-comparative trails [15, 16]. The PEDro scale has 11 criteria of which only 10 are scored. The score of six is considered the cut-point at which the studies are considered of high quality i.e., 6-7 good and 8-10 excellent while studies scoring less than six is considered of low quality i.e., 4-5 fair and less than 4 is considered poor. The MINORS scale has eight items for non-comparative, each item has a maximum score of two with a total score of 16. Any discrepancy in the scoring was resolved by discussion with the senior author.

Data extraction

The following items were extracted from each included article and summarized in the data extraction sheet including the participants characteristics, the intervention characteristics, the outcome measures and the results.

Data Synthesis

The analysis started by calculating the arithmetic mean and standard deviation of paired difference between pre- and post-intervention values of each study. Then we calculated the standard error of the paired difference. The mean and the standard error of paired difference were used to calculate the pooled effect size across all included studies. Pooled effect size was expressed as the arithmetic mean and the 95%CI for every study as well as the weighted mean and the 95%CI across all studies. Heterogeneity across the studies was represented by I^2 statistics. Fixed effect model was used as a default however, If heterogeneity was considerable ($I^2 > 50\%$), the random effect model was used instead. 2-sided p value < 0.05 was considered statistically significant. Meta-analysis was done using MedCalc Version 23.0.2 for Microsoft Windows (MedCalc Software Ltd, Mariakerke, Belgium).

RESULTS

The systematic search resulted in 563 records, after removal of duplicates using Mendeley software 273 records were included in the filtration process yielding a total of 25 included studies [17-40] **Figure (1).** The main reason for exclusion was the inappropriate assessment of fatigue presence which is a crucial element in the inclusion criteria **Appendix (2).**

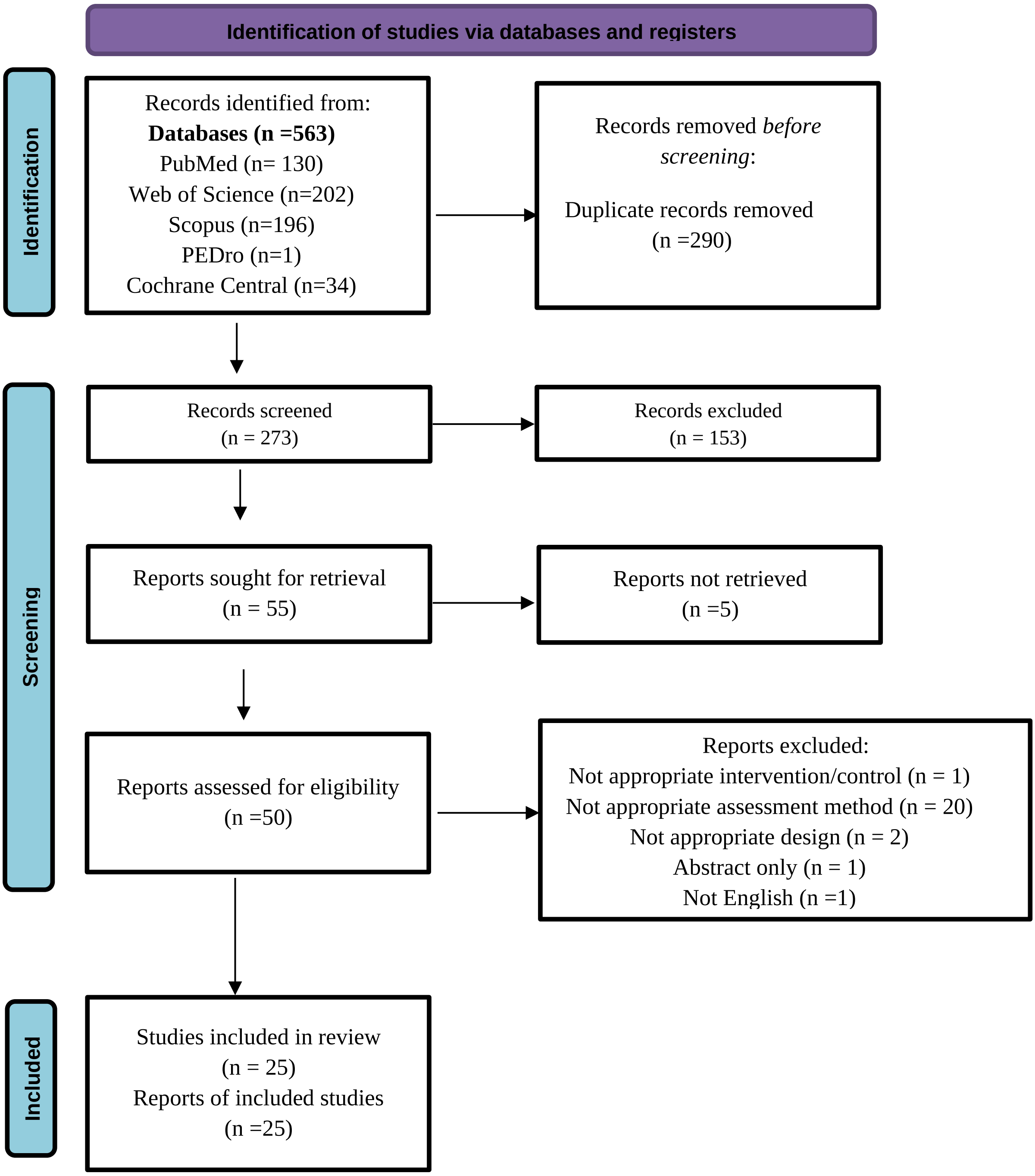

Figure (1): PRISMA flow diagram

Source: Page MJ, et al. BMJ 2021;372:n71. doi: 10.1136/bmj.n71.

Characteristics of the included studies

The included studies total population was 578 healthy participants across 25 studies. It is worth mentioning that seven studies included athletic participants [24, 29, 31, 36, 38-40]. The mean age of the participants included ranged from 20 to 35 years with 64% of the participant being males **Table (1).**

Most of the included studies were single group repeated measure design without follow up however, five studies were randomized crossover studies [19, 24, 31, 32, 37], three studies were randomized controlled trails and one study was a controlled trail [36]. Their quality score ranged from 4 to 10 out of 16 for single group studies and 3 to 7 out of 10 for the controlled and RCTs **Table (2).**

Table (1): Characteristics of the included studies

Study	Design	Population				Fatigue protocol	Outcome Measure	Results
		Type	N	Gender (M:F)	Age (Y)			
Adamo et al., 2020	SG pretest posttest	Healthy	30	NR	23.2±2.6	Isometric ex. At 50% of MVC for both shoulder flexors and ER until Borg score reached 10/10.	- Kinematics of shoulder joint (motion analysis)	- Following shoulder flexors fatigue of the dominant limb, significant increase was observed regarding mean distance, mean angle and decrease in ROM while ER fatigue significantly increased mean distance and mean angle only. - Regarding non-dominant limb, ER fatigue significantly increased mean distance and mean angle while flexors fatigue only affected mean angle and increased ROM.
Stella et al., 2024	SG pretest posttest	Swimmers	14	11:3	21±3	30 min of front-crawl swimming until Borg score reached 10/10	- TMG of PM, Trapezius and LD - Muscle power (HHD)	- TMG results showed statistically significant difference following fatigue protocol regarding LD and PM muscles only. - Only extension torque was affected following fatigue protocol.
Teyhen et al., 2008	SG pretest posttest	Healthy	20	20M	27.7±3.6	Rotator cuff fatigue through arm elevation in prone lying T- position with 5% of body mass until strength decreased by 40% from the prefatigue strength	- Muscle power (HHD) - GH migration (DFV)	- Significant differences were observed regarding GH migration and muscle strength following fatigue protocol.

Iida et al., 2014	**Randomized crossover**	**Overhead athletes**	**15**	**15M**	**22.1±3.4**	**Isokinetic IR & ER fatigue protocol until the torque of ER decreased by 40% of the peak torque**	**- JPS (isokinetic dynamometer) - ROM (motion analysis) - Muscle activity (EMG)**	**- IR and ER peak torque decreased significantly following IR and ER fatigue respectively while the opposite did not occur. - MPF of PM and LD decreased significantly following IR fatigue while infraspinatus decreased following ER fatigue. - IEMG of PM & LD showed higher values following IR fatigue compared to prefatigued values also infraspinatus showed higher values following ER fatigue compared to prefatigued values.**
Joshi et al., 2011	**SG pretest posttest**	**Overhead athletes**	**25**	**15:10**	**20±2**	**ER fatigue protocol using a dumbbell 25% of the baseline peak force generated by infraspinatus muscle until average ER peak force decreased by more than 25% from baseline peak force**	**- Muscle activity (EMG) - Shoulder kinematics (motion analysis) - Muscle power (HHD)**	**- Regarding MVC, only the infraspinatus showed a significant decrease following fatigue protocol in the descending phase of the diagonal elevation pattern. - Scapular upward rotation was greater at post-fatigue compared to pre-fatigue, on contrast no differences were observed regarding anterior and posterior tilting or IR and ER. - Regarding EMG, RMS decreased significantly following fatigue in lower trapezius muscle only.**
Bowman et al., 2006	**Randomized crossover**	**Overhead athletes**	**20**	**20M**	**24.76±4.03**	**Intervention: Bouts of baseball throwing from kneeling position until ball velocity decreased by 10% of the maximum recorded velocity. Control: No intervention for 20 min**	**- Deceleration time**	**- Significant difference was observed following fatigue protocol compared to control regarding shoulder deceleration time.**

Henry et al., 2001	**SG pretest posttest**	**Healthy**	**10**	**10M**	**20.2±3.6**	**Isokinetic fatigue protocol in functional diagonal pattern until the torque value fell below 25% of the initial peak-torque**	**- Muscle activity (EMG)**	**- No significant differences were observed regarding deltoid, infraspinatus and subscapularis muscles activity between pre-fatigue and post-fatigue assessment.**
Guo et al., 2011	**SG pretest posttest**	**Healthy**	**20**	**10:10**	**20±1.5**	**IR fatigue protocol using a dumbbell 80% of MVC until the measured maximum force was decreased to 50% below the initial maximum force**	**- Proprioceptive acuity (motion analysis)**	**- Fatigue of internal rotators did not affect the glenohumeral and scapulothoracic joints proprioception.**
Carpenter et al., 1998	**SG pretest posttest**	**Healthy**	**20**	**11:9**	**23.7±2.75**	**IR and ER isokinetic fatigue protocol until peak torque decreased by 50% of MVC**	**- Proprioceptive acuity (isokinetic dynamometer)**	**- Motion detection ability threshold significantly increased following fatigue protocol of both the IR and ER muscles**

Ali et al., 2023	**Randomized crossover**	**Overhead athletes**	**20**	**20 M**	**21.3±1.59**	**Prone kneeling & half kneeling ER fatigue protocol using dumbbell 70% of 1RM until Borg score reaches 15/20.**	**- Muscle power (HHD)**	**- Concentric contraction peak force, velocity, power, average power, and total work showed statistically significant difference in both groups compared to baseline measurements while eccentric contraction measurements were significant only in peak force, average power and total work. - No differences were observed between the two fatigue protocols.**
Sterner et al., 1998	**Randomized crossover**	**Recreationally active**	**20**	**20M**	**23.81±2.77**	**Isokinetic IR & ER fatigue protocol until peak torque declined below 50% of MVC.**	**- Proprioceptive acuity (isokinetic dynamometer)**	**- No significant differences were observed between fatigue and control groups regarding all proprioceptive acuity parameters.**
Lee et al., 2003	**SG pretest posttest**	**Healthy**	**11**	**11M**	**27.3±3**	**Isokinetic IR & ER fatigue protocol until peak torque declined below 50% of MVC.**	**- Proprioceptive acuity (isokinetic dynamometer)**	**- No significant difference between pre-fatigue and post-fatigue active and passive repositioning of IR and passive repositioning of ER however, active repositioning of ER revealed statistically significant difference compared to pre-fatigue condition.**

Myers et al., 1999	**RCT**	**Healthy active**	**32**	**16:16**	**21.82±1.46**	**Intervention: Isokinetic IR & ER fatigue protocol until peak torque declined below 50% of MVC.** **Control: No intervention for 5 min between assessment**	**- Proprioceptive acuity (AAR)** **- Dynamic stability (SADS)**	**- No statistically significant difference observed between groups regarding AAR test and SADS test.**
Chang et al., 2006	**SG pretest posttest**	**Healthy**	**13**	**5:8**	**24.46±2.07**	**Isokinetic IR & ER fatigue protocol until peak force declined below 50% of MVC**	**- JPS (isokinetic dynamometer)** **- Muscle power (isokinetic dynamometer)**	**- Muscle power decreased significantly following fatigue protocol by 39.75%**
Voight et al., 1996	**SG pretest posttest**	**Healthy**	**80**	**37:43**	**23.7±2.8**	**Isokinetic IR & ER fatigue protocol until declined below 50% of MVC**	**- Proprioceptive acuity (Isokinetic dynamometer)**	**Based on pre- and post-fatigue active and passive repositioning values, glenohumeral repositioning ability significantly changed following fatigue.**

Côté et al., 2005	**SG pretest posttest**	**Healthy**	**30**	**24:6**	**35±9.5**	**Continuous hammering at 70% of MVC till BORG scale reached a score of 8/10**	**- UL kinematics (motion analysis) - Handgrip strength (handgrip dynamometer)**	**- Significant differences were observed regarding amplitude, peak velocity, peak acceleration and time interval regarding elbow movement and time interval in grip strength only. - Maximum grip strength decreased significantly following fatigue protocol compared to pre-fatigue condition.**
King et al., 2022	**Controlled trail**	**Swimmers, WP players & healthy controls**	**37**	**37F**	**22.56±4**	**Isokinetic IR fatigue protocol until Borg score reached 8/10.**	**- Muscle activity (EMG) - Muscle power (isokinetic dynamometer)**	**- Between group comparison statistical data were not reported.**
Dupuis et al., 2021	**RCT**	**Healthy**	**40**	**24:16**	**26±3**	**Intervention: Manipulating screws on a wooden board for two min, 20 rep of arm elevations in sagittal plane and 20 reps in scapular plane with 2 lb. dumbbell for women and 4 lb. for men until Borg score reached 8/10. Control: No intervention for 10 min break.**	**- Shoulder kinematics (IMUs) - Muscle activity (EMG)**	**- Anterior deltoid EMG amplitude showed a statistically significant increase favouring fatigue group in 40-60s measurement while MDF showed significant decreases in both 0-20s and 20-40s measurements. On contrast, Middle deltoid EMG results were similar between groups. - Joint kinematics during VR reaching tasks changed significantly following fatigue protocol compared to control with more reliance on trunk rotation and SC motion compared to GH motion.**

Thomas et al., 2023	**SG pretest posttest**	**Baseball players**	**9**	**9M**	**20.1±1.1**	**Isokinetic ER fatigue protocol until peak force declined below 40% of MVC**	**- Muscle activity (EMG)** **- Muscle synergies VAF (KINARM)**	**- VAF changed significantly following fatigue in only one synergy out of four.**
Dupuis et al., 2022	**RCT**	**Healthy**	**40**	**24:16**	**26±3**	**Intervention: Manipulating screws on a wooden board for two min, 20 rep of arm elevations in sagittal plane and 20 reps in scapular plane with 2 lb. dumbbell for women and 4 lb. for men until Borg score reached 8/10.** **Control: No intervention for 10 min break.**	**- Shoulder kinematics (IMUs)** **- Muscle activity (EMG)**	**- During the reaching tasks, SC elevation and spatiotemporal parameters of shoulder motion were statistically higher in the fatigue group compared to the control group.** **- EMG amplitude of upper trapezius showed statistically significant difference favouring the fatigue group compared to the control group.**
Sadler et al., 2019	**Randomized crossover**	**Healthy**	**16**	**8:8**	**23.5±2.8**	**A repetitive pointing task performed to fatigue until Borg score reached 8/10.**	**- Proprioceptive estimation task (KINARM)**	**- Proprioceptive biases were less accurate in both the left and right hands.**

Fuller et al., 2009	**SG pretest posttest**	**Healthy**	**14**	**8:6**	**25.1±5.9**	**A repetitive reaching task to fatigue until Borg score reached 8/10.**	**- UL kinematics (motion analysis)**	**- The average shoulder joint position was located more superior in the SI direction, more towards the non-reaching side in the ML direction, and more posterior in the AP direction during fatigue. - The average elbow position was located significantly more posterior during fatigue while ML and SI average elbow positions were unaltered. Wrist joint linear ROM also increased in the AP direction.**
Emery et al., 2012	**SG pretest posttest**	**healthy**	**18**	**9:9**	**18-28**	**A repetitive pointing task performed to fatigue until Borg score reached 8/10.**	**- Proprioceptive acuity (motion analysis) - Muscle activity (EMG)**	**- No effect was observed of fatigue on Finger and shoulder position sense. - Muscle activity showed statistically significant increase following fatigue regarding anterior deltoid, middle deltoid and triceps.**
Sutton et al., 2024	**SG pretest posttest**	**Handball players**	**12**	**12M**	**26±4.6**	**Five bouts of 10 handball throwing tasks until Borg score reaches 15/20.**	**- JPS**	**- JPS was significantly affected following fatigue after bout one and five compared to the non-fatigued limb.**

1RM: one repetition maximum; AAR: Active Angle reproduction; AP: Anteroposterior; DFV: Digital fluoroscopic video; Ex.: Exercises; GH: Glenohumeral; IMUs: Inertial measurement units; JPS: Joint position sense; LD: Latissimus dorsi; Min: minutes; ML: Medio-lateral; MVC: Maximum voluntary contraction; NA: Not applicable; NR: Not reported; PM: Pectoralis major; Reps: repetitions; RMS: Root mean square; SADS: single-arm dynamic stability; SC: Sternoclavicular; SG: single group; SI: superior-inferior; TMG: Tensiomyography; UL: Upper limb; VAF: Variance accounted for; VR: Virtual reality; Y: Years.

Table (2): Characteristics of the included studies

Single group studies (MINORS)									
Study	**Q1: A clearly stated aim**	**Q2: Inclusion of consecutive patients**	**Q3: Prospective collection of data**	**Q4: Endpoints appropriate to the aim of the study**	**Q5: Unbiased assessment of the study endpoint**	**Q6: Follow-up period appropriate to the aim of the study**	**Q7: Loss to follow up less than 5%:**	**Prospective calculation of study size**	**Score (16)**
Adamo et al., 2020	**2**	**1**	**2**	**1**	**0**	**0**	**2**	**0**	**8**
Stella et al., 2024	**2**	**2**	**2**	**1**	**0**	**0**	**2**	**0**	**10**
Teyhen et al., 2008	**2**	**1**	**2**	**1**	**0**	**0**	**0**	**0**	**6**
Joshi et al., 2011	**2**	**1**	**2**	**1**	**0**	**0**	**0**	**0**	**6**
Henry et al., 2001	**2**	**1**	**2**	**1**	**0**	**0**	**0**	**0**	**6**
Guo et al., 2011	**2**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**4**
Carpenter et al.,1998	**2**	**1**	**2**	**1**	**0**	**0**	**0**	**0**	**6**
Tse et al., 2016	**2**	**1**	**2**	**1**	**0**	**0**	**0**	**0**	**6**
Lee et al., 2003	**2**	**1**	**2**	**1**	**0**	**0**	**0**	**0**	**6**
Chang et al., 2006	**2**	**1**	**0**	**1**	**0**	**2**	**0**	**0**	**6**
Voight et al., 1996	**2**	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**5**
Côté et al., 2005	**2**	**1**	**2**	**1**	**0**	**0**	**0**	**0**	**6**
Thomas et al., 2023	**2**	**1**	**2**	**1**	**0**	**0**	**0**	**0**	**6**
Fuller et al., 2009	**2**	**1**	**2**	**0**	**0**	**0**	**2**	**0**	**7**

Emery et al., 2012	**2**	**1**	**2**	**0**	**0**	**0**	**0**	**0**	**5**
Sutton et al., 2024	**2**	**1**	**2**	**1**	**0**	**0**	**2**	**0**	**8**

Comparative Studies (PEDro)

	Q1: Eligibility Criteria	Q2: Randomization	Q3: Concealed Allocation	Q4: Baseline Similarity	Q5: Subjects Blinding	Q6: Therapists Blinding	Q7: Assessor Blinding	Q8: Drop-out	Q9: Intention-to-treat	Q10: between-group statistical comparisons	Q11: Measures of variability	Total (10)
Iida et al., 2014	**No**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**3**
Bowman et al.,2006	**No**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**3**
Sterner et al., 1998	**Yes**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**4**
Myers et al., 1999	**No**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**4**
King et al., 2022	**Yes**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**1**	**3**
Dupuis et al., 2021	**Yes**	**1**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**1**	**1**	**5**
Dupuis et al., 2022	**Yes**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**1**	**4**
Sadler et al., 2019	**No**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**3**
Ali et al., 2023	**Yes**	**1**	**1**	**1**	**0**	**0**	**0**	**1**	**1**	**1**	**1**	**7**

Intervention Characteristics

Ten studies performed the fatigue procedure using isokinetic dynamometer fatigue protocol [17-22, 25, 31, 36, 38], Five studies performed free weights active resistive exercises to fatigue [26, 28, 29, 33, 37] while the rest of the included studies induced fatigue throw performance of specific activities such as swimming [39], baseball throwing [24], handball throwing [40], hammering [23], combined manual activities [34, 35] and repetitive pointing or reaching tasks [27, 30, 32]. Fatigue was confirmed either throw decline in peak force and torque or rating of perceived exertion via Borg scale.

Outcome measures

The main outcomes of interest were **proprioceptive acuity** via joint position sense or active reproduction test [17-20, 22, 25, 28, 30-32, 40], **kinematics of upper extremity** including axes of rotation characteristics [33], glenohumeral head migration [26], range of motion [27, 29, 31, 34, 35], shoulder deceleration time [24], spatiotemporal parameter of upper limb motion [23], **muscle activity** mostly via electromyography [21, 29-31, 34-36, 38] or via tensiomyography [39] and **muscle power** either though hand held dynamometer or isokinetic dynamometer [25, 26, 29, 36, 37, 39] or handgrip dynamometer [23].

The effect of induced fatigue on proprioceptive acuity

Proprioceptive acuity was assessed via active reproduction of active and passive positioning tests, and threshold to detect motion tests. Five studies [17, 19, 20, 28, 40] were included in quantitative analysis showing no significant difference between fatigue and prefatigue condition (Z= 0.875, 95%CI [-1.037 - 2.708], P = 0.382). It is worth mentioning that the data of the included studies showed significant statistical heterogeneity (97.05%, P < 0.0001) so it was necessary to use the random effect model **Figure (2).**

Meta-analysis: generic inverse variance method

Variable for studies	Study
Variable for estimate:	Effect_size Effect size
Variable for Standard Error:	SE

Study	Estimate	Standard Error	95% CI	z	P	Weight (%)	
						Fixed	Random
Voight et al., 1996	3.300	0.160	2.986 to 3.614			63.69	22.07
Sterner et al., 1998	-0.110	0.600	-1.286 to 1.066			4.53	20.42
Myers et al., 1999	0.860	0.580	-0.277 to 1.997			4.85	20.53
Guo et al., 2011	-0.600	1.390	-3.324 to 2.124			0.84	15.10
Sutton et al., 2024	0.200	0.250	-0.290 to 0.690			26.09	21.88
Total (fixed effects)	2.186	0.128	1.935 to 2.436	17.117	<0.001	100.00	100.00
Total (random effects)	0.836	0.955	-1.037 to 2.708	0.875	0.382	100.00	100.00

Test for heterogeneity

Q	135.4709
DF	4
Significance level	P < 0.0001
I^2 (inconsistency)	97.05%
95% CI for I^2	95.13 to 98.21

Publication bias

Egger's test	
Intercept	-5.5529
95% CI	-18.7884 to 7.6826
Significance level	P = 0.2741
Begg's test	
Kendall's Tau	0.0000
Significance level	P = 1.0000

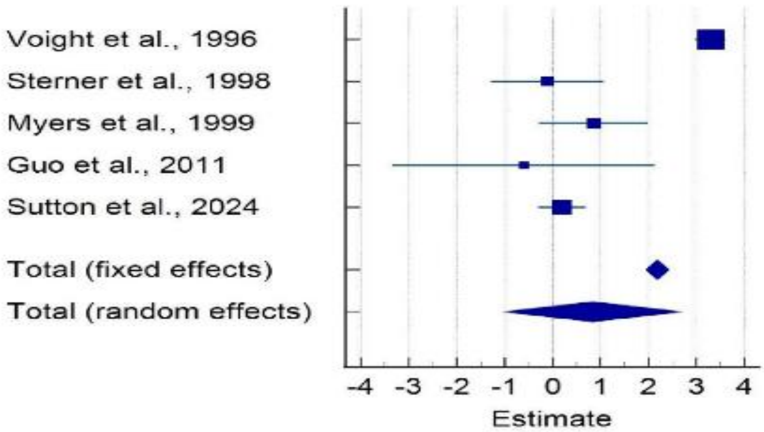

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Figure (2) Descriptive Meta-analysis: Proprioceptive acuity pre & post fatigue comparison

The effect of induced fatigue on kinematics of the upper extremity

Kinematics of upper extremity was investigated in nine included studies [23, 24, 26, 27, [29, 31, 33-35]. The effect of induced fatigue was statistically significant in terms of dispersion of axis of rotation i.e., helical axis dispersion [33], glenohumeral migration [26], and shoulder joint angle and displacement [27]. Regarding, upper extremity range of motion, most of the included studies showed that fatigue statistically altered the ROM of upper extremity motions including scapular upward rotation, internal and external rotation, all GH motions, elbow flexion and extension [23, 29, 33, 34], however scapular tilting [29] and glenohumeral abduction [34] did not show statistical differences following fatigue in two studies respectively.

The induction of fatigue in one shoulder affected also the contralateral shoulder specifically fatigue of shoulder flexor which resulted in higher ROM in the contralateral shoulder [33] and higher sternoclavicular elevation [35], however, this did not affect the other joints in the contralateral limb and no effect was observed following external rotation fatigue protocol.

Post fatigue assessment of kinematics during the performance of sports or manual activities revealed increased deceleration time in baseball players [24] and decreased elbow velocity and acceleration during hammering [23], however, it did not affect all other joints of during hammering task.

The effect of induced fatigue on muscle power

Muscle strength, power or torque were assessed in seven studies [23, 25, 27, 31, 36, 37, 39] via isokinetic dynamometer or handheld dynamometer. Single study [23] assessed handgrip strength via hand grip dynamometer. Most of the included studies revealed statistically significant decrease of muscle power following fatigue including shoulder extension, external rotation, internal rotation, shoulder elevation and handgrip strength [23, 25, 27, 31, 36, 37, 39], however two studies showed insignificant results regarding shoulder flexion, internal and external rotation [39] and elbow flexion and extension [27].

The effect of induced fatigue on muscle activity

Ten studies [21, 27, 29-31, 34-36, 38, 39] assessed muscle activity following fatigue. The assessed muscles were shoulder girdle muscles such as trapezius, deltoid, pectoralis major, latissimus dorsi or rotator cuff muscles.

The muscle activity alteration varied across the assessed muscle; for instance, the upper trapezius activity increased following fatigue protocol in both the fatigued arm [27] and the contralateral arm [35] as well as the activity of pectoralis major muscle [31, 36], however, it was not affected in overhead athletes [29]. On the contrary, the middle trapezius showed decreased activity in both healthy and water polo players [36] as well as the lower trapezius in overhead athletes [29].

The results were conflicting regarding the activity of the anterior deltoid, middle deltoid, triceps, subscapularis, latissimus dorsi and infraspinatus muscles between the included studies [21, 27, 30, 31, 34, 36], however, the activity of the posterior deltoid decreased following fatigue in both healthy controls and water polo players but not swimmers [36]. The serratus anterior and biceps brachii muscles were each studied in a single study revealing no difference between the prefatigue and post fatigue conditions [27, 29].

Two studies used different assessment tools to assess muscle activity; One study [39] utilized tensiomyography to assess the activity of deltoid, latissimus dorsi, pectoralis major and the three parts of the trapezius muscles following 30 minutes of front-crawl swimming revealed significant difference in terms of maximal radial displacement in latissimus dorsi and pectoralis major and time of contraction of latissimus dorsi muscle while the other study [38] assessed the synergy of four groups of muscles revealing no difference following fatigue in all groups except the first group which included the middle trapezius, lower trapezius, middle deltoid, posterior deltoid and infraspinatus muscles.

DISCUSSION

The current systematic review examined the effect of induced fatigue of the shoulder complex muscles on sensorimotor functions of the upper extremity in sedentary participants, active healthy participants and athletes. Considering the high risk of bias existing in the included studies and the significant methodological and statistical heterogeneity, induced shoulder musculature fatigue may alter the joint kinematics and reduce the muscle power of the upper extremity, however, its effect on muscle activity and proprioception is questionable.

The results of the current systematic review showed that induced fatigue may have a clear impact on the arthrokinematics of the glenohumeral joint. The results of the included studies highlighted the effect of fatigue on dispersion of the helical axis of rotation of the glenohumeral joint which means that fatigue affected the position of the humeral head within the glenoid cavity [33], in addition, another included study [26] which showed that fatigue altered humeral head migration.

This effect could be a risk factor to induce shoulder pathologies such as shoulder impingement syndrome as postulated in Yu et al., who reported that fatigue causes the humeral head superior migration in subjects with subacromial pain. This is due to weakness of rotator cuff muscles and overly active deltoid muscles, which result in changes to neuromuscular control and may lead to instability in the shoulder joint [41]. This is evident in Teyhen et al., that reported even in healthy participants, fatigue caused superior migration of the humeral head which could contribute to the incidence of shoulder impingement syndrome and rotator cuff pathologies [26, 42]

In addition, the induction of fatigue affected most of the range of motion parameters of the upper limb joints which may be attributed to the same mechanism as Cheng et al., stated that Loss of torque due to fatigue, decreased torque from muscle shortening, and passive tension in opposing muscles all lead to a reduced active range of motion [43]. This effect not only on the same extremity but rather extended to the contralateral extremity affecting the sternoclavicular and glenohumeral joints.

The impact of shoulder fatigue on the kinematics of the upper extremity was accompanied by its effect on muscle strength, power or torque. Most of the included studies reported reduction in muscle torque following fatigue even though it extended to the handgrip strength, Fatigue decreases isometric force, slows maximum shortening velocity, and increases the curvature of the force-velocity relationship, all contributing to power loss [44].

The effect of fatigue on muscle activity was ambiguous. The results were conflicting across many of the muscles investigated not only the presence of statistical significance of not but also, the direction of the effect was variable even in the same muscles i.e., increased or decreased activity. This highlights the issue of heterogeneity and variability of the methodological procedures adopted within the previous literature and not building upon the previous gained knowledge but rather adapting different methods without filling the existing gap within the current literature.

Even the only outcome that could be statistically pooled i.e., proprioception, although it showed no statistically significant effect of fatigue on proprioceptive acuity, the results come from the application of the random effects model of the meta-analysis which was obligatory due to the significant statistical heterogeneity (97.05%) within the included studies. This was confirmed by applying the fixed effects model and ignoring the statistical heterogeneity resulting in a very significant effect of fatigue on proprioception ($P < 0.001$) however, it is not statistically appropriate.

Limitations

The meta-analysis was only applicable in one outcome i.e., proprioception however, the statistical heterogeneity was very high i.e., 97.05%, also, the included studies showed high risk of bias and low methodological quality with great variability across the intervention procedures including the fatigue protocol which was applied through various activities and measurement procedures such as measuring different kinematic parameters and using different assessment tools. Furthermore, most of the included studies were single group repeated measure design and not randomized controlled trails which is a major defect, and the statistical designs and statistical data reported within the studies were inappropriate and inadequate. Also, this systematic review included only studies written in English, however, most of the retrieved records were written in English.

Future Implications

The results of this systematic review highlight the deficits in the methodological quality of this research point. There is an urgent need for well-structured randomized controlled trails with more standardized methods of induced fatigue, measurements and activities at which the outcome measures will be obtained. In addition, authors of clinical trials should shed light on the impact of fatigue on more types of athletic participants.

CONCLUSION

Induced fatigue of the shoulder complex musculature may influence the kinematics and muscle power of the upper extremity. However, the low methodological quality of the included trials and significant heterogeneity in the investigated variables hinder drawing definitive conclusion regarding the effect of fatigue. More high quality RCTs are required to reach a definitive conclusion regarding the effects of induced fatigue on upper extremity sensorimotor functions.

REFERENCES

1. Matthews M, Green D, H. M, et al. The effects of swimming fatigue on shoulder strength, range of motion, joint control, and performance in swimmers. *Physical therapy in sport : official journal of the Association of Chartered Physiotherapists in Sports Medicine* 2017; 23. DOI: doi:10.1016/j.ptsp.2016.08.011.

2. Wan J, Qin Z, Wang P, et al. Muscle fatigue: general understanding and treatment. *Experimental & molecular medicine* 2017; 49. DOI: doi:10.1038/emm.2017.194.

3. Yoon J-H, Park N-H, Kang Y-E, et al. The demographic features of fatigue in the general population worldwide: a systematic review and meta-analysis. *Frontiers in Public Health* 2023; 11. Systematic Review. DOI: 10.3389/fpubh.2023.1192121.

4. Kadi R, Milants A and Shahabpour M. Shoulder Anatomy and Normal Variants. *Journal of The Belgian Society of Radiology* 2017; 101. DOI: https://doi.org/10.5334/jbr-btr.1467.

5. Neumann D. *Kinesiology of the Musculoskeletal System*. St. Louis, Missouri.: Elsevier, 2017.

6. Dyer L, Swanenburg J, Schwameder H, et al. Defining the glenohumeral range of motion required for overhead shoulder mobility: an observational study. *Archives of Physiotherapy* 2024; 14: 47-55. DOI: https://doi.org/10.33393/aop.2024.3015.

7. Erik Giphart JE, van der Meijden AJO and Millett JP. The effects of arm elevation on the 3-dimensional acromiohumeral distance: a biplane fluoroscopy study with normative data. *Journal of Shoulder and Elbow Surgery* 2012; 21: 1593-1600. DOI: https://doi.org/10.1016/j.jse.2011.11.023.

8. Urra O, Casals A and Jane R. The impact of visual feedback on the motor control of the upper-limb. *Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)* 2015. DOI: https://doi.org/10.1109/embc.2015.7319257.

9. Bachasson D, Singh A, Shah B, et al. The role of the peripheral and central nervous systems in rotator cuff disease. *Journal of Shoulder and Elbow Surgery* 2015; 24: 1322-1335. DOI: https://doi.org/10.1016/j.jse.2015.04.004.

10. Enoka R and Duchateau J. Translating Fatigue to Human Performance. *Medicine and science in sports and exercise* 2015; 48. DOI: https://doi.org/10.1249/MSS.0000000000000929.

11. Spargoli G. The Acute Effects of Concentric Versus Eccentric Muscle Fatigue on Shoulder Active Repositioning Sense. *Int J Sports Phys Ther* 2017; 12: 219-226. DOI: doi:.

12. Taylor J, Amann M, Duchateau J, et al. Neural Contributions to Muscle Fatigue: From the Brain to the Muscle and Back Again. *Medicine and science in sports and exercise* 2016; 48. DOI: doi:10.1249/MSS.0000000000000923 %X: During exercise, there is a progressive reduction in the ability to produce muscle force. Processes within the nervous system as well as within the muscles contribute to this fatigue. In addition to impaired function of the motor system, sensations associated with fatigue and impairment of homeost ….

13. Edouard P, Bankolé C, Calmels P, et al. Isokinetic rotator muscles fatigue in glenohumeral joint instability before and after Latarjet surgery: a pilot prospective study. *Scandinavian journal of medicine & science in sports* 2013; 23: e74-80. DOI: https://doi.org/10.1111/sms.12011.
14. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ* 2021; 372. DOI: doi:10.1136/bmj.n71.
15. Slim K, Nini E, Forestier D, et al. Methodological index for non-randomized studies (minors): development and validation of a new instrument. *ANZ journal of surgery* 2003; 73. DOI: 10.1046/j.1445-2197.2003.02748.x.
16. Cashin A and McAuley J. Clinimetrics: Physiotherapy Evidence Database (PEDro) Scale. *Journal of physiotherapy* 2020; 66. DOI: 10.1016/j.jphys.2019.08.005.
17. Voight M, Hardin J, Blackburn T, et al. The effects of muscle fatigue on and the relationship of arm dominance to shoulder proprioception. *The Journal of orthopaedic and sports physical therapy* 1996; 23. DOI: doi:10.2519/jospt.1996.23.6.348.
18. Carpenter J, Blasier R and Pellizzon G. The effects of muscle fatigue on shoulder joint position sense. *The American journal of sports medicine* 1998; 26. DOI: doi:10.1177/03635465980260021701.
19. Sterner R, Pincivero D and Lephart S. The effects of muscular fatigue on shoulder proprioception. *Clinical journal of sport medicine : official journal of the Canadian Academy of Sport Medicine* 1998; 8. DOI: doi:10.1097/00042752-199804000-00006.
20. Myers J, Guskiewicz K, Schneider R, et al. Proprioception and neuromuscular control of the shoulder after muscle fatigue. *J Athl Train* 1999; 34: 362-367. DOI: doi:.
21. Henry TJ, Lephart SM, Giraldo J, et al. The Effect of Muscle Fatigue on Muscle Force-Couple Activation of the Shoulder. *Journal of Sport Rehabilitation* 2001; 10. DOI: doi:10.1123/jsr.10.4.246.
22. Lee H, Liau J, Cheng C, et al. Evaluation of shoulder proprioception following muscle fatigue. *Clinical biomechanics (Bristol, Avon)* 2003; 18. DOI: doi:10.1016/s0268-0033(03)00151-7.
23. Côté J, Raymond D, Mathieu P, et al. Differences in multi-joint kinematic patterns of repetitive hammering in healthy, fatigued and shoulder-injured individuals. *Clinical biomechanics (Bristol, Avon)* 2005; 20. DOI: doi:10.1016/j.clinbiomech.2005.02.012.
24. Bowman T, Hart J, McGuire B, et al. A functional fatiguing protocol and deceleration time of the shoulder from an internal rotation perturbation. *J Athl Train* 2006; 41: 275-279. DOI: doi:.
25. Chang H-Y, Chen C-S, Wei S-H, et al. Recovery of Joint Position Sense in the Shoulder after Muscle Fatigue. *Journal of Sport Rehabilitation* 2006; 15. DOI: doi:10.1123/jsr.15.4.312.
26. Teyhen D, Miller J, Middag T, et al. Rotator cuff fatigue and glenohumeral kinematics in participants without shoulder dysfunction. *Journal of athletic training* 2008; 43. DOI: doi:10.4085/1062-6050-43.4.352.
27. Fuller J, Lomond K, Fung J, et al. Posture-movement changes following repetitive motion-induced shoulder muscle fatigue. *Journal of electromyography and kinesiology : official journal of the International Society of Electrophysiological Kinesiology* 2009; 19. DOI: doi:10.1016/j.jelekin.2008.10.009.
28. Guo L-Y, Lin C-F, Yang C-H, et al. Evaluation of Internal Rotator Muscle Fatigue on Shoulder and Scapular Proprioception. *Journal of Mechanics in Medicine and Biology* 2011; 11. DOI: doi:10.1142/S0219519411003892.
29. Joshi M, Thigpen C, Bunn K, et al. Shoulder external rotation fatigue and scapular muscle activation and kinematics in overhead athletes. *Journal of athletic training* 2011; 46. DOI: doi:10.4085/1062-6050-46.4.349.
30. Emery K and Côté J. Repetitive arm motion-induced fatigue affects shoulder but not endpoint position sense. *Experimental brain research* 2012; 216. DOI: doi:10.1007/s00221-011-2959-6.
31. Iida N, Kaneko F, Aoki N, et al. The effect of fatigued internal rotator and external rotator muscles of the shoulder on the shoulder position sense. *Journal of electromyography*

and kinesiology : official journal of the International Society of Electrophysiological Kinesiology 2014; 24. DOI: doi:10.1016/j.jelekin.2013.10.008.
32. Sadler C and Cressman E. Central fatigue mechanisms are responsible for decreases in hand proprioceptive acuity following shoulder muscle fatigue. *Human movement science* 2019; 66. DOI: doi:10.1016/j.humov.2019.04.016.
33. Adamo P, Temporiti F, Natali F, et al. Dispersion of shoulder helical axes during upper limb movements after muscle fatigue. *Journal of biomechanics* 2020; 113. DOI: doi:10.1016/j.jbiomech.2020.110075.
34. Dupuis F, Sole G, Wassinger C, et al. Fatigue, induced via repetitive upper-limb motor tasks, influences trunk and shoulder kinematics during an upper limb reaching task in a virtual reality environment. *PloS one* 2021; 16. DOI: doi:10.1371/journal.pone.0249403.
35. Dupuis F, Sole G, Mercier C, et al. Impact of fatigue at the shoulder on the contralateral upper limb kinematics and performance. *PLoS ONE* 2022; 17. DOI: doi:10.1371/journal.pone.0266370.
36. King S, Dong L, Caron M, et al. Changes in Muscle Activation During and After a Shoulder-Fatiguing Task: A Comparison of Elite Female Swimmers and Water Polo Players. *Frontiers in sports and active living* 2022; 4. DOI: doi:10.3389/fspor.2022.881582.
37. Ali R, Ali I and Sharma S. Comparison of shoulder external rotation fatigue protocols on kinetic determinants and fatigue index in overhead athletes: a cross over study. *Comparative Exercise Physiology* 2023; 19. DOI: doi:10.3920/CEP220045.
38. Thomas S, Castillo G, Topley M, et al. The Effects of Fatigue on Muscle Synergies in the Shoulders of Baseball Players. *Sports health* 2023; 15. DOI: doi:10.1177/19417381221084982.
39. Stella BA, Cargnel A, Raffini A, et al. Shoulder Tensiomyography and Isometric Strength in Swimmers Before and After a Fatiguing Protocol. *Journal of athletic training* 2024; 59. DOI: doi:10.4085/1062-6050-0265.23.
40. Sutton P, Lund Ohlsson M and Röijezon U. Reduced shoulder proprioception due to fatigue after repeated handball throws and evaluation of test-retest reliability of a clinical shoulder joint position test. *Shoulder & elbow* 2024; 16. DOI: doi:10.1177/17585732221139795.
41. Yu X, Zhu H and Griffin L. Fatigue-related changes in intermuscular electromyographic coherence across rotator cuff and deltoid muscles in individuals with and without subacromial pain. *Journal of neurophysiology* 2024; 132. DOI: doi:10.1152/jn.00431.2023.
42. Chopp J and Dickerson C. Resolving the contributions of fatigue-induced migration and scapular reorientation on the subacromial space: an orthopaedic geometric simulation analysis. *Human Movement Science* 2012; 31: 448-460. DOI: https://doi.org/10.1016/j.humov.2011.09.005.
43. Cheng A and Rice C. Factors contributing to the fatigue-related reduction in active dorsiflexion joint range of motion. *Applied physiology, nutrition, and metabolism* 2013; 38. DOI: doi:10.1139/apnm-2012-0357.
44. Jones D. Changes in the force-velocity relationship of fatigued muscle: implications for power production and possible causes. *The Journal of physiology* 2010; 588. DOI: doi:10.1113/jphysiol.2010.190934.

Appendix I: Detailed search strategy

Database	Searching Strategy
PubMed	(Fatigue[Title] AND Shoulder[Title])
Cochrane Central	#1 (“fatigue”:ti) #2 (“shoulder”:ti) #1 AND #2
Web of Science	(TI=(fatigue)) AND TI=(shoulder)
Scopus	(TITLE (fatigue) AND TITLE (shoulder))
PEDro	“Fatigue” “shoulder” Title only

Appendix II: Details of Excluded Articles

Study	Exclusion Reason
Andrade et al., 2016	Invalid assessment of fatigue
Backus et al., 2013	Abstract only
Cools et al., 2002	Invalid assessment of fatigue
Dube & Roy, 2019	Invalid assessment of fatigue
Ebaugh et al., 2006	Invalid assessment of fatigue
Gaudet et al., 2018	Invalid assessment of fatigue
Hammarskjöld & Harms-Ringdahl, 1992	Invalid assessment of fatigue
Hawkes et al., 2018	Invalid assessment of fatigue
Jensen et al., 2000	Invalid assessment of fatigue
Julienne et al., 2012	Invalid assessment of fatigue
Kawczyński et al., 2007	Invalid assessment of fatigue
Matthews et al., 2017	Invalid assessment of fatigue
McQuade et al., 1998	Invalid assessment of fatigue
Mullaney et al., 2006	Invalid assessment of fatigue
Niederbracht & Shim, 2008	Not intervention
Otto et al., 2018	Not comparator and inappropriate statistical comparison
Park et al., 2010	Not language
Pedersen et al., 1999	Invalid assessment of fatigue
Pontaga, 2018	Invalid assessment of fatigue
Spargoli, 2007	Not comparator and inappropriate statistical comparison
Suzuki et al., 2023	Invalid assessment of fatigue
Tse et al., 2016	Invalid assessment of fatigue
Umehara et al., 2018	Invalid assessment of fatigue
Weerakkody & Allen, 2017	Invalid assessment of fatigue
Yassierli & Nussbaum, 2007	Invalid assessment of fatigue