REVIEW ARTICLE

A review of the fatigue's effect on shoulder proprioception

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Abstract

Background: Fatigue is considered a significant contributing factor to shoulder injuries that most commonly happen at the later phases of a competitive game, possibly due to reduced proprioception. The main objective of the current review was to provide information based on the available literature regarding fatigue's impact on shoulder proprioception.

Methods: We performed a literature search via the EBSCO, PubMed, and Scopus electronic databases using the keywords ("muscle fatigue" OR "muscular fatigue" OR "fatigue exercise" OR "fatiguing activity") AND ("proprioception") AND ("shoulder"). The studies incorporated in this review were required to meet the Population, Intervention, Comparison, Outcome, and Study design (PICOS) criteria.

Results: A total of 12 studies fulfilled the inclusion criteria, examining the impact of tiredness on shoulder joint repositioning sense (n =9), the threshold for detecting passive movement (n =2), and the sense of force reproduction (n =1).

Conclusions: Exercise-induced fatigue can cause considerable impairment of shoulder joint position sense. The other subcategories of proprioception, including kinesthesia and sense of force reproduction, are also affected due to fatigue. HIPPOKRATIA 2024, 28 (2):45-49.

Keywords: Muscle fatigue, proprioception, joint position sense, kinesthesia, shoulder

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Background

Shoulder disorders are a common source of musculoskeletal pain and impairment[1]. In addition, shoulder pain ranks as the third most prevalent musculoskeletal condition, following low back and cervical pain[2]. The prognosis for persons experiencing musculoskeletal shoulder discomfort exhibits significant variation among individuals. On average, over 50 % of individuals with shoulder pain continue to report symptoms six months after seeking primary care[3]. In 68.8 % of the athletes who reported shoulder pain, training, and competition were most often linked to the development of pain[4]. The increased incidence of shoulder pain may have been caused by the training load and lack of recuperation between events, as most sports injuries in adolescents happened through indirect processes[4,5]. Athletes of elite level who perform overhead sports engage in high-intensity activities that could result in transient and end-match neuromuscular fatigue, which may explain the high prevalence of injuries during the latter half of a game or the final part of a training session[6].

Fatigue, defined as a decline in the muscle's capacity to produce force or power due to exercise, is influenced by both peripheral and central factors[7]. This decline is associated with an elevation in perceived exertion, which refers to the level of subjective effort, strain, discomfort, or fatigue experienced during physical activity[8]. Muscle fatigue has been postulated to hinder proprioceptive acuity through the elevation of muscle spindle discharge threshold and the disruption of afferent feedback[9]. The observed decline in proprioception following fatigue-induced exercise may be attributed to increased metabolites and inflammatory substances within the muscles. These substances directly influence the release pattern of muscle spindles and the activation of alpha-gamma receptors[10,11].

Proprioception refers to the collective neural input received by the central nervous system from mechanoreceptors, which are specialized nerve endings situated in various anatomical structures such as joints, capsules, ligaments, muscles, tendons, and skin[12,13]. Proprioception is commonly categorized into three subcategories: sense of tension (resistance), sense of movement, and sense of joint position[14]. The evaluation of proprioception is conducted with specific tests[15,16] that use either passive conditions, which involve biasing joint mechanoreceptors, or active conditions involving activating joint and muscle-tendon mechanoreceptors[15,17]. According to Lephart et al[18] and Benjaminse et al[19], joint position sense tests evaluate the level of precision or accuracy in repositioning a joint at a preset target angle. Kinesthesia assessments evaluate an individual's capacity to perceive joint movement, measured through various methods such as threshold to detection of passive motion (TTDPM)[18,19], movement discrimination tests[20,21], or the acuity of a tracking task[22]. Force sense tests evaluate an individual's capacity to perceive and generate a preset and controlled amount of force below the maximum threshold[19,23,24].

Several studies were designed to examine the impact of exercise-induced fatigue on several aspects of proprioception, such as joint position sense and kinesthesia, due to its detrimental effect on shoulder proprioception[12,13,25-27]. However, fewer studies have been conducted on the shoulder compared to knee and ankle joints. To date, no review has been conducted that exclusively investigates the effect of the exercise-induced fatigue on shoulder proprioception.

This review aimed to provide information from existing literature on fatigue's effect on shoulder proprioception and discuss possible outcomes based on this information.

Methods

The literature search was performed via the EBSCO, Pubmed, and Scopus electronic databases using the keywords ("muscle fatigue" OR "muscular fatigue" OR "fatigue exercise" OR "fatiguing activity") AND ("proprioception") AND ("shoulder"). We operated the exact sequence of the above keywords in each database. There were no restrictions regarding the publication date of the studies. We used the reference management software RefWorks (Proquest LLC, Ann Arbor, MI, USA) to screen, select, and eliminate duplicate articles. Furthermore, the studies incorporated in this review were required to meet the Population, Intervention, Comparison, Outcome, and Study design (PICOS) criteria (Table 1). We excluded from the analysis books, case reports, case series, review articles, conference abstracts, study protocols, and studies that involved patients with neurological diseases, or lacked sufficient information about the muscle fatigue protocol. We specified no specific limitations on the publication date.

Results

Fatigue and joint repositioning sense (JRS)

Nine studies[12,25-32] investigated the impact of fatigue on the shoulder JRS. All studies used the active repositioning (ARP) method to detect the target angles, while five[12,26-28,30] used passive repositioning (PRP) method. In one study[29], elite and amateur overhead throwers participated, while the remaining studies enrolled healthy, nonmentioned athletes. In total, 290 individuals participated in the studies (156 males, 53.79 %, and 98 females, 33.79 %). One study[29] did not mention the participant's gender. Six studies[12,25,27,30-32] used the isokinetic dynamometer to assess the JRS; two[26,28] used the isokinetic dynamometer with other proprioception testing devices, and one[32] used the digital inclinometer. Most included studies evaluated the JRS of the shoulder external or/internal rotation, while one[32] assessed JRS in shoulder flexion. Despite the target angles during the JRS assessment, Chang et al[30] assessed four target angles (5° from full internal rotation, 5° from full external rotation, mid-point of full range of motion for shoulder internal rotation, and mid-point of full range of motion for shoulder external rotation). Kablan et al[29] evaluated six target angles (10°, 15°, and 20° in internal and external rotation). Lee et al[26] used two replicated angles (45° of internal and 75° of external rotation). Lida et al[27] examined two target angles (mid-range for internal and external rotation). Myers et al[25] utilized three target angles (30° of internal and 30° of external rotation. Spargoli[31] assessed only one target angle (30° of external rotation). Sterner et al[28] examined the mid-range angle of both internal and external rotation, and Voight et al[12] assessed a solitary replicated angle (75° of external rotation). Guo et al[32] examined three target angles (30°, 60°, and 120° of shoulder flexion). The initial participants' positions for the proprioceptive assessments were sitting[12,27,29,30,32], supine[25,26,28], and standing[31]. Studies that used an isokinetic dynamometer for fatigue induction applied angular speeds of 180°/sec[12,25,26,31], 60°/sec[29], and 90°/sec[30]. In addition, these studies performed continuous maximal isokinetic contractions for fatigue confirmation until the peak torque was reduced to a specific percentage value for three consecutive repetitions. All studies involved a protocol of concentric-induced fatigue with the isokinetic dynamometer. Nevertheless, one study[31] utilized eccentric exercise-induced fatigue protocol. Guo et al[32] used a fatigue protocol, a repetitive exercise using dumbbells loaded at roughly 80 % of the participant's maximum force. Then, fatigue was confirmed when the recorded maximum force was reduced to 50 % below the initial maximum force. Six studies[12,25-27,29,30] confirmed the impairment of shoulder JRS due to fatigue, while three studies did not demonstrate any significant difference in angular error scores pre- and post-fatigue intervention[28,31,32]. The main characteristics of the above studies are described in Table 2.

Table 1: The Population, Intervention, Comparison, Outcome, and Study design (PICOS) criteria of the current review regarding fatigue's impact on shoulder proprioception.

Population	Healthy participants from all genders and ages
Intervention	Exercise-induced fatigue of the shoulder either in controlled laboratory conditions using an isokinetic dynamometer or a hand-held dynamometer, or through activities involving repetitive throwing movements.
Control	Non-fatigued limb or non-fatigued group of participants
Outcome measures	Shoulder proprioception including joint repositioning sense or/and threshold to detection of passive movement or/and force reproduction
Study design	Test-retest design trial

Table 2: The main characteristics of the included studies in current review regarding fatigue's impact on shoulder proprioception.

Study	Sample	Proprioceptive measures	Fatigue protocol	Mean ± SD pre	Mean ± SD post	Percentage (%) change (↑, ↓)
Voight et al[12]	80 healthy subjects (37 M, 47 F)	ARP, PRP	180°/sec, 50% decrease of peak torque for three consecutive repetitions.	3.95˚± 1.18˚ 13.7˚± 3.38˚	6.45˚± 1.8˚ 45.9˚± 10.98˚	ARP:↑ 63.29 % * PRP: ↑ 235.03 % *
Carpenter et al[13]	20 healthy subjects (11 M, 9 F)	TTDPM	50% decrease of peak torque for three consecutive repetitions	0.91˚± 0.235˚	1.59˚± 0.59˚	↑ 74.72% *
Sterner et al[28]	20 recreationally active subjects (all M)	ARP, PRP, TTDPM	50% decrease of peak torque for three consecutive repetitions	4.58˚± 2.55˚ 5.52˚± 3.67˚ 1.73 s ± 0.59 s	3.16˚± 2.50˚ 5.48˚± 3.67˚ 2.69 s ± 1.73 s	ARP: ↓ 31 % PRP: ↓ 0.72 % TTDPM: ↑ 55.49 %
Myers et al[25]	32 healthy subjects (16 M, 16 F)	ARP	180°/sec, 50% decrease of peak torque for three consecutive repetitions	4.72˚± 2.43˚	5.58˚± 2.23˚	↑ 18.22 % *
Lee et al[26]	11 healthy subjects (all M)	ARP, PRP	180°/sec, 50% decrease of peak torque for three consecutive repetitions	2.57˚± 1.02˚ NR	4.96˚± 1.73˚ NR	ARP: ↑ 92.99 % * Note: Only for external rotation PRP: No significant differences
Kablan et al[29]	40 volleyball players (20 elite, 20 beginners)	ARP	60◦/sec, 50% decrease of peak torque for three consecutive repetitions	3.8˚± 2.39˚ 4.5˚± 3.88˚	6.1˚± 3.83˚ 8.1˚± 5.72˚	↑ 60.52 % * Note: Elite players at 20˚ of internal rotation target angle ↑ 80 % * Note: Beginner players at 10˚of internal rotation target angle.
Yun Chang et al[30]	13 healthy subjects (8 F, 5 M)	PRP	90˚/sec, 50% decrease of peak torque for three consecutive repetitions	2.57˚± 1.67˚	6.39˚± 2.90˚	↑ 148.63 % *
Lida et al[27]	15 healthy subjects (all M)	ARP, PRP	60% decrease of peak torque for three consecutive repetitions	2.68˚ 2.32˚	4.19˚ 4.05˚	↑ 56.34 % * Note: Angular error of internal rotation ↑ 74.56 % Note: Angular error of external rotation
Spargoli[31]	22 healthy subjects (14 M, 8 F)	ARP	180°/second. The threshold for shoulder muscular fatigue was determined as the maximum peak torque of MVC minus 30%.	7.4˚± 4.29˚	7.2˚± 4.99˚	↓ 2.70 %
Guo et al[32]	20 healthy subjects (10 M, 10 F)	ARP	A repetitive exercise was performed using dumbbells loaded at roughly 80% of their maximal force. Fatigue was considered typical when the recorded maximum force reduced to 50% below the initial maximum force.	5.7˚± 4.4˚	4.6˚± 4˚	↓ 19.29%
Coskun et al[33]	17 M healthy subjects	FRP	120˚/sec, 50% decrease of peak torque for three consecutive repetitions	2.51 ± 1.96 Nm 1.36 ± 1.09 Nm	3.23 ± 2.17 Nm 1.27 ± 1.05 Nm	↑ 28.68% * Note: FRP for internal rotation ↓ 6.61% Note: FRP for external rotation

M: males, F: females, SD: standard deviation, ARP: active reposition, PRP: passive reposition, FRP: force reproduction, TTDPM: threshold to detection of passive motion, MVC: maximal voluntary contraction, °: degrees, Nm: Newton-meters, ↑: increase, ↓: decrease, *: p-value <0.05.

Fatigue and TTDPM

Two studies[13,28] investigated TTDPM of the shoulder (Table 2). Both studies evaluated the TTDPM for shoulder internal and external rotation, with all trials employing an identical starting shoulder position of 90° shoulder abduction and 90° flexion, while the participants were in a seated position. However, the angular speed of the passive movement varied throughout the investigations. Sterner et al[28] employed an angular speed of 0.5°/sec, whereas Carpenter et al[13] utilized an angular speed of 1°/sec. Both investigations used the same protocol to produce fatigue. The results varied in both investigations as Sterner et al[28] discovered no notable disparities in TTDPM before and after the fatigue intervention. In contrast, Carpenter et al[13] found a noteworthy rise in TTDPM following the fatigue intervention.

Fatigue and sense of force reproduction

Only one study[33] assessed the impact of fatigue on the sense of force reproduction (Table 2), in which seventeen healthy males participated. Before and after a fatigue procedure, each participant had to replicate a specific target in three consecutive trials. Before fatigue's onset, the force exerted by the participants did not show a significant difference compared to the desired value ($p = 0.073$). Nevertheless, following the fatiguing procedure, the magnitude of this force was much lower than the intended objective. No significant interactions were identified when repeated for external rotation ($p = 0.425$).

Discussion

This review aimed to provide the existing evidence in the current literature regarding the impact of muscle fatigue on shoulder proprioception. The primary findings of this review indicate that muscular fatigue adversely impacts the JRS of the shoulder. The prevailing consensus among the majority of studies (66.66 %) supports this hypothesis. Nevertheless, conflicting findings and insufficient evidence exist regarding the impact of fatigue on shoulder kinesthesia and the sense of force reproduction.

The observed decline in shoulder JRS following fatigue-induced exercise may be attributed to increased levels of several metabolites and inflammatory substances within the muscles. These substances directly influence the release pattern of muscle spindles and the activation of alpha-gamma receptors[10,11].

Only two studies[13,28] have examined the impact of muscular fatigue on the TTDPM of the shoulder, and they yielded conflicting results. Carpenter et al[13] found that following the fatigue intervention, the mean TTDPM (combined internal and external rotation) increased to 73 %, while no significant differences in TTDPM by Sterner et al[28], before and after a fatigue intervention. The methodological differences (initial participant's assessment position, angular speed, sample) between the two investigations may account for the conflicting results. It is hypothesized that fatigue decreases the kinesthetic information, reducing the sensitivity of muscle spindles, commonly acknowledged as the main receptors for kinesthesia[9]. Further evidence from a separate source confirms that muscle spindles have a crucial role in kinesthesia. This evidence comes from the observation that passive tension in muscles, both in and outside the eye, depends on the previous muscle contractions and changes in length, a phenomenon known as muscle thixotropy[9].

Due to the limited number of studies, there is limited evidence regarding the impact of exercise-induced fatigue of the rotator cuff on sense of force reproduction. Coskun et al[33] observed that the individuals demonstrated a significantly higher proficiency in recreating external rotation forces compared to their ability to reproduce internal rotation forces. A plausible rationale for this disparity, which the researchers gave, can be attributed to the testing position. The participants were examined in a maximum range of motion (ROM) position, specifically a complete external rotation and 90° of abduction. This position, similar to the final stage of cocking in overhead sports, generates specific tension in the ligaments of the front shoulder and offers proprioceptive feedback[34]. When a muscle is stretched passively, it causes the muscle spindles within the muscle to become active and produce brain impulses[35,36]. Greater elongation of the muscles, specifically the internal rotators, towards the end of the range of motion can lead to a higher quantity of stimulated muscle spindles in these muscles[37,38]. The simultaneous application of increased stress on ligaments, capsular structures, and the internal rotators can enhance proprioceptive feedback, improving accuracy in force reproduction[39].

Clinical recommendations

Physically active people are advised to incorporate well-organized training routines in order to enhance their endurance and develop a higher level of resistance to fatigue.

It is advisable to assess shoulder proprioception using reliable measurement equipment, such as an isokinetic dynamometer, in order to detect any proprioceptive abnormalities.

Evaluation of proprioception should also be conducted before and immediately following fatigue.

If a notable proprioceptive problem is detected during the assessment, targeted exercises should be implemented to improve proprioception.

Proprioception-enhancing exercises should be utilized even when experiencing fatigue to enhance mechanoreceptors' sensitivity in these situations.

Conclusion

Exercise-induced fatigue can cause significant impairment of shoulder joint position sense. The other subcategories of proprioception, including kinesthesia and sense of force reproduction also seem to be affected due to fatigue. Nevertheless, given the scarcity of existing studies, additional research is needed to establish more secure results.

Conflict of Interest

Authors declare no conflicts of interest.

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