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**SHOULDER MUSCULAR FATIGUE: APPLICATION,**  
**ASSESSMENT AND CLINICAL IMPLICATIONS**

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***Abstract***

**Objective:** To present the available scientific information regarding shoulder muscle fatigue, with its clinical aspects and implications, and to outline the tools and methods used to assess and quantify it. **Methods:** The available literature was appraised and relevant studies were identified using the following keywords, separate or in combination: “shoulder”, “muscle”, “fatigue”, “assessment”. **Results:** The muscles around shoulder joint behave differently to fatigue, internal rotators appearing to be more fatigue-resistant than external rotators. A decrease of 30% or more in the rotator cuff strength appears to be significant enough to result in a structural “impingement position”. Different tools and practices exist to assess and quantify muscular fatigue. Hand-held dynamometer is frequently used by clinicians, despite the fact that isometric contractions are not often met in daily activities. Isokinetic apparatus has a high level of accuracy and numerous outcomes, but a standardised and reliable protocol has to be established. Surface electromyography is limited to accurate analyses of immediate underneath skin muscles and only during static situations. 3D motion analyses have shown interesting compensatory adaptations in opposition with previous believes, therefore further investigations are needed. **Conclusions:** Fatigue of shoulder muscle groups induces sensory motor perturbation, which alters shoulder joint kinematics overloading different structures and decreasing performance. So far, there seems to be no consensus regarding “the ultimate assessment tool”. Isokinetic machines have shown to be the most accurate, but more work is needed to design the most adequate and reliable protocol to induce and quantify shoulder muscular fatigue.

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**Keywords:** Fatigue, isokinetic work, pathologies, tools.



## **1. Introduction**

Repetitive arm movements are a major component of many sporting and leisure activities, as well as several work tasks. Shoulder muscle fatigue, especially rotator cuff group, was identified as a possible cause of shoulder dysfunction (Roy, Ma, Macdermid, & Woodhouse, 2011) and was associated with performance decrease and a higher risk of injury (Ebaugh, McClure, & Karduna, 2006).

Muscle fatigue is a complex and time-dependent process involving physiological, biomechanical and psychological components (Seghers & Spaepen, 2004), occurring during repetitive muscular contractions (Gandevia, 2001) (either isometric, concentric or eccentric) displayed as a reduction of force-generating capacity (Longpre, Potvin, & Maly, 2013) or a defective functional outcome (De Luca, 1985; Sesboue & Guincestre, 2006), regardless if the task can be sustained or not (Bigland-Ritchie & Woods, 1984).

## **2. Problem Statement**

The muscular fatigue evolution rate is subject to several factors like the level of generated force, contraction duration, rest duration between contractions, fibre-type distribution, nerve conduction velocity and different central nervous system-related factors like motivation (Minning, Eliot, Uhl, & Malone, 2007).

Scientists used different practices to assess muscular fatigue; from some with a high level of accuracy (i.e. isokinetic machine), but a low functional component, to others (i.e. task-related movements) which are functionally oriented, but less accurate. Shoulder muscular fatigue was quantified through the evaluation of muscular strength (Mullaney & McHugh, 2006), endurance (Iida, Kaneko, Aoki, & Shibata, 2014; Royer et al., 2009), joint position sense (Carpenter, Blasler, & Pellizzon, 1998) and task accomplishment (Chopp, O'Neill, Hurley, & Dickerson, 2010; Rota, Morel, Saboul, Rogowski, & Hautier, 2014). It remains unclear which approach is optimal.

## **3. Research Questions**

What is the optimal modality to assess and quantify fatigue of shoulder rotator muscles?

## **4. Purpose of the Study**

The objectives of this work were to present the available scientific information regarding shoulder muscle fatigue, with its clinical aspects and implications, and also to outline the tools and methods used to assess and quantify it.

## **5. Research Methods**

Different databases like "PubMed", "Science direct", "Taylor and Francis", "Springer" were explored. Relevant studies were identified by scanning titles, abstracts and full papers using the following keywords: "shoulder", "muscle", "fatigue", "assessment", alone or in different combinations.

## 6. Findings

Muscular fatigue was studied in relation to different aspects happening inside the muscle, like voluntary contraction (Stackhouse, Stapleton, Wagner, & McClure, 2010) or neuromuscular control through reproducibility of an arm position (Carpenter et al., 1998; Iida et al., 2014; Tripp, Yochem, & Uhl, 2007), movement deceleration times (Bowman, Hart, McGuire, Palmieri, & Ingersoll, 2006) or movement stability (Gates & Dingwell, 2010). As well, the effects of fatigue were investigated in relation to glenohumeral arthrokinematics, either static (Chopp et al., 2010; Cote, Gomlinski, Tracy, & Mazzocca, 2009) or dynamic (Royer et al., 2009; Teyhen, Miller, Middag, & Kane, 2008). Differences between agonist and antagonist muscles (Ellenbecker & Roetert, 1999) and between dominant and non-dominant arm (Ellenbecker & Roetert, 1999; Julienne, Gauthier, & Davenne, 2012) were also explored. The latest pieces of research looked at the fatigue implication in the upper limb kinematics (Qin, Lin, Faber, Buchholz, & Xu, 2014) and its influence on sport activity performance (Rota et al., 2014).

The effects of shoulder muscular fatigue can be easily anticipated, but its exact implications in sport performance need to be assessed (Qin et al., 2014; Rota et al., 2014). During a repetitive fatiguing task, Qin et al. (2014) found that kinematic and kinetic adaptations of the upper-limb chain system likely occurred to reduce the load on fatigued shoulder muscles or to counteract the development of subsequent fatigue. On the same line, Rota et al. (2014) have found that upper limb muscles have different fatigue sensibility, which induces certain adaptation strategies to limit performance loss during specific tennis actions. It is still unclear if specific muscle fatigue (rotator cuff) or general scapular muscle fatigue has more influence on the upper limb “malfunction”, as there is only a single article on this issue (Chopp et al., 2010), which has no conclusive evidence. What is clear is that the muscles around shoulder joint behave differently to fatigue, internal rotators (IR) appearing to be more fatigue-resistant than external rotators (ER) in sporting (Ellenbecker & Roetert, 1999) and sedentary (Forthomme et al., 2008) populations.

Beside the performance implication of shoulder muscle fatigue, another important body of research has been attributed to its relation with shoulder injuries, especially “subacromial impingement syndrome”. Subacromial syndrome is a term used to describe the conflict between structures situated in the space delimited by the acromion and humeral head. There are two theories to justify the narrowing of this space: “bottom-up” – the superior migration of humeral head or “roof down” – scapula (and the implicit acromion rotation into the space) reorientation (down rotation, anterior tilt and protraction) (Chopp et al., 2010). Humeral migration received an important piece of literature, which concluded that this “natural excursion” was accentuated by the rotator cuff muscle fatigue (Chopp et al., 2010; Michener, McClure, & Karduna, 2003; Royer et al., 2009; Teyhen et al., 2008). This prolonged excursion was quantified statically, by plain radiographic investigations at 0°, 45°, 90° and 135° shoulder flexion in the scapular plane (Chopp et al., 2010; Teyhen et al., 2008), and dynamically, by the dynamic motion X-ray system (Royer et al., 2009). A decrease of 30% or more in the rotator cuff strength appears to be significant enough to result in superior positioning of the humeral head (Royer et al., 2009), which is mainly caused by the upward pull from the deltoid muscle. Regarding the scapular deficit movements, there are no clear findings. There is evidence confirming the reorientation of scapula after a global shoulder muscle fatigue protocol, but in a direction which has effectively widened the subacromial space (Chopp, Fischer, & Dickerson, 2011; Maenhout,

Dhooge, Van Herzeele, Palmans, & Cools, 2015), and not narrowed it, as previously showed (Chopp et al., 2010; Michener et al., 2003; Teyhen et al., 2008). More research is needed to clarify these aspects.

The rotator cuff fatigue has been proved to be the cause behind the failure of voluntary activation of infraspinatus muscle (Stackhouse et al., 2010). Even the infraspinatus is not the only ER, it is the main force generator (McCully, Suprak, Kosek, & Karduna, 2006). Therefore, in a fatigue state, the delayed activation of infraspinatus might result in the position sense error towards internal rotation (Iida et al., 2014) and the ability to detect (Carpenter et al., 1998) and decelerate movement (Bowman et al., 2006) in that direction. In sport actions, Tripp et al. (2007) have shown that fatigue decreases overall endpoint acuity altering the arm's position sense. Taking into consideration the multiple muscles involved in shoulder joint movements and their different levels of fatigue, we can assume that the compensatory actions aiming to maintain task precision might overload, in time, different structures (i.e. tendons, ligaments) (Gates & Dingwell, 2010).

In summary, the fatigue of shoulder muscle group induces sensory motor perturbation, which alters shoulder joint kinematics overloading different structures, with the intent to maintain performance level.

### **6.1. Fatigue assessment**

In order to reach the fatigue state, a muscle must be activated isometrically, isotonicly or isokinetically, either concentrically or eccentrically. There are different methods to assess muscular fatigue: analytic isometric contractions (Avin et al., 2010; Minning et al., 2007; Stackhouse et al., 2010), successive controlled (Carpenter et al., 1998; Ellenbecker & Roetert, 1999; Iida et al., 2014; Julienne et al., 2012; Roy et al., 2011) and uncontrolled movements (Chopp et al., 2010), repetitive arm movements (Cote et al., 2009; Royer et al., 2009), specific overhead sport actions (Bowman et al., 2006; Dale, Kovaleski, Ogletree, Heitman, & Norrell, 2007; Rota et al., 2014; Tripp et al., 2007) or certain job tasks (Chopp et al., 2011; Gates & Dingwell, 2010; Qin et al., 2014).

The hand-held dynamometer was used to assess fatigue in targeted muscles through isometric contractions (Avin et al., 2010; Minning et al., 2007; Stackhouse et al., 2010), but without great interest in designing reliable protocols and procedures especially for the shoulder joint.

Isokinetic machine is widely used to investigate shoulder muscular properties, due to its high level of accuracy and numerous outcome parameters. There seems to be no agreement regarding different technical aspects of the testing protocol (body position, arm spatial orientation) or resistance effort (speed, number of repetitions, mode of contraction) when assessing the rotator cuff muscles.

Different body positions (i.e. standing, seated, lying) and numerous arm spatial orientation possibilities exist (Carpenter et al., 1998; Iida et al., 2014; Julienne et al., 2012; Mullaney & McHugh, 2006; Roy et al., 2011). The most used arm position is at 90° abduction in the frontal plane (Ellenbecker & Roetert, 1999; Iida et al., 2014; Mullaney & McHugh, 2006), because this is the rough position of most overhead sport actions (i.e. tennis serve, volleyball spike, overhead throws). Variations of this position exist with arm abducted to 45° in the frontal plane (Forthomme, Croisier, Ciccarone, Crielaard, & Cloes, 2005) or with 90° arm flexion (Julienne et al., 2012) or by performing movements in the scapular plane (Carpenter et al., 1998). The ideal testing position should be a pain-free one, with a clinically accepted reliability of measured parameters and which replicates the natural activity environment.

An even more important aspect when assessing muscular fatigue, beside the position, is the resistance effort. It is influenced by the speed of execution, mode of contraction and number of repetitions. The speed (measured as degrees per second) at which fatigue strength is tested varies from 60°/s (Roy et al., 2011) to 300°/s (Ellenbecker & Roetert, 1999). It has been mentioned that speeds over 120°/s cannot be achieved during the concentric isokinetic phase (Mullaney & McHugh, 2006). Despite this, the speed of 180°/s is most frequently used (Carpenter et al., 1998; Iida et al., 2014), maybe as a compromise between slow speeds, which might overload the structures from the beginning, and high speeds, which are hard to reach immediately (Bosquet et al., 2010). The mode of contraction is in close relationship with speed, repeated concentric contraction being the most used method to induce fatigue using isokinetic machine (Carpenter et al., 1998; Ellenbecker & Roetert, 1999; Forthomme et al., 2005; Roy et al., 2011). Nevertheless, eccentric mode was used to induce fatigue (Mullaney & McHugh, 2006). This mode of contraction should be used with precaution for fatigue testing purposes, especially in sedentary subjects, due to its subsequent manifestations at muscular level (i.e. delay in the onset of muscular fatigue) and modest knowledge at the tendon site (Andarawis-Puri & Flatow, 2011). To mention that isometric contractions were used as well, but without great interest. The number of repetitions varies from 20 (Ellenbecker & Roetert, 1999) to the maximum possible (Carpenter et al., 1998; Iida et al., 2014). Some authors proposed to perform a maximal amount of contractions over a predetermined number of cycles, while others assessed force production until a certain decrease (40-50% in most cases) in maximum voluntary contraction was reached.

Another debate is about the effort levels that should be considered. Some authors preferred the full involvement – maximal output (100%) (Bowman et al., 2006; Carpenter et al., 1998; Dale et al., 2007; Ellenbecker & Roetert, 1999; Iida et al., 2014; Stackhouse et al., 2010; Tripp et al., 2007), while others – moderate involvement (50-60%) (Roy et al., 2011). As expected, the maximal output protocol will have a shorter duration than the ones with moderate involvement. The cutting point can be decided volitionally by the participants (Chopp et al., 2011; Gates & Dingwell, 2010; Tripp et al., 2007) or the assessor when a certain number of sets/repetitions has been achieved (Dale et al., 2007; Julienne et al., 2012; Minning et al., 2007; Qin et al., 2014; Rota et al., 2014; Roy et al., 2011; Stackhouse et al., 2010) or when performance drops below a certain level (Bowman et al., 2006; Carpenter et al., 1998; Cote et al., 2009; Iida et al., 2014; Royer et al., 2009). An uncontrolled aspect of any testing method is represented by the participants' motivation. This aspect can be covered by verbal encouragements done in a standardised way, after a certain number of repetitions (Roy et al., 2011) or continuously (Bosquet et al., 2010; Edouard et al., 2013; Ellenbecker & Roetert, 1999; Stackhouse et al., 2010) with (Stackhouse et al., 2010) or without (Edouard et al., 2013; Ellenbecker & Roetert, 1999) visual feedback about the performance.

A standardised and reliable protocol has not been yet established, as there are many variables to consider when designing a muscular fatigue protocol using isokinetic apparatus. Nevertheless, the isokinetic machine has been proven to be a reliable tool to assess fatigue in certain shoulder muscular groups, the test-retest reliability varying from high (ICC = 0.78 to 0.83) (Roy et al., 2011) to moderate (ICC = 0.66 to 0.81) (Dale et al., 2007), as the authors used different protocols and populations. The more the technical aspects of the protocol are standardised, better results and higher test-retest reliability are obtained (Roy et al., 2011). Probably the most appropriate way to assess shoulder muscular fatigue is by repetitively executing a certain movement (Chen, Simonian, Wickiewicz, Otis, & Warren, 1999; Chopp et al., 2010;

Cote et al., 2009; Royer et al., 2009; Teyhen et al., 2008), a cyclic job (Gates & Dingwell, 2010; Qin et al., 2014) or a sport action (Dale et al., 2007; Rota et al., 2014). Such a protocol must take into account that the targeted muscle actions may vary in accordance with arm spatial orientation. An important limitation of this modality is represented by the difficulties in data collection and quantification of compensatory movements.

## **6.2. Modalities to quantify fatigue**

Quantifying fatigue can be done directly, by calculating different fatigue indexes based on muscle performance, and indirectly, by looking at its consequences using different additional tools like X-ray machine (Chopp et al., 2010; Cote et al., 2009; Royer et al., 2009) or 3D motion analyses (Chopp et al., 2011; Qin et al., 2014). At muscular level, fatigue was quantified measuring myoelectric activity by the method of surface electromyography (sEMG), which is also referred to as neuromuscular fatigue (Cifrek, Medved, Tonkovic, & Ostojic, 2009). Neuromuscular fatigue was associated with an increase in the signal amplitude and lower frequencies of the power spectrum (shifting it to the left). While, for static situations, data interpretation can be done straight forward, for dynamic situations, we should take into consideration that the muscles are moving underneath the electrodes, which complicates the signal considerably, adding confounding factors.

Fatigue indexes were calculated either as a pre-post intervention outcome (Nitschke, 1992) or by computing the decrease in muscular performance during the intervention (Dale et al., 2007; Ellenbecker & Roetert, 1999; Mullaney & McHugh, 2006). The pre-post outcome is expressed as a ratio or percentage difference between the performance prior and after the fatiguing event (Minning et al., 2007; Rota et al., 2014). Calculation formula varies: some authors take into consideration only the data of the last 3, 5 or 10 repetitions and compare them with their equivalent at the beginning of the test (Dale et al., 2007; Ellenbecker & Roetert, 1999; Mullaney & McHugh, 2006), while others take into consideration data over all repetitions (Bosquet et al., 2010) and compare them with maximum possible theoretical work. As well, the fatigue rate is determined by plotting performance of each repetition across the assessment (Bosquet et al., 2010; Julienne et al., 2012). Data interpretation option is totally in the researcher's hands and so far there is only the work of Bosquet et al. (2010) investigating the reliability of 3 different statistical calculation methods, but without bringing to discussion the implications of different fatigue index calculation modalities in clinical activity or sport performance.

The indirect modalities for quantifying muscular fatigue of shoulder rotators related to the consequences on joint kinematics and upper limb kinetics. Shoulder muscular fatigue tasks were associated with kinematics, kinetics and arm movement variability (Qin et al., 2014). Shoulder joint kinematics was quantified using radiographic analysis (Chen et al., 1999; Chopp et al., 2010; Cote et al., 2009; Teyhen et al., 2008), through which muscular fatigue repercussions were linked to shoulder injuries (i.e. subacromial impingement). Arm kinetics and, more recently, scapula movement variability (Maenhout et al., 2015) were assessed using 3D motion analysis systems. This investigation method has shown some natural fatigue adaptations, which are represented by the variation in fatigued joint angles and joint torques (elbow, wrist) (Qin et al., 2014) and the reorientation of scapula position (Maenhout et al., 2015).

### 6.3. Clinical implications and practical applications

From a clinical point of view (treatment and prevention), the joint alignment and muscle function are two important aspects that should be assessed under the fatigue state using available tools and procedures. In practice, clinicians and the coaching staff should limit the number of repetitions/sets of certain drills to avoid overloading the “at-risk” structures, but should emphasise the work of shoulder stabilisation systems under the fatigue state. Isokinetic machine is the most used tool to assess muscular fatigue, due to its high level of accuracy and numerous outcomes, but there is a need for further research to investigate the clinical relevance of such protocols. sEMG, for the moment, is limited to accurate analyses of immediate underneath skin muscles and only during static situations. Dynamic situation techniques and calculation formulas should be more developed. 3D motion analyses have shown interesting compensatory adaptations that are in opposition to what was previously known and believed, therefore need to be explored in more depth.

## 7. Conclusion

Shoulder rotator cuff muscles have received an important amount of literature, which explored their implications in shoulder malfunction, performance decrease and possible relation with an increased risk of injuries. Different apparatus and modalities have been validated to assess the fatigue of different shoulder muscles, each providing interesting and useful information. So far, there seems to be no consensus regarding “the ultimate tool” or assessment protocol. Systematic review and meta-analysis studies are necessary to assess the clinical relevance of different apparatus and protocols and to challenge their practical applicability.

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