Physical Therapy in Sport 37 (2019) 64–68

Contents lists available at ScienceDirect

Physical Therapy in Sport

journal homepage: www.elsevier.com/ptsp

Original Research

Shoulder muscle onset timing during clinical assessment movements is the same in elite handball players as non-athletes: Implications for clinical assessment

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ARTICLE INFO

Article history:
Received 16 November 2018
Received in revised form
26 February 2019
Accepted 27 February 2019

Keywords:
Overhead
Athlete
Patterns
Electromyography

ABSTRACT

Objectives: This study examines neuromuscular firing patterns in overhead athletes and non-athletes of the periscapular, prime-moving, and rotator cuff muscles during "clinical" cardinal plane physiological movements.
Design: Cohort prospective study.
Setting: EMG recordings were taken of the periscapular, prime-moving, and rotator cuff muscles during flexion, scaption, and abduction performed at fast, medium, and slow speeds with a loaded (3 kg) and unloaded arm.
Participants: 14 Handball players and 20 non-athletes. Differences in firing patterns between groups were analyzed by fitting mixed linear models with random intercepts per subject, and fixed factors for group, muscle, movement type, speed, and load.
Main outcome measures: No difference in timing of activation was seen between the professional athletes and non-athletes.
Results: Speed and load appear to independently vary muscle activation timing in a non-intuitive manner in both athletes and non-athletes. Onset timing of periscapular, prime movers and rotator cuff muscles are prior to movement in all scenarios studied, with rotator cuff muscles firing last.
Conclusions: Onset activation patterns in overhead athletes are not different to non-athletes during cardinal plane movements.

1. Introduction

Participants in overhead sports display anatomic differences to non-athletes such bony changes (Worsley et al., 2013)' functional asymmetries (postural, total rotational ROM, GIRD, ERD (Cools, Cambier, & Witvrouw, 2008; Cools et al., 2014b; Lewis, 2009), as well as sports-specific strength adaptations (Cools et al., 2014b; De Mey et al., 2013a). During overhead movements, the complex interaction of scapular and humeral contributions will be influenced by these factors, but likely more so by variations in muscle firing patterns. Through years of deliberate sporting practice, the motor patterns of these athletes during their sport could be different to non-athletes, and the question arises whether assessing "standardized" clinical (as opposed to sport-specific) movements are different in this population (De Mey et al., 2013b; Milton, Solodkin, Hluštík, & Small, 2007). If this is the case, then a strong argument arises to ignore "clinical" movement assessment findings in elite athletes, and to only gather examination information from sports-specific "functional" activity. Alternately, if these movement patterns are universal, then a "standardized" clinical examination can be recommended.

Onset activation patterns have been examined in healthy non-athletes as well as individuals diagnosed with rotator cuff disorders (Chester, Smith, Hooper, & Dixon, 2010; De Mey et al., 2013a;

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https://doi.org/10.1016/j.ptsp.2019.02.007
1466-853X/

Lewis, 2009; Whiteley, Oceguera, Valencia, & Mitchell, 2012), but not in overhead athletes. Recently, Møller et al., 2017 demonstrated that scapular dyskinesis during active movements was associated with subsequent shoulder injury when training loads are increased excessively in handball players (Phadke & Ludewig, 2013). In this study, scapular dyskinesia was examined during slow, unloaded active movements in these otherwise healthy players where it is unlikely that muscle weakness would be a limiting factor and aberrant scapular movement is more likely a reflection of the individual's motor pattern. Surprisingly, despite the commonly held clinical belief that the assessment of overhead athletes should be tailored to this population (Cools et al., 2008; Kibler et al., 2013) there are no data on muscle onset activation patterns (rotator cuff and scapular) of throwing athletes during typical physical assessment movements.

Previous research has examined the interplay between the scapular and rotator cuff muscles (Sangwan, Green, & Taylor, 2014) showing alterations in timing and magnitude of the upper trapezius (UT) during shoulder elevation in the presence of shoulder pathology which was more pronounced during loaded movements (Pizzari, Wickham, Balster, Ganderton, & Watson, 2014). In addition, early activation of the serratus anterior (SA) and lower trapezius (LT) have been also reported prior to movement for all physiological movements [(35)]. In a rotator cuff injured cohort, Reed, Cathers, Halaki, and Ginn (2013), reported early activation during abduction of all rotator cuff muscles and of the deltoid muscle during abduction and scaption, whether loaded or unloaded (Sangwan et al., 2014).

Differences in scapular muscle onset activation have been demonstrated in swimmers with a diagnosis of subacromial impingement. Wadsworth & Bullock-Saxton (1997) observed preactivation of the UT (−217 msec) followed by SA (−53 msec) prior to movement while the LT activated 349 ms after movement was initiated (Wattanaprakornkul, Cathers, Halaki, & Ginn, 2011).

It is difficult to compare EMG studies because of methodological and procedural differences. In a systematic review, Sangwan, Green, & Taylor, 2015 reported 6 studies with poor evidence of onset activation of the RC prior to movement (Sangwan et al., 2015). Overall, there is limited information about onset activation patterns during physiological movements, at low or high speed, loaded or unloaded as often used during clinical assessment (Sangwan et al., 2015).

Despite the anatomical differences and physiological demands of overhead athletes, clinical movement assessments are typically standardized for overhead and nonathletes. To identify if altered onset activation patterns are clinically relevant in these populations, we first need to understand onset activation patterns in healthy non-athletes and overhead athletes during these physiological movements that clinicians use during typical physical examination procedures. With this information, valid interpretation of any variation in scapular dyskinesis can be made, and appropriate treatment implications inferred.

The aim of this study therefore is to identify and describe muscle onset activation patterns in the prime movers, periscapular, and rotator cuff muscles during physiological movements performed during a standardized shoulder assessment at different speeds and loads in non-athletes and overhead athletes.

1.1. Methods & methods

Thirty-four healthy volunteers were recruited for the study and were split in two groups: non-athletes (20 males; age 30 ± 3.8 years; height 174 ± 9.2 cm; weight 75 ± 10.9 kg) and professional handball players (14 male overhead athletes; age 24.6 ± 4.6; height 181 ± 12.6 cm; weight 79.8 ± 5.8 kg). Participants were excluded if they had shoulder pain in the dominant arm, required medical treatment for their shoulder during the previous year, or any needle apprehension. Ethical approval was obtained by the local committee (Approval No: F2014000050, Qatar Anti-Doping Lab). Participants were verbally informed as to the nature and purpose of the research and written informed consent was obtained prior to the assessment.

1.2. Procedure

All volunteers underwent a standardized shoulder physiotherapy assessment. EMG recordings were taken using a wireless system (Delsys, Inc. Boston, USA). Surface EMG (sEMG) and indwelling EMG (iEMG) was used in combination to measure the activity of the prime movers, periscapular, and rotator cuff (RC) muscles during three repetitions each of: flexion, scaption, and abduction at three different speeds and two different loads with the elbow fully extended, and the forearm in neutral rotation, performed in the same order. Surface EMG recordings were taken from the UT, LT, SA, anterior deltoid (AD), middle deltoid (MD), posterior deltoid (PD), and pectoralis major (PM). For convenience, we have arbitrarily grouped the investigated muscles as periscapular (LT, UT, and SA), and prime moving (Pec, AD, MD, and PD). The RC muscles included the supraspinatus (SS), infraspinatus (IS) and subscapularis (SSc) measured with iEMG. sEMG electrodes were applied according to SENIAM guidelines (http://www.seniam.org/) for skin preparation and positioning, and indwelling electrodes were introduced according to procedures reported previously (Kadaba et al., 1992). Electrode placement was verified by visual monitoring of EMG signal while performing voluntary contraction.

All EMG was collected with a 16-bit digital system, with a gain of 300 μV. Signal was band pass-filtered at 5 Hz-200 Hz and converted from analog to digital at 2000 Hz. The band pass filter was tested by the investigators to ensure minimal noise for iEMG. Data analyses were performed using custom methods written in MATLAB R2009a, (MATLAB & Simulink, Iceland). The EMG signal was normalized relative to the resting baseline, which was the EMG recording while the subject was instructed to relax with their arm by their side (Kadaba et al., 1992). Timing of activation of the muscles was normalized to onset of arm movement, detected by an accelerometer attached to the subject's wrist (Delsys, Inc. Boston, USA, accelerometer sample rate: 250 Hz).

Active movements were performed at three speeds: "slow" (full elevation from pendant to completely overhead in a total of 5 s), "medium" (3 s), and "fast" (1 s) with the subject viewing a stopwatch and verified by the researcher. These movements were performed both unloaded, and with a 3 kg weight for the "loaded" condition. Movements were recorded in the same order: flexion (slow unloaded, slow loaded, medium unloaded, medium loaded, fast unload, and fast loaded) followed by scaption (with the same loading and speed process as flexion) and abduction (with the same loading and speed process) respectively. Volunteers received instructions before each movement and were allowed practice of each movement before data acquisition. Resting time was at least 30 s between repetitions, and 1 min at least between conditions.

1.3. Data analysis

EMG onset activation was set as the first EMG signal greater than two standard deviations of the resting baseline prior movement onset of the UT, AD, MD, PD, LT, Pec, SA, SSc, SS and IS muscles. We computed the mean ± confidence interval (95%CI) for each group, muscle, movement speed, and load. To determine significant changes between groups, we fit a linear mixed model with random intercept for each subject and fixed factor of: group (athletes and non-athletes), muscles, movement, speed, and load. Statistical significance was established at an alpha of 0.05. All analyses were performed using SPSS 21.0.

2. Results

The effects of: movement, muscle, speed, and load for overhead athlete and non-athlete groups are presented in Table 1.

We observed no significant differences between athletes and non-athletes in the mean time of EMG onset activation for the prime movers, periscapular, or RC muscles during physiological movements at different speeds or loads. For the entire cohort, significant differences in muscle onset activation were observed when considering the different speed and load conditions. We observed significantly earlier activation of the AD [-453.27 to −348.08, p > 0.001, d = −0.981], UT [-399.32 to −293.54, p > 0.001, d = −0.974], and MD [-389.88 to −284.48, p > 0,001, d = −0.973] with respect to the other periscapular and RC muscles. The periscapular muscles activated before the RC muscles, showing a tendency to activate prior to movement except for the IS in the non-athlete population.

We also observed differences in onset activation according to the speed of movement, with the medium-speed movement showing significantly earlier activation of the periscapular and RC muscles than slow and fast exercises. Activation in the loaded condition was also significantly earlier than in the unloaded condition. The interaction between EMG onset activation for movement, speed, and load is illustrated in Figs. 1–3.

Table 1
EMG onset timing of activation (msec±SD) for each group and muscle during physiological movements at different speed and loads.

Factors	n	Mean(95%CI)	Effect-Size	p-value
OH_NonAth				.173
OH	14	-203.08[-265.57 to -140.58]	-0.42	
Non_Ath	20	-177.07[-229.19 to -124.96]		
Muscle				p<.001
UT	34	-346.43[-399.32 to -293.54]	-0.97	*
AD	34	-400.68[-453.27 to -348.08]	-0.98	*
MD	34	-337.18[-389.88 to -284.48]	-0.97	*
PD	34	-136.91[-191.24 to -82.57]	-0.79	
LT	34	-165.67[-220.1 to -111.23]	-0.86	
Pec	34	-81.98[-136.75 to -27.21]	-0.46	
SA	34	-226.71[-280.82 to -172.61]	-0.93	
Ssc	34	-63.07[-137.76 to 11.62]	-0.22	
SS	34	-97.13[-166.99 to -27.28]	-0.56	
IS	34	-45.01[-125.22 to 35.19]		
Movement				.096
Flex	34	-198.5[-243.55 to -153.45]	-0.54	
Abd	34	-202.68[-247.65 to -157.72]	-0.6	
Scap	34	-169.04[-213.99 to -124.09]		
Speed				.000
Slow	34	-224.98[-270.93 to -179.02]	-0.94	*
Medium	34	-252.23[-297.01 to -207.45]	-0.96	*
Fast	34	-93.02[-137.37 to -48.66]		
Load				.000
L	34	-245.3[-288.29 to -202.32]	-0.93	
UL	34	-134.85[-177.9 to -91.79]		

Abbreviations: * denotes significant difference to other items within the group. The categories that are compare between 2 variables (Oh Vs NonAth) or (UL vs L), the * is in the category (orange line) (p < 0,0.005), Overhead Athlete (OH), Non-Athlete (Non-Ath), Upper Trapezius (UT), Anterior Deltoid (AD), Middle Deltoid (MD), Posterior Deltoid (PD), Lower Trapezius (LT), Pectoralis Major (Pec), Serratus Anterior (SA), Subscapularis (SSc), Supraspinatus (SS), Infraspinatus (IS). Flexion (Flex), Abduction (Abd), Scaption (Scap), Slow speed, 5 s (Slow), Middle speed, 3 s (Medium), Fast speed 1 s (Fast), Loaded condition, 3 kg (L), Unloaded Condition, no weight (UL).

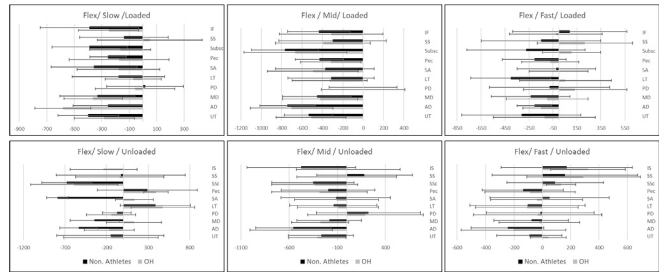

Fig. 1. EMG onset timing (mSec) (mean ± SD) during Flexion movement.

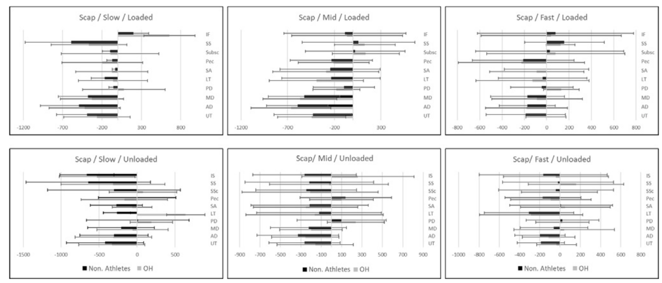

Fig. 2. EMG onset timing (mSec) (mean ± SD) during Scaption movement.

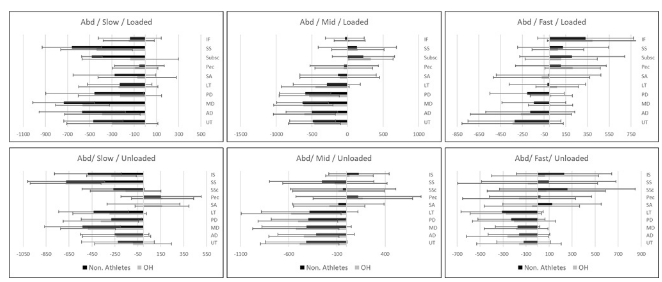

Fig. 3. EMG onset timing (mSec) (mean ± SD) during Abduction movement.

3. Discussion

This study has demonstrated no difference in onset activation patterns of the rotator cuff, periscapular, or prime moving muscles when comparing professional handball players to non-athletes during routinely performed clinical examination procedures. The rotator cuff muscles were seen to activate latest, closest to the onset of movement, with essentially all the other investigated muscles activating prior to this. The infraspinatus muscle activated last in both groups, slightly after the onset of movement for the non-athletes which was the only significant difference in onset activation between the two groups. The magnitude of this difference (approximately 0.15 s) is relatively small, and the clinical significance of this delay is uncertain given the findings for the remainder of this data.

The term "overhead athletes" is typically used to include players in all sports that require repetitive movements with the arm above the head, even though these sports may differ markedly in the overhead movements used. Overhead sports include: swimming, water polo, tennis, gymnastics, baseball, handball, and throwing athletes. Anatomical adaptations seen in professional athletes differ between sports: throwing athletes often torsional differences in the humerus along with thickening of the posterior shoulder structures and/or humeral rotational range of motion (Worsley et al., 2013), while these adaptations are less common in other overhead sports

(Walsworth, Doukas, Murphy, Mielcarek, & Michener, 2007). Despite evidence of anatomical adaptations and differences, clinical assessment is often similar for overhead and nonathletes. The results of this study and others (Cools, Johansson, Borms, & Maenhout, 2015; Hawkes et al., 2012; Kibler et al., 2013) suggest that in terms of muscle onset activation patterns, this is a valid approach.

In overhead athletes, it could be thought that mechanical demands and anatomical adaptations through repetitive sports-specific movements could potentially result also in adaptive onset activation patterns in other movements. The results of this study suggest that these sporting activities do not significantly change onset activation patterns with overhead athletes not showing different onset activation patterns than nonathletes. ($p = 0.173$).

Previous research into sports specific activation patterns (tennis serving) show earlier onset of the AD and UT in comparison to the RC (Kibler, Chandler, Shapiro, & Conuel, 2007), similar to the findings for the clinical movements examined here.

The current findings concur with previous research examining muscle activation patterns in non-athletes describing delayed activation of the deeper rotator cuff musculature in comparison to the more superficial musculature (Cools et al., 2014b; Day, Taylor, & Green, 2012; Reed et al., 2013; Van Den Tillaar & Ettema, 2007). AD, UT, and MD showed significantly earlier activation followed by SA, LT, PD, Pec Major, SS, SSc, and IS. It has been suggested that for healthy shoulder function the RC needs to activate to 'stabilise' the glenohumeral joint prior to activation of the prime moving muscles (Palastanga, 2008), these findings along with the work of others showing delayed RC activation cast doubt on this assertion (Cools et al., 2014b; Day et al., 2012; Reed et al., 2013; Van Den Tillaar & Ettema, 2007).

Although we observed no changes between the two groups in onset activation patterns during flexion, scaption and abduction, there were significant differences in onset activation for speed and load.

Previous studies have reported feedforward muscle activation during fast movements (Day et al., 2012). Our study supports this evidence on early activation prior to movement, although we did have some unexpected results in terms of onset of activation timing. While the fastest onset activation was observed for "medium" speed movement followed closely by slow movement, the slowest onset activation was observed for the fastest movement. Previous research has usually not accounted for speed of movement, and when this has been done, usually only 2 speeds (i.e. "fast" and "slow") are considered. The current data both question this approach and suggest that speed of movement is more complicated than previously thought as it applies to timing of muscle onset activation. Our data showing the "medium" speed movement to have the earliest muscle activation compared to the slow and fast conditions suggest a complex dose-response relationship that warrants further investigation and serves to underscore the importance of task specificity when making clinical implications. While the "fast" speed examined here is likely similar to the speed of arm abduction during the cocking phase of throwing (Wagner et al., 2014); i.e. getting the arm to approximately 90° of abduction in about 0.5 s, no differences were seen for the athletic and non-athletic populations, and both groups showed later onset activation during this movement than at the slower movement speeds. The clinical implications of this remain unclear.

In the current study differences were also seen during the loaded and unloaded movements with delayed onset activation in the unloaded condition. This more intuitive finding suggests earlier activation in the more difficult (loaded) condition where greater effort and presumably shoulder stabilization is required.

Despite the clear differences other researchers have seen in anatomy and function of throwers compared to non-athletes, the firing patterns are basically the same for these "clinical" assessments. Thus, it could be said that in healthy subjects onset activation patterns of non-athletes could be used to describe also onset activation patterns of overhead athletes during physiological movements. Two conclusions that can be drawn are that these "clinical" assessments may not be relevant to the sport-specific movements, or that overhead athletes may not be that different to non-athletes in terms of muscle onset activation patterns.

Future research could look at changes in onset activation patterns when pain or injury is present in overhead and non-athletic populations, as well as the interaction between training load, injury, and firing patterns (Phadke & Ludewig, 2013). Recently, decreased shoulder external rotation strength and scapula dyskinesia have been found to increase injury rate in handball players when training load is increased (Phadke & Ludewig, 2013). These findings along with the present study tentatively suggest that examination of onset activation patterns (and movements) during sports specific movements and fatigued state could provide insight into injury mechanisms and potential injury risk factor.

This study has some limitations that should be considered when evaluating the results. The overhead group only includes professional handball players, which may not be representative of other overhead athletes, particularly those playing sports that do not involve throwing. Other limitations of this study, which have also been noted by previous researchers, are the variability of EMG data and the relatively small number of subjects. There is some debate whether data from sEMG and iEMG should be compared in the same study (Sangwan et al., 2014) however to minimize error, we used a broad bandwidth to ensure iEMG data were correctly registered (Burden, Lewis, & Willcox, 2014).

4. Conclusions

We observed no differences between overhead athletes and non-athletes in onset activation patterns of the prime movers, periscapular, and RC muscles during routinely performed clinical assessment movements at different speeds, with different loads. Muscle onset activation occurred prior to movement in all muscles and for all movements with AD, UT, and MD the earliest muscles to activate, followed by other prime movers and periscapular muscles, with the RC being the latest to fire. The fastest activation was observed during medium-speed movements and loaded arm. These finding provide an insight into onset activation patterns during physiological movements at different speeds and loads in overhead athletes and the non-athlete population.

Conflicts of interest

We have no conflicts of interest to disclose.

Statement of institutional review board and ethics committee

Ethical approval was obtained by the scientific committee at Aspetar Sports medicine Hospital. Approval No: F2014000050, Qatar Anti-Doping Lab.

Funding

This research did not received any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

Acknowledgement

All the volunteers who participated in the study, Einar Einarson for his assistance with EMG, and FC Barcelona for allowing use of their facilities and equipment.

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