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# Surface electromyography of the forearm musculature during an overhead throwing rehabilitation progression program

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ABSTRACT

*Objective:* The flexor carpi ulnaris (FCU) and flexor digitorum superficialis (FDS) provide dynamic stabilization to the medial elbow. It remains unclear how these muscles function during progressive throwing exercises. Our objective was to compare FCU and FDS surface electromyography (sEMG) during a throwing progression.
*Design:* Crossover.
*Setting:* Laboratory.
*Participants:* Sixteen healthy males.
*Main outcome measures:* Participants completed a plyometric throw (PLYO), long-toss 50% ($LT_{50}$), long-toss 75% ($LT_{75}$), and pitch (PITCH). sEMG was synchronized with three-dimensional kinematics to assess the acceleration phase of each exercise. Peak sEMG amplitude (%MVIC) and percentage change between progressive exercises was measured. Continuous sEMG data were assessed to determine when peak activation occurred during acceleration.
*Results:* FCU activity was greater during PITCH than $LT_{50}$, and during $LT_{75}$ than $LT_{50}$. Percentage change was greater from $LT_{50}$-to-$LT_{75}$ than PLYO-to-$LT_{50}$ for both muscles. PLYO and PITCH increased most during late acceleration, whereas $LT_{50}$ and $LT_{75}$ increased most during mid-acceleration.
*Conclusions:* FCU activity did not increase in a stepwise manner, and FDS remained unchanged. Each muscle demonstrated a disproportionate increase in activation during the second exercise progression ($LT_{50}$-to-$LT_{75}$) compared to the first (PLYO-to-$LT_{50}$), suggesting that additional exercises may be required to achieve a stepwise progression relative to forearm muscle activation.


## 1. Introduction

Medial elbow injuries have continued to rise among young, active individuals. Specifically, ulnar collateral ligament (UCL) injuries are one of the most commonly diagnosed overuse injuries in overhead-throwing athletes (Dick et al., 2007). A recent review (Erickson et al., 2015) of trends in UCL reconstruction (UCLR) indicate the frequency of UCLR performed on adolescent and young adults has tripled in recent years. UCLR appears most frequent among male (Erickson et al., 2015; Mahure, Mollon, Shamah, Kwon, & Rokito, 2016) baseball pitchers (Erickson et al., 2016) between 15 and 24 years old (Erickson et al., 2015). While the incidence of revision UCLR remains low among non-professional overhead-throwing athletes (1–1.9%) (Cain et al., 2010; Osbahr et al., 2014), the rate of revision for major league baseball pitchers has recently been reported to be much higher (13.2%) (Liu et al., 2016). These data appear to highlight the continued need to examine post-surgical rehabilitation programming and modifiable risk factors for secondary injury in athletes who return to an elite level of sport

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(Petty, Andrews, Fleisig, & Cain, 2004).

Overhead throwing inherently generates high loads through the medial elbow, which may contribute to unsuccessful outcomes (Hodgins, Vitale, Arons, & Ahmad, 2016; Petty et al., 2004). The acceleration phase of throwing is specifically relevant when evaluating pitching biomechanics given the association with high joint loading and injury (Werner, Fleisig, Dillman, & Andrews, 1993). During the transition from late cocking to acceleration, a tremendous valgus torque is placed on the medial elbow (up to 120 Nm), which is maximized during the rapid motion of acceleration (Gregory & Nyland, 2013; Vitale & Ahmad, 2008). These data suggest that the UCL is most vulnerable during acceleration (Fortenbaugh, Fleisig, & Andrews, 2009). As little as 22.7–33.0 Nm of torque may be required to cause UCL failure (Otoshi, Kikuch, Shishido, & Konno, 2014; Vitale & Ahmad, 2008), highlighting the importance of surrounding musculature. The flexor-pronator mass is theorized to provide dynamic stabilization of the medial elbow, and account for the disparity in loading that occurs during throwing (Lin et al., 2007; Otoshi et al., 2014). Specifically, the flexor carpi ulnaris (FCU) and flexor digitorum superficialis (FDS) have been reported to provide dynamic stability due to their anatomical location over the UCL (Davidson, Pink, Perry, & Jobe, 1995; Gregory & Nyland, 2013; Lin et al., 2007; Otoshi et al., 2014). Previous *in vivo* studies (Glousman, Barron, Jobe, Perry, & Pink, 1992; Hamilton et al., 1996; Sisto, Jobe, Moynes, & Antonelli, 1987) have used surface electromyography (sEMG) to demonstrate peak muscle activation of the FCU and FDS occurs during the late cocking and acceleration phases of pitching, which coincide with the greatest risk of UCL injury. These data (Glousman et al., 1992; Hamilton et al., 1996; Lin et al., 2007; Sisto et al., 1987) indicate that both muscles provide dynamic stability to the medial elbow, and may alleviate stress placed on the UCL during pitching. However, no studies have evaluated FCU and FDS activity to ensure each muscle is appropriately targeted during progressive throwing exercises used in rehabilitation.

A progressive rehabilitation program is advocated to optimize return to sport following UCLR. Four distinct phases of rehabilitation for UCL injuries have been described, spanning approximately 9 months before returning to competitive throwing (Wilk, Arrigo, & Andrews, 1993, 2012). Following the restoration of pain free range of motion and early improvements in strength and endurance, patients are introduced to advanced strengthening exercises and early throwing, such as plyometrics and the Thrower's Ten (Wilk, Yenchak, Arrigo, & Andrews, 2011), during the third phase (Wilk et al., 1993a). During the fourth phase, the athlete is gradually reintroduced to pitching by performing a progression of long-toss and light pitching activities until return to sport (Wilk et al., 1993a, 2012). Although this progression (Wilk et al., 1993a) appears rational, to our knowledge, no study has determined whether the progression from plyometric exercise to pitching is appropriate with respect to FCU and FDS muscle activation. Since these muscles are the primary dynamic stabilizers of the elbow during the acceleration phase of pitching, one would expect that transitioning from plyometrics to a throwing progression is truly progressive in nature. However, it remains unclear whether this progression is optimal, which may have implications for exercise selection.

Therefore, the purpose of this study was to compare sEMG activity of the FCU and FDS during a progression of exercises common to UCLR rehabilitation in healthy individuals with pitching experience. The paucity of literature concerning an appropriate exercise progression relative to the forearm musculature highlights a need to first examine the activity of these muscles in a healthy population. We specifically aimed to compare sEMG activation of the FCU and FDS during the acceleration phase of a: (1) plyometric exercise, (2) long-toss throw at 50% effort, (3) long-toss throw at 75% effort, and (4) pitch. Secondly, we aimed to compare the amount of change in muscle activity between progressive exercises. As an exploratory aim, we aimed to describe the phase of acceleration (early, middle, late) at which peak muscle activation occurred. These exercises were chosen because they represent those commonly used to progress a patient through the later phases of rehabilitation, as outlined previously (Wilk et al., 1993a, 2011). We hypothesized that FCU and FDS activity would differ between each exercise, from plyometric (lowest) to pitch (highest). However, we hypothesized that there would be a disproportionate increase in muscle activity from plyometric to long-toss exercise at 50% effort, indicating that an intermediate exercise may be appropriate to implement when transitioning to early throwing exercises.

## 2. Methods

This was a descriptive laboratory study with a crossover design used to assess muscle activity of the FCU and FDS. The independent variable was exercise: plyometric (PLYO), long-toss at 50% effort ($LT_{50}$), long-toss at 75% effort ($LT_{75}$), and pitch (PITCH). The dependent variables were peak normalized sEMG amplitude and percentage change in sEMG amplitude between progressive exercise conditions: PLYO-$LT_{50}$, $LT_{50}$-$LT_{75}$, and $LT_{75}$-PITCH. Mean normalized sEMG amplitudes were further evaluated on a continuous scale to determine the primary phase of activation during acceleration for each exercise.

### 2.1. Participants

Sixteen healthy, recreationally active, males volunteered to participate in this study (Table 1). Participants must have had (1) a minimum of three years experience pitching, or self-reported as an active pitcher, (2) a Patient Rated Elbow Evaluation (PREE) score of $\leq$20/100, (3) a palmaris longus present, (4) no history of upper extremity injury resulting in symptoms over the last 3 months, and (5) no history of upper extremity surgery, to be eligible for enrollment. Our University's Biomedical Institutional Review Board approved this study, and all participants provided written and verbal consent prior to enrollment.

### 2.2. Procedures

Participants completed all testing procedures during one session. The order of testing was counterbalanced to minimize the influence of fatigue or prior exercise. The sequence of testing was determined by placing participants in one of three groups sequentially based on the order of enrollment (group 1 = PLYO, LT, PITCH; group 2 = LT, PITCH, PLYO; group 3 = PITCH, PLYO, LT). The

**Table 1**
Participant demographics (mean ± SD).

| | |
|---|---|
| Age (years) | 22.0 ± 2.5 |
| Height (cm) | 180.7 ± 7.8 |
| Mass (kg) | 87.1 ± 14.1 |
| PREE (out of 100) | 2.8 ± 4.4 |
| Dominant limb | 12 right, 4 left |
| Actual pitch speed (mph)[a] | 68.7 ± 6.2* |
| Calculated pitch speed[b] | 70.9 ± 7.0* |
| Actual long-toss 75% speed (mph)[a] | 54.1 ± 5.9 |
| Calculated 75% speed[b] | 53.2 ± 5.2 |
| Actual long-toss 50% speed (mph)[a] | 41.4 ± 6.2* |
| Calculated 50% speed[b] | 35.4 ± 3.5* |

Abbreviations: PREE, Patient Rated Elbow Evaluation.
* Statistically different at $P \leq .05$ (2-tailed paired *t*-test).
[a] Throwing speed recorded during analyzed test trials.
[b] Throwing speed calculated based on maximum speed during pre-test trials.