

Measurement of Pitching Fatigue with a Custom-Made Device

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Overuse Pitching Issues

- ▣ Posterior capsular contractures and thickening
- ▣ Scapula Dyskinesia
- ▣ Lat, biceps, forearm and RTC strains
- ▣ UCL injuries
- ▣ Labral tears
- ▣ **Dead Arm**

Magnetic Resonance Imaging of the asymptomatic shoulder of overhead athletes

Connor PM, et al.

Am J Sports Med, 2003


- ▣ 12 dominant shoulders of college pitchers
 - 12 non-dominant shoulders were normal
- ▣ 3 with partial thickness or full thickness RTC tears
- ▣ 4 with Bennett's lesion
- ▣ All remained asymptomatic at 5 yr F/U

Shoulder weakness in professional baseball pitchers
Magnusson SP, et al.
Med Sci Sports Exerc, 1994

- ▣ Measured ROM and eccentric strength in professional pitchers and controls
 - Dominant and non-dominant shoulders
- ▣ “Our results show that pitchers were weaker in eccentric ER, ABD, and SUP on the dominant side compared with age-matched controls. The lack of dominance in pitchers and the weakness compared to controls suggests that the demands of pitching are insufficient to produce eccentric strength gains and may in fact result in muscle weakness.”
- ▣ “The dominant-sided SUP (supraspinatus) weakness observed in pitchers in the present study may reflect chronic fatigue or subclinical pathology.”

Current Strategies to Prevent Injuries

- ▣ Monitor and Maintain ROM
- ▣ Exercise Programs to maintain strength
 - Shoulder
 - Core
 - Hips
- ▣ Monitor Workload
 - Pitch and Inning Counts



AGE	DAILY MAX PITCHES	REQUIRED REST (PITCHES)				
		0 Days	1 Days	2 Days	3 Days	4 Days
7-8	50	1-20	21-35	36-50	N/A	N/A
9-10	75	1-20	21-35	36-50	51-65	66+
11-12	85	1-20	21-35	36-50	51-65	66+
13-14	95	1-20	21-35	36-50	51-65	66+
15-16	95	1-30	31-45	46-60	61-75	76+
17-18	105	1-30	31-45	46-60	61-75	76+

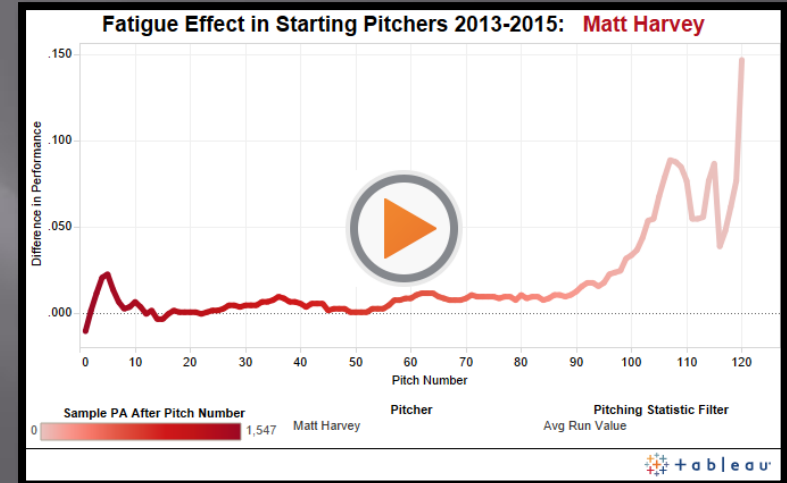
What are we doing now?

Measuring workload

- ▣ pitch and inning counts
- ▣ # of games

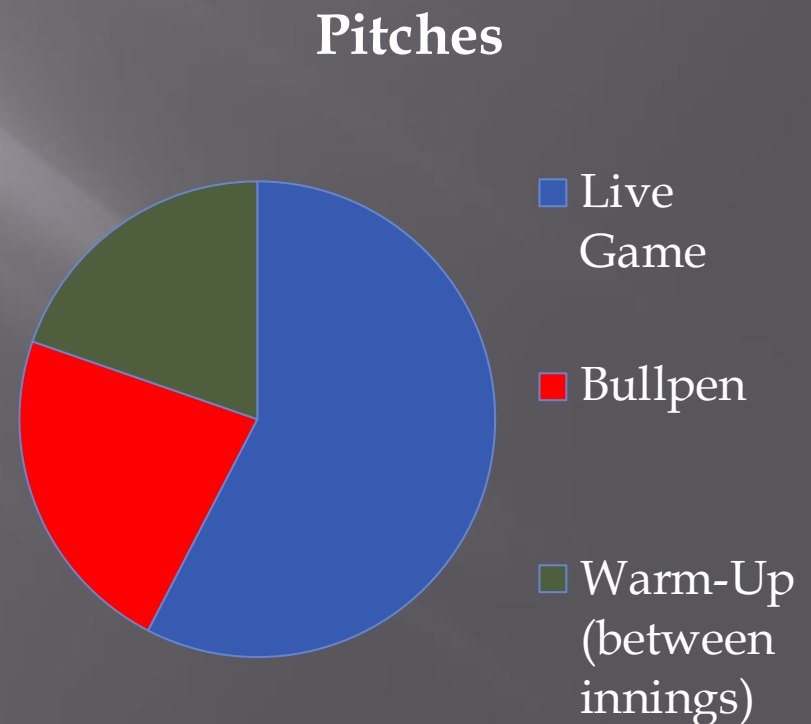
Signs of Fatigue

- ▣ Body language
- ▣ Loss of command
- ▣ Change in mechanics
- ▣ Loss of velocity



Unaccounted Workload Factor Game-Day Pitch Counts in High School Baseball Pitchers—An Observational Study Zaremski JL, et al Ortho J Sports Med, 2018

- ▣ Counted all of the pitches thrown from a mound on varsity game days at 34 FL high schools in 2017
- ▣ 13,769 pitches
- ▣ 42.4% not included in the official pitch count
 - Not to mention throws made at other positions
- ▣ Large variability in the number of pitches in the bullpen



Risk factors for shoulder and elbow injuries for adolescent baseball pitchers

Olsen SJ, et al.

Am J Sports Med, 2006

- ▣ A survey of HS pitchers
 - 95 with injury history
 - ▣ 6 inn, 88 pitches, 8 mos
 - ▣ **52% regularly pitched despite arm fatigue**
 - ▣ 67% pitched despite arm pain
 - 45 controls (pitchers without an injury history)
 - ▣ 4 inn, 66 pitches, 5.5 mos
 - ▣ **11% regularly pitched despite arm fatigue**
 - ▣ 42% pitched despite arm pain

Risk factors for shoulder and elbow injuries for adolescent baseball pitchers

Olsen SJ, et al.

Am J Sports Med, 2006

- ▣ Average > 80 pitches = 4x risk of surgery
- ▣ Pitch competitively > 8 months/year = 5x likelihood of injury
- ▣ Pitching regularly with fatigued arm = 36x as likely to have an injury and potentially need surgery!

Relationship Between Pitching a Complete Game and Spending Time on the Disabled List for Major League Baseball Pitchers

Erickson BJ, et al.

Ortho J Sports Med 2018

- ▣ Reviewing pitching data between 2010 and 2016 to compare pitchers who threw a CG and those who didn't
 - 74% of pitchers who threw a CG spent time on the DL, as compared with 20% of controls. Pitchers who threw a CG during the study period spent more time on the DL in subsequent seasons than matched controls who did not throw a CG.
 - Suggests that throwing a CG is not necessarily a risk factor for being placed on the DL; instead, being a high-volume pitcher in general increases the risk of spending time on the DL, as compared with being a lower-volume pitcher.

Command, Velocity, Mechanics

This requires the entire kinetic chain that generates the force

If the mechanics don't change,

If the velocity doesn't decline,

If the pitcher is effective,

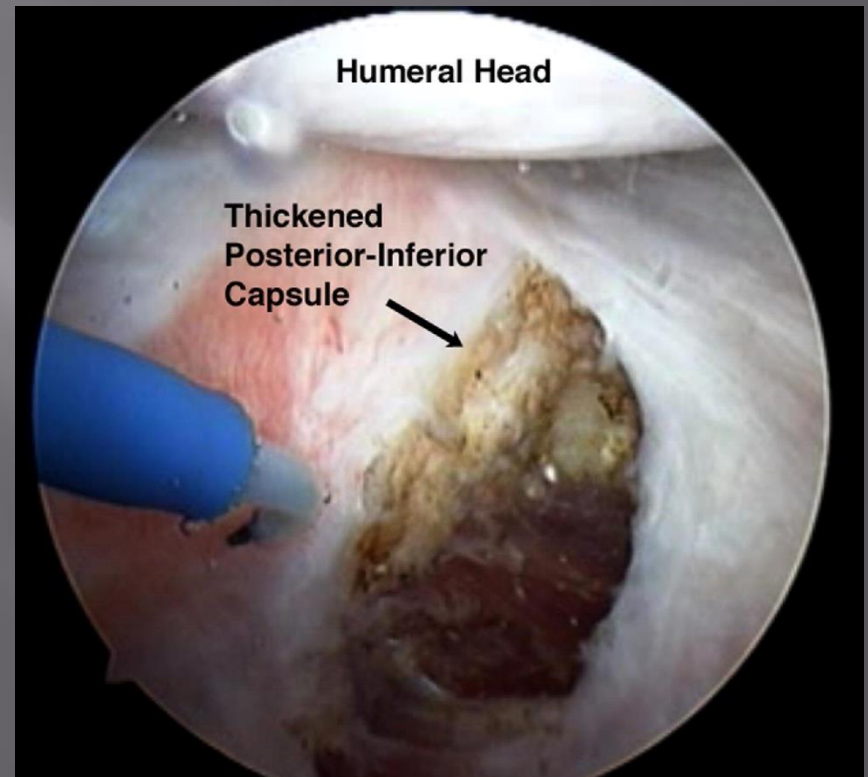
Why does he still get hurt?

Arm Deceleration / Follow Through

- ▣ The shoulder needs to not only decelerate the arm, but also counter the distraction force of the joint (750-950N).
- ▣ Distraction force approximately equal to body weight (23)
- ▣ Eccentric stresses up to 108% of body weight (+/- 16%)(13)

The Posterior Capsule

- Capsule failure load 800-1200N (1)
- Posterior capsule thickening
 - Adaptive??
- GIRD
 - Symptomatic with a $> 25\%$ total arc of motion loss (14)
 - Associated with a nearly 2 fold increased risk of injury (15)



Arm Deceleration / Follow Through

How does the body absorb/dissipate the force?

□ Kinetic Chain

- Plant leg

- Core

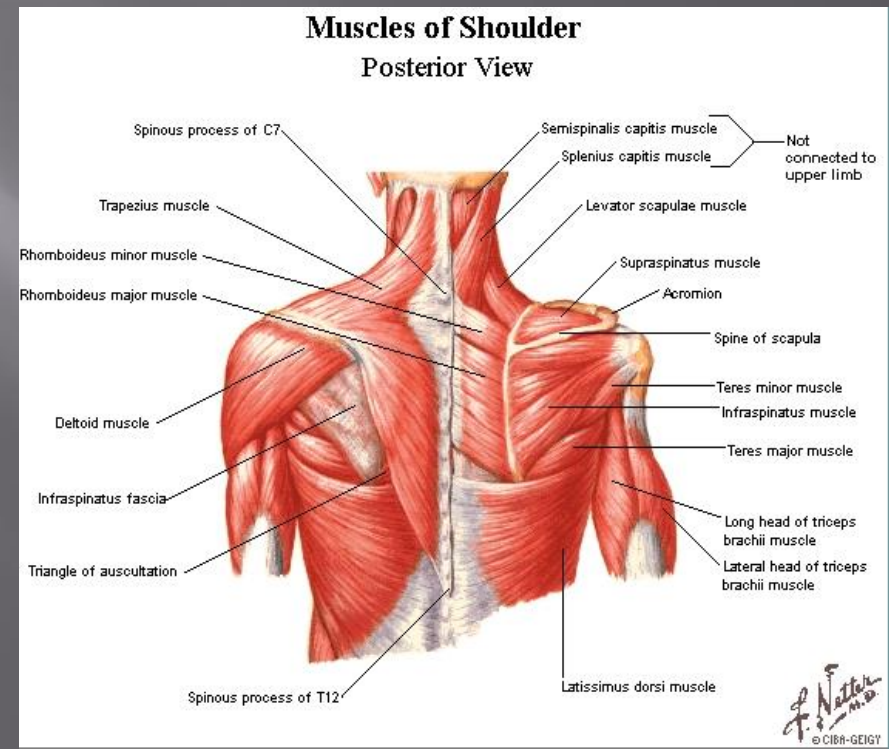
- Shoulder

- **STATIC**

- Glenohumeral joint geometry
- Adhesion-cohesion
- Capsuloligamentous restraints
 - Posterior capsule of the shoulder
 - PIGHL

- **DYNAMIC**

- Supraspinatus, Infraspinatus, Teres Minor Muscles (2,3,4)
- Scapula Stabilizing Muscles



What are we missing?

What happens after the ball is released?

“In healthy baseball players the posterior rotator cuff and scapula stabilizers function to minimize the stress placed on the static restraints” (26,14,25)

Neuromuscular and stiffness adaptations in division I
collegiate baseball players

Thomas SJ, et al.

J of Electromyography and Kinesiology, 2013

- ▣ “There was an increase in short range stiffness on the dominant arm compared to the non-dominant arm, however there was a non-significant correlation with posterior capsule thickness. This further suggests that this increase in stiffness may be due to an increased adaptive tightness of the series of elastic and/or contractile components of the posterior rotator cuff caused by repetitive throwing”
 - Capsule thickening is not an adaptive response but a fibroblastic hypertrophy secondary to repetitive microtrauma, ie. failure of the dynamic stabilizers.

Arm Deceleration / Follow Through Dynamic Contributors

- ▣ Supraspinatus
- ▣ Infraspinatus
- ▣ Teres Minor Muscles
- ▣ Scapula Stabilizing Muscles
 - Lower trapezius
 - Middle trapezius
 - Serratus anterior
 - Rhomboideus minor
 - Rhomboideus major
- ▣ Perhaps teres major, latissimus dorsi, long head of the triceps, long and short head of the biceps
 - Every muscle that crosses the glenohumeral joint might help absorb the distraction force

Arm Decelerating Muscles

- ▣ In asymptomatic pitchers the shoulder strength with external rotation is $> 65\%$ of internal rotation strength (16)
- ▣ Preseason external rotation and supraspinatus weakness is associated with in-season throwing related injuries requiring surgery (17)
- ▣ Players with ulnar collateral ligament tears demonstrate decreased rotator cuff strength compared to healthy controls (8)

Upper and lower extremity muscle fatigue after a baseball pitching performance

Mullaney MJ, et al.

Am J Sports Med, 2005

- ▣ Hand held dynamometer testing
- ▣ Measurements of scapular stabilizers, external rotation strength and empty can
 - Large standard deviations variations
 - ▣ Hard to standardize the testing?
 - ▣ Every player fatigues differently?
 - Different muscles
- ▣ Dominant arm was weaker at baseline with external rotation and empty can
- ▣ Significant changes from baseline did not occur after pitching with empty can and external rotators

Fatigue of the Arm Decelerators

- ▣ McHugh et al. The effect of high pitch volume on musculoskeletal adaptations in high school baseball pitchers. (10)
 - Rotator cuff strength declined over the course of the season in high volume pitchers

Fatigue of the Arm Decelerators

- ▣ Bowman et al. A functional fatiguing protocol and deceleration time of the shoulder from an internal rotation perturbation. (5)
 - Internal rotation resistance fatigues

Fatigue of the Arm Decelerators

- ▣ Gandhi et al. Voluntary activation deficits of the infraspinatus present as a consequence of pitching-induced fatigue. (7)
 - Fatigue leads to neuromuscular activation deficits of the infraspinatus

Muscle Strength and Fatigue

- Unique to each individual
- Different at different stages of development
- Varies from one day to the next
 - Nutrition
 - Hydration
 - Sleep
 - Workload

The strength characteristics of internal and external rotator cuff muscles in professional baseball pitchers

Wilk KE, et al.

Am J Sports Med, 1993

- ❑ External rotators are weaker in the dominant arm of pitchers but relatively stronger in the dominant arm of non-pitchers (28)
- ❑ Pitchers' shoulder adductors are twice as strong as abductors
- ❑ **“It is imperative to quantify and qualify muscular performance for the dynamic stabilizers of the shoulder in the throwing athlete. One means of doing this is by isokinetic testing of the shoulder.”**
- ❑ Avoided eccentric testing “because of the significant amount of posteccentric-induced muscle soreness previously reported (delayed onset muscle soreness).”

Preseason shoulder strength measurements in professional baseball pitchers

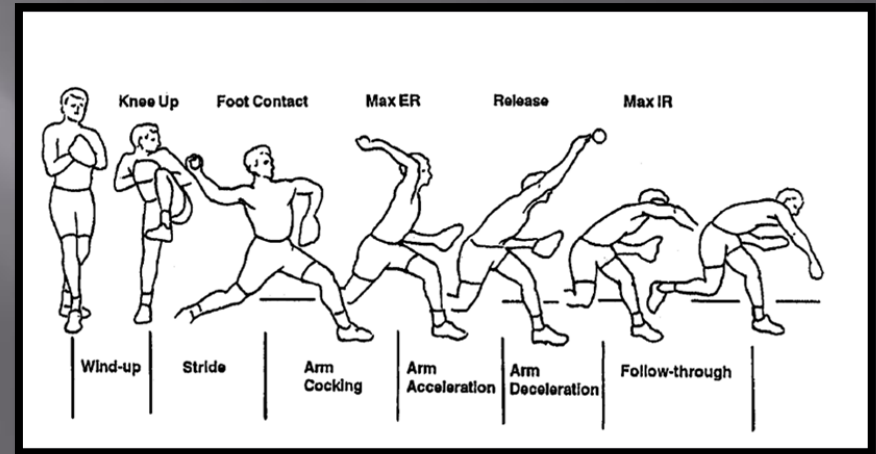
Byram IR, et al.
Am J Sports Med, 2010

- ▣ Relative external rotation weakness and lower ext/int rotation strength ratios in dominant arms is known, but a correlation with injury is unknown
- ▣ Several studies have theorized that better balance of the RTC musculature might lower the risk of injury
 - ▣ Authors don't break it down into accelerators and decelerators
- ▣ Hand held dynamometers
 - Prone IR and ER, seated ER and SS
 - **Weakness with SER, PER and SS testing were statistically significant risk factors for injuries, particularly injuries requiring surgery.**
 - ▣ Unfortunately, traumatic vs subacute injuries weren't stratified
- ▣ Isometric testing is more reliable than eccentric (21 and 22)
 - ▣ Safer too!! (16)

Measuring Pitching Fatigue

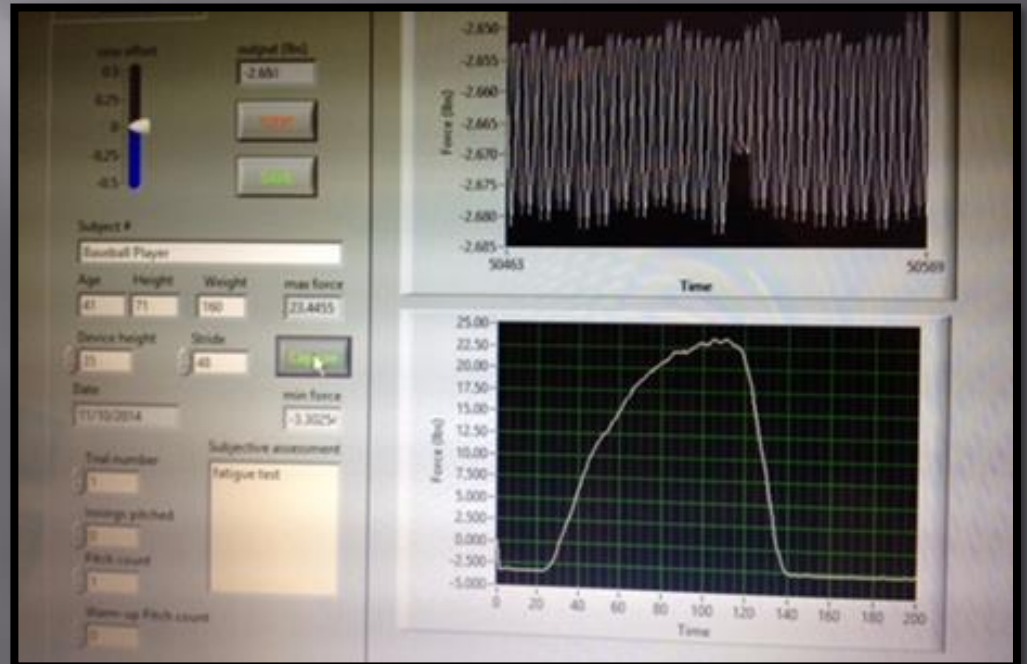
Hypothesis

- ▣ Muscle fatigue of a pitcher's arm decelerators can be identified using a custom-made device



(12)

The Device



How to use the Device



What does it measure?

- ▣ The peak isometric force generated in the vertical plane.
 - Isometric testing is more reliable than eccentric (21, 22) and avoids risk of soreness (16)
- ▣ When used properly, this force represents the posterior rotator cuff and the scapula stabilizing muscles (all of the decelerators)

Validation Testing

- EMG analysis was performed
- 3 different handle heights relative to the thrower were analyzed
 - Knee, waist and chest
- At waist height the muscle activation most closely mimicked that reported in the deceleration phase of throwing.

	Supraspinatus	Infraspinatus	Teres Minor
Device	107%	63%	88%
During Pitch (DiGiovine '92)	60%	74%	84%

Values are presented as % of MVIC

Reliability Testing 2016

- ▣ College and 2 High Schools
- ▣ 15 pitchers used the device on 2 or more occasions
- ▣ Ave force value was 27.27 lbs. +/- 7.9 lbs.
- ▣ Intraclass Correlations [$ICC_{2,k}$] = .837
- ▣ Standard Error of the Measure [SEM] = 2.3 lbs.
- ▣ Minimal Detectable Change [MDC_{95}] = 6.4 lbs.
(23%)

But...

Reliability Testing

- ▣ 7 pitchers used the device on 3 or more separate occasions
- ▣ Intraclass Correlations [$ICC_{2,k}$] = .967
- ▣ Standard Error of the Measure [SEM] = 1.1 lbs.
- ▣ Minimal Detectable Change [MDC_{95}] = 3.1 lbs. (11%)

We anticipate as a pitcher becomes more familiar with the device these numbers will improve even more

Measuring Pitching Fatigue

Methods

- ▣ Blinded Pre-Game and Post Game Measurements
- ▣ Blinded Subjective Evaluations by Players, Coaches and Athletic Trainers
- ▣ Paired T-Tests
- ▣ Reliability Analysis

Results

Pre-Game Values

	N	Mean	S D	P-value vs. Game 1
Game 1	7	28.3	6.2	
Game 2	7	29.1	3.8	0.701
Game 1	3	28.2	1.6	
Game 3	3	29.8	3.6	0.338

Post-Game Values

	N	Mean	S D	P-value vs. Game 1
Game 1	4	28.1	7.3	
Game 2	4	28.4	9.0	.935
Game 1	2	32.5	1.6	
Game 3	2	24.9	3.6	.003

- ▣ 2 Pitchers showed pre-game declines in strength $> 10\%$
 - 1 reported “dead arm”
- ▣ Data appears reliable
 - $r = .6-.96$ pre-game and $.81$ post-game

2017 Training Study

- Driveline
- Weighted Ball Training
- Some players were resistant to fatigue of the decelerating muscles and experienced no pain.
- Perhaps differences in pitching mechanics?

Player	Duration (mins)	Baseline (lbs)	Decline (lbs)	Change (%)
#1	28	37.42	9.31	25
#2	32	38.12	13.32	35*
#3	21	29.84	4.31	14
#4	20	26.90	7.22	27
#5	33	34.37	8.65	25
#6	34	37.10	0.97	3
#7	36	27.08	1.16	4
#8	30	35.41	7.44	21
#9	27	45.42	10.28	23
#10	19	37.12	11.42	36*
#11	25	24.98	3.14	13
#12	20	29.97	9.99	33
#13	19	28.43	-1.12	-4

* stopped because of dead arm/some pain in biceps/proximal forearm

2017 Div 1 Collegiate Pitchers

- ▣ 9 pitchers were tested after a brief warm up throughout the season
- ▣ Average strength declined by about 5% over the course of the season
 - One pitcher's strength decreased by 15% early in the season and his performance struggled from then on
 - One pitcher had a gradual decline of 10% over the course of the season
 - One pitcher's strength dropped >20% over the first 2 weeks of the season. He went on the DL a couple of weeks later and did not return.
 - A pitcher coming off a shoulder injury saw a >20% decline from Feb-April. He then gradually rebounded towards baseline in May.

2017 Professional Pitchers

- ▣ All available were tested before, 1/3 into, 2/3 into, and at the end of the season
- ▣ 14 pitchers to start
 - 12 stayed through the 1st 1/3
 - 9 made it 2/3
 - 7 completed the season with the team



2017 Professional Pitchers

- ▣ The Intraclass Correlation (ICC) at baseline was .915
 - At season end it was .97
- ▣ 12 at 1/3
 - Ave decrease of 1.5 lbs or about 5%
- ▣ 9 at 2/3 (3 data points)
 - Ave **increase** of 4 lbs or about 13% (p-value .214)



2017 Professional Pitchers

- ▣ One pitcher showed a steady decline in strength over the course of the season
 - 28, 29, 24, then 18 lbs
 - He was found to have scapula dyskinesis and low trap dysfunction at 2018 pre-season physicals (by a “blinded” examiner)

2017 Professional Pitchers

- ▣ The changes in strength over the course of the season were significant
 - A decline of 1.5 lbs from preseason to end of first 1/3 correlates with the time of year with a high rate of injuries in professional pitchers.
 - The increase in strength from 1.5 lbs below baseline to 4 lbs above baseline over the last 2/3 of the season is statistically significant.
 - ▣ 5.5 lbs increase
 - ▣ Evidence of the dedicated exercise program and the careful monitoring of workload in this group of pitchers resulting in **No Injuries**.

8 Years of Experience

- ▣ The ICC improves with frequent use
- ▣ If a player is not motivated to give maximal effort the data is less consistent
 - I now show them the results as they are using the device



8 Years of Experience

- ▣ 5 pitchers who had pain with throwing used the device
 - 2 used the device preseason without pain and after the season with pain
 - All 5 experienced the same pain as with throwing when they used the device
 - ▣ 2 posterior shoulder (RTC)
 - ▣ 1 proximal biceps tendon, long head
 - ▣ 2 distal biceps musculotendinous junction
- ▣ No one else has had any complaints of discomfort using the device

What's Next

- ▣ If the device were used on a daily basis between starts, can we track muscle recovery time?
- ▣ If we start with a pitcher rehabbing an arm or shoulder issue, what amount of strength increase is associated with return to play?
- ▣ Continue to monitor pitchers to show weakness as measured with this device correlates with injuries.
- ▣ Allow individual pitchers to monitor the effects of their workload on their arm decelerating muscles' strength.

Measuring Pitching Fatigue

Conclusions

- ▣ Safe & Fast
- ▣ Portable & Durable
- ▣ Unique!!
 - Isometric - most reliable (21,22)
 - Only means of measuring all of the arm decelerating muscles in their functional position
 - NOT examiner dependent



Measuring Pitching Fatigue

Conclusions

- ▣ The Data
 - Reliable
 - Objective
 - Correlates with subjective reports of fatigue/pain



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