

**Return to Play/Throwing Testing:  
Neurocognitive Testing:  
The Missing Rehab Component**  
Kevin E. Wilk, PT, DPT, FAPTA

**CSM** **Select MEDICAL** **ASMI**

1

**Return to Play/Throwing Testing**  
*Presentation Goals:*

- ✓ Why is it important
- ✓ What is it !
- ✓ *Neurocognitive Testing*
- ✓ Examples at the UE
- ✓ *What Am I Doing*
- ✓ Future – RTP Testing
- ✓ RTP a must - changing

**Think Outside the Box**  
Challenge existing cultural thinking

**EBM**  
Clinical Expertise, Best Evidence, Patient Values

**Are They Ready to Play Safely & Effectively**

10

**ACL Return to Play Criteria**  
*Testing Protocols*

- ✓ What are the Best Tests?
- ✓ What tests are We Doing?
- ✓ Recommendations?
- ✓ Why Test?
- ✓ Isn't Time Based Return Good Enough
- ✓ Clinical Exam - Function

11

**ACL Return to Play Criteria**  
*Testing Protocols*

- ✓ What are the Best Tests?
- ✓ What tests are We Doing?
- ✓ Research data?
- ✓ Recommendations?

12

**Want to Reduce Re-Injury Rates**  
**4 Things You Can Do !**

13

**Reduce Re-Injury Rate by 84%** **Strict Objective Criteria to Return to Sports**

**Simple decision rules can reduce reinjury risk by 84% after ACL reconstruction: the Delaware-Oslo ACL cohort study**  
Hegge Grottden,<sup>1</sup> Lynn Snyden-Mackie,<sup>2</sup> Håvard Morknes,<sup>3</sup> Lars Engelsen,<sup>1,4</sup> May Arna Ribberg<sup>1,4</sup>

**ABSTRACT**  
**Background:** Knee injury after ACL reconstruction is common and increases the risk of reoperation. There is a need for objective criteria to guide return to sport (RTS) decisions in this population.  
**Objective:** To assess the relationship between knee injury after ACL reconstruction and (1) return to level sports, (2) timing of RTS and (3) knee function prior to return.  
**Methods:** 106 patients who participated in a structured sports participation in this prospective 2-year cohort study. Sports participation and knee injury were monitored during the follow-up period. The primary outcome was the time to return to level sports. Secondary outcomes were the number of reoperations, the number of days of absence from work, and the number of days of absence from school.  
**Results:** 106 patients who participated in a structured sports participation in this prospective 2-year cohort study. Sports participation and knee injury were monitored during the follow-up period. The primary outcome was the time to return to level sports. Secondary outcomes were the number of reoperations, the number of days of absence from work, and the number of days of absence from school.  
**Conclusion:** Simple decision rules based on preoperative knee function and postoperative knee function could reduce the risk of reoperation and increase the time to return to level sports. These results support the use of simple decision rules to guide return to sport decisions in patients with ACL reconstruction. The decision to return to level sports should be based on a combination of preoperative and postoperative knee function.

14

*Grindem, Snyder-Mackler, Engebretsen, et al: BJSM '16*

- Can we reduce re-injury rates in ACLR pts
- Delaware-Oslo ACL Cohort Study
- 106 patients ACLR – 2yr FU
- #2** 30% pts returning Level I sustained re-injury, 8% returning to a lower level (4x higher reinj rate)
- #3** Every month delayed returned to sports until 9mos – rate of re-injury was reduced 51%
- #4** More symmetrical quadriceps strength prior to return to sports sign. Reduced re-injury rate

15

**2023**

**IJSPT**

Wilk K, Thomas DM, Arrigo CA, Davies GJ. The Need To Change Return to Play Testing in Athletes Following ACL Injury: A Theoretical Model. *IJSPT*. 2023;18(1):275-281.

Clinical Commentary/Current Concept Review

**The Need To Change Return to Play Testing in Athletes Following ACL Injury: A Theoretical Model**

Kevin Wilk, PT, DPT, FAPTA<sup>1,2</sup>, Zachary M Thomas, PT, DPT, OCS, CSCS<sup>3</sup>, Christopher A Arrigo, MS, PT, ATC<sup>4</sup>, George J Davies, PT, DPT, ATC, CSCS<sup>5,6,7</sup>

<sup>1</sup> Vice President National Director Clinical Education & Research, Champion Sports Medicine, Select Medical, <sup>2</sup> Director of Rehabilitative Research, American Sports Medicine Institute, <sup>3</sup> Sports Physical Therapy Fellow, Champion Sports Medicine, <sup>4</sup> Advanced Rehabilitation, <sup>5</sup> Physical Therapy, Georgia Southern University, <sup>6</sup> Coastal Therapy & Sports Rehab, <sup>7</sup> Gundersen Health System

Keywords: ACL injury, neurocognitive training, reactive testing, return to play

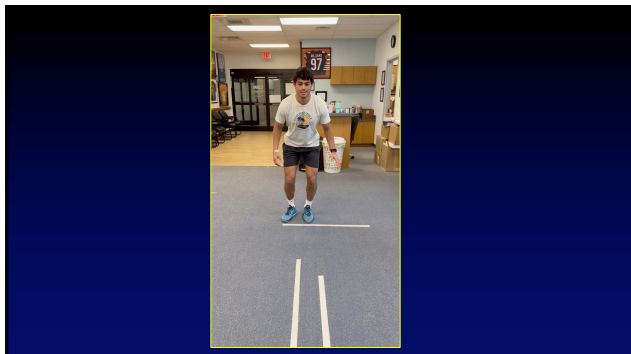
<https://doi.org/10.26663/IJ016.617988>

International Journal of Sports Physical Therapy

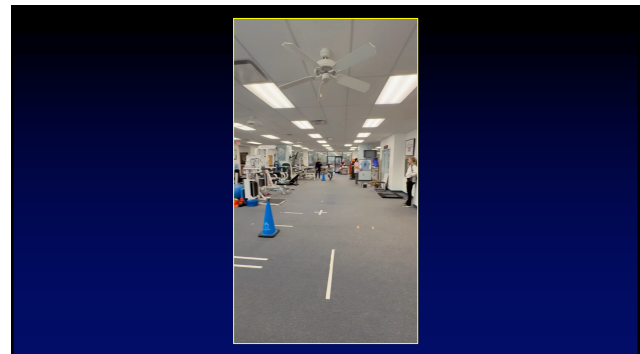
Vol. 18, Issue 1, 2023

The incidence of knee injuries in sport, particularly involving the ACL, appears to be increasing yearly, especially in younger age athletes. Even more concerning is the

16



17



18

**Cognitive Motor Reaction Tests (30 sec)**

19

**2020**

**IJSPT**

CLINICAL COMMENTARY

**RETURN TO SPORT PARTICIPATION CRITERIA FOLLOWING SHOULDER INJURY: A CLINICAL COMMENTARY**

Kevin E. Wilk, PT, DPT, FAPTA<sup>1,2</sup>  
Michael S. Bagwell, PT, DPT, OCS, CMPT<sup>3</sup>  
George J. Davies, PT, DPT, ATC, LAT, MEd, SCS, FAPTA, CSCS<sup>4,5,6</sup>  
Christopher A. Arrigo, MS, PT, ATC<sup>7</sup>

**ABSTRACT**

**Context:** The shoulder complex is frequently injured during sports. The tremendous mobility of the shoulder makes returning to sport participation following shoulder injury a challenging task for both the clinician and athlete. The purpose of this clinical commentary is to review the current literature on return to sport criteria and provide evidence-informed and clinically useful guidelines and recommendations to aid in clinical decision making for return to sports after shoulder micro- and macro-traumatic injuries.

**Evidence Acquisition:** A search of the PubMed database using the terms functional loss, upper extremity testing, return to play, and shoulder injury was performed. Further evaluation of the bibliographies of the identified articles expanded the evidence. This evidence was used to inform the clinical commentary.

**Results:** Return to sport decision making is a sequential, criterion-based process. Assessment of patient reported outcomes, range of motion, strength, and functional performance must all be considered. Numerical rates are available for the clinician to determine whether a patient is ready to return to sports following a shoulder injury or surgery. A different set of tests should be utilized for the overhead athlete (macrotrauma injury) compared to the patient with a macrotraumatic shoulder injury because of the differing demands and sports requirements.

**Conclusion:** Use of predetermined criteria, available in the literature, minimizes the reliance on the subjective elic-

**RTP Articles:  
Knee : 1988  
Shoulder: 718**

21

**IJSPT 2023**

**Clinical Commentary/Current Concept Review**  
**Neurocognitive and Reactive Return to Play Testing Protocol in Overhead Athletes Following Upper Extremity Injury**


Kevin E. Wilk,<sup>1</sup> Zachary M. Thomas,<sup>2</sup> Robert E. Mangione,<sup>3</sup> Paul Keller,<sup>4</sup> George J. Davies<sup>5,6</sup>

<sup>1</sup>Champion Sports Medicine, <sup>2</sup>American Sports Medicine Institute, <sup>3</sup>Sports Physical Therapy Fellow, Champion Sports Medicine, <sup>4</sup>Department of Athletics, University of Cincinnati, <sup>5</sup>Georgia Southern University, <sup>6</sup>Coastal Therapy & Sports Rehab, <sup>7</sup>Graduate Health Sports Medicine Research, LLC, Injury treatment, shoulder instability, neurocognitive training, team performance

<https://doi.org/10.26601/IJSPT.2023>

International Journal of Sports Physical Therapy  
 Vol. 18, Issue 6, 2023

The incidence of upper extremity (UE) injuries in sport, particularly with the shoulder and elbow in baseball/softball players, appears to be increasing yearly, especially in younger age athletes. Improving the objective criteria and testing methods used to determine return to play (RTP) readiness following non-operative or post-operative management of UE injuries is one aspect of the rehabilitation process that may significantly help in reducing injury rates. Currently, the majority of clinicians are using post-operative time frame and/or strength/range of motion as their main criteria for clearance to RTP following UE injury. This demonstrates an inadequate reflection of the actual unpredictable, dynamic environment athletes are returning to participate in. In our clinical experiences, objective testing to allow for clearance to sport participants should incorporate neurocognitive and reactive testing to promote improvements in athlete's ability to dual task and focus/concentrate on the multi-dimensional tasks hand. We know that neuroplastic changes occur following UE injury resulting in decreased proprioception and increased motor activation with simple UE tasks. Our research on UE return to play testing is limited. The purpose of this clinical



Criteria	Number of Athletes	Return to Play Rate
Strength	100	85.0%
ROM	100	80.0%
Time Frame	100	75.0%
Neurocognitive	100	90.0%
Reactive	100	88.0%

Criteria	Number of Athletes	Return to Play Rate
Strength	100	85.0%
ROM	100	80.0%
Time Frame	100	75.0%
Neurocognitive	100	90.0%
Reactive	100	88.0%

22

## Return to Play Testing & Criteria

- **Overhead Athletes:**
  - ✓ Satisfactory Clinical Exam
  - ✓ Appropriate ROM
  - ✓ Satisfactory Muscle Strength (HHD)
  - ✓ Specific Testing:
    - ✓ Prone Plyoball Ball Drop (30sec)
    - ✓ 90/90 Plyoball Wall Throws (30 sec)
    - ✓ Baseball Throws into Rebounder
    - ✓ 90/90 Plyoball Wall Throws w/ Neurocognitive
    - ✓ Single Leg Step Down (30 sec)

23

## Return to Play Testing & Criteria

- **Collision Athletes:**
  - ✓ Clinical Exam
  - ✓ Satisfactory ROM (Functional)
  - ✓ Muscle Testing (HHD)
  - ✓ Specific Testing:
    - ✓ Single Arm Chest Press
    - ✓ Single Arm Rowing
    - ✓ UE Step Over Box (20 sec)
    - ✓ Target Lights (4) Plank
    - ✓ Target Lights (Red-Blue) Plank
    - ✓ Prone Ball Drop Test (30 sec)

24

## Return to Play Testing & Criteria

- **Overhead Athletes:**
  - ✓ Satisfactory Clinical Exam
  - ✓ Appropriate ROM
  - ✓ Satisfactory Muscle Strength (HHD)
  - ✓ Specific Testing:
    - ✓ Prone Plyoball Ball Drop (30sec)
    - ✓ 90/90 Plyoball Wall Throws (30 sec)
    - ✓ Baseball Throws into Rebounder
    - ✓ 90/90 Plyoball Wall Throws w/ Neurocognitive
    - ✓ Single Leg Step Down (30 sec)
- **Collision Athletes:**
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  - ✓ Satisfactory ROM (Functional)
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  - ✓ Specific Testing:
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    - ✓ Single Arm Rowing
    - ✓ UE Step Over Box (20 sec)
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    - ✓ Target Lights (Red-Blue) Plank
    - ✓ Prone Ball Drop Test (30 sec)


25

## Functional Testing for the UE in Athletes


Overhead Athletes

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Collision Athletes

26



28

### Shoulder Injuries & Proprioception

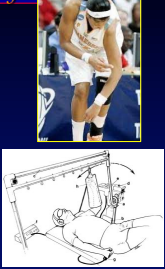
*Deficits Occur Following Injury*

- Following Glenohumeral Joint Injury
- GH Joint Dislocations
- ✓ Proprioception Deficits Occur

*Lephart et al: JSES '94*  
*Zuckerman JSES '03*

- ✓ Occurs alterations in CNS – feedback loop may be altered in some cases

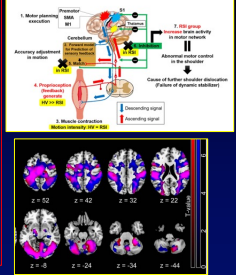
*Warren et al: CORR '96*  
*Lephart et JSES '94*



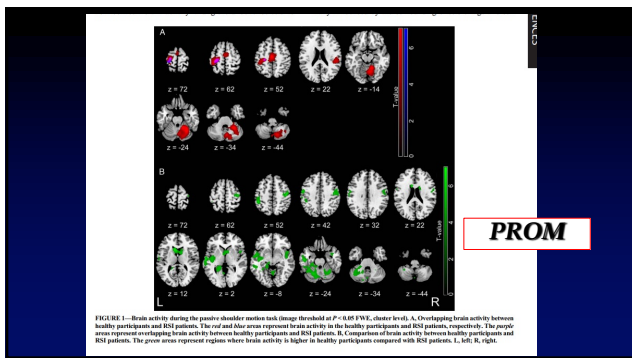
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### *Shitara et al: Med Sci Sports Ex '22*

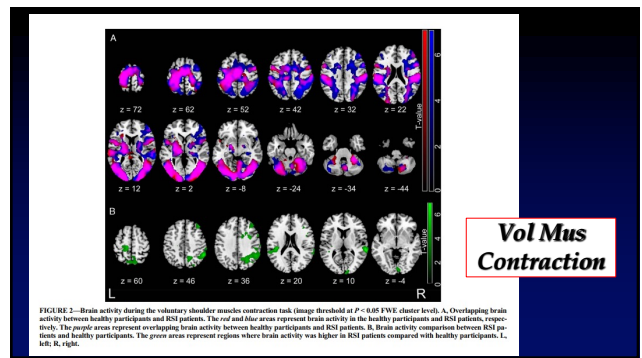
- Neuroplasticity Caused by Shoulder Injury
- MRI Brain Scan – during shoulder PROM & Voluntary Muscle Contraction
- Subjects: RSI n=13, Healthy n=12
- ✓ Difference in Brain Activity b/t grps
- ✓ Abnormal motor control & activation in RSI group



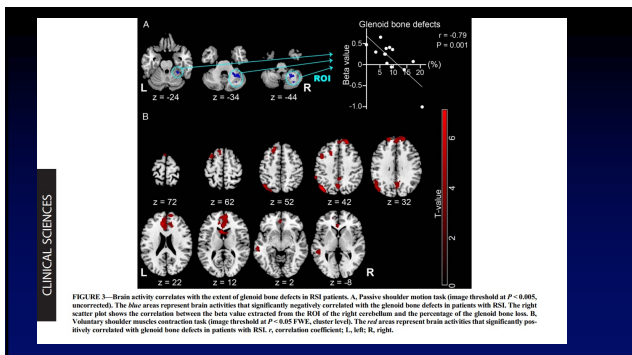
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36



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38

**Rehabilitation in 2024 Has Significantly Changed!**

49

**Functional Testing Overhead Athlete**  
*Specific Tests*

- ✓ Range of Motion
- ✓ Manual Muscle Testing (HHD)
- ✓ Special Tests
- ✓ *Functional Tests*
  - ✓ Ball Drop Testing
  - ✓ Ball Wall Dribble Testing
  - ✓ Throws
  - ✓ Single Leg Squats
- ✓ *Reactive Neurocognitive Testing:*
  - ✓ Target Light Testing
  - ✓ Series of 4 Tests

52

**Neurocognitive Testing**  
*Four Throwers' Series*

- ✓ High Plank Triangle Reactive BlazePod
- ✓ High Plank 4 BlazePods (Red- Blue)
- ✓ Standing 90/90 throws with contralateral target taps
- ✓ Standing 4 BlazePods (Red – Blue)

53

**What is NeuroCognitive Rehabilitation/Training?**

54

**What is NeuroCognitive Rehabilitation/Training?**

- ✓ To be able to perform:
- ✓ Contributes to several areas of sports performance:
  - ✓ Skill & fine motor skills
  - ✓ Visual Processing, Sequencing, Memory
  - ✓ Dual tasking
  - ✓ Focus on task – concentration
  - ✓ Coordination - Ability to recognize & react
  - ✓ Cognitive Reactive Motor Response

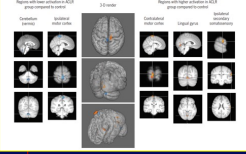

*Recognize, React, Move Efficiently, & Skillfully*

55

### Neuroplasticity in Sports Medicine

*Following Knee Injury - ACL*

- Changes in Brain Function:
- Brain is rewired – reorganized
- ✓ Rewired to function in some way that differs from how it previously functioned
- ✓ Positive changes – adaptations
- ✓ Negative changes -






56

### Criteria to Return to Throwing

#### Clinical Exam

- ✓ Physician Clinical Exam
- ✓ Satisfactory exam
- ✓ Special tests
- ✓ Shoulder Joint
  - ✓ SLAP tests
  - ✓ Rotator Cuff tests
  - ✓ Laxity exam
- ✓ Elbow Joint
  - ✓ UCL testing
  - ✓ Ulnar nerve testing
  - ✓ ...



58

### Criteria Return to Throwing

#### Shoulder Motion PROM

- Full Non-Painful ROM
- Shoulder TROM within 5° bilateral
- Horizontal adduction 40° ≥
- GIRD < 15°
- Elbow full non-painful ROM
- Wrist full non-painful ROM



*Wilk et al: CORR '12*  
*Wilk et al: AJSM '15*




59

### The Thrower's Shoulder

#### Range of Motion: ER/IR

60

Visual inspection

Humeral Stabilization

Scapular Stabilization


61

[ Sports Physical Therapy ] J Sports Health '09

### Glenohumeral Internal Rotation Measurements Differ Depending on Stabilization Techniques

Kath E. Wilk, PT, DPT\*\* Michael M. Dierolf, PT, DPT, ATC, CSCS† Leonard C. Macrina, MSPT, SCS† Ron Porterfield, MS, ATC† and James R. Andrews, MD†

Background: The loss of glenohumeral internal rotation range of motion in overhead athletes has been well documented in the literature. Several different methods of assessing this measurement have been described, making comparisons between the results of studies difficult. Hypothesis: Significant differences in the amount of internal rotation range of motion exist when using different methods of stabilization. Study Design: Prospective laboratory study.



62



63



64



65

*Wilk, Macrina, Porterfield et al: 2015  
Pitchers Shoulder ROM ('05-'15)*

	D	ND
• ER at 90° abduction:	131.1	125.1
• IR at 90° abduction:	53.3	63.2
• Total Rotational ROM:	184.3	187.4
• Horizontal adduction:	42.9	45.2
• ER Horz Adduction:	32.5	28.1

N= 1226

66

Clin Orthop Rel Res  
DOI: 10.1007/s11999-012-2204-z
Clinical Orthopedics  
and Related Research  
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SYMPOSIUM: INJURIES IN OVERHEAD ATHLETES

**CORR '12**

**Passive Range of Motion Characteristics in the Overhead Baseball Pitcher and Their Implications for Rehabilitation**

Kevin E. Wilk, PT, DPT, Leonard C. Martino MSPT, SCS, CSCS, Christopher Arigo MS, PT

ROM characteristic	Dominant	Nondominant	Significance
External rotation at 45°	102 ± 12	98 ± 12	< 0.001
External rotation at 90°	132 ± 11	127 ± 11	< 0.001
Internal rotation at 90°	52 ± 12	63 ± 12	< 0.001
Total rotational motion	184	190	< 0.001
Horizontal adduction	42 ± 8	44 ± 8	0.001

\* Mean in degrees.

**N=369**

(r = 0.12; p < 0.001) with throwing side horizontal adduction.

67

**Thrower's Shoulder ROM  
PROM Assessment**


**Shoulder Flexion**

**Shoulder Horz Abd**

68

### Criteria to RTP Thrower's Range of Motion Goals

- ✓ TROM within 5°
- ✓ Horizontal adduction 40°>
- ✓ GIRD < 20°
- ✓ Elbow full ROM
- ✓ Wrist full ROM
- ✓ Non-painful ROM




69

### J Sports Health 2021

#### Effect of Forearm Position on Glenohumeral External Rotation Measurements in Baseball Players

W. Steffen, M.D., Aaron Pappas, Ph.D., A.T.C., Peter Smith, M.D., M.P.H., and Brian Knapik, M.D., Ph.D.



**Background:** Measurement of glenohumeral external rotation (ER) is a common clinical and research tool used to assess shoulder function in athletes. However, the accuracy of ER measurements may be affected by forearm position. The purpose of this study was to determine the effect of forearm position on ER measurements in baseball players.

**Methods:** Ten professional baseball players (10 pitchers) were recruited for this study. Each player underwent three measurements of ER with the forearm in three different positions: neutral, pronated, and supinated. The measurements were taken with the player in a standing position.

**Results:** When the forearm was in the neutral position, ER measurements were significantly higher than when the forearm was in the pronated or supinated positions. The difference in ER measurements between the neutral and pronated positions was 10.5 degrees (95% CI, 6.5-14.5), and between the neutral and supinated positions was 11.5 degrees (95% CI, 7.5-15.5).

**Conclusion:** The choice of forearm position when measuring ER can significantly affect the results. The neutral position consistently yields the highest ER measurements, while the pronated and supinated positions yield lower measurements.

**Clinical Relevance:** Measurement of ER should be standardized to the neutral forearm position to ensure accurate and reliable results. Clinicians should be aware of the effect of forearm position on ER measurements and adjust their techniques accordingly.

70



71

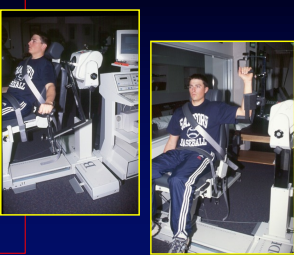
Table 3. Motion comparisons by position reported as mean (SD)

	Pitchers (n = 32)	Position Players (n = 28)	P
<b>Internal rotation</b>			
Throwing	24.8 (8.9)	32.1 (6.5)	<.01
Nonthrowing	34.4 (9.2)	37.2 (7.0)	0.20
<b>External rotation neutral</b>			
Throwing	85.2 (9.5)	81.5 (9.2)	0.13
Nonthrowing	86.2 (10.4)	85.2 (5.5)	0.67
<b>External rotation pronated</b>			
Throwing	73.4 (10.0)	72.9 (9.0)	0.82
Nonthrowing	81.4 (9.5)	81.2 (5.7)	0.91
<b>Total arc neutral</b>			
Throwing	110.0 (10.5)	113.6 (11.8)	0.21
Nonthrowing	120.6 (9.6)	122.4 (9.1)	0.45
<b>Total arc pronated</b>			
Throwing	96.3 (10.7)	105.0 (10.4)	0.02
Nonthrowing	115.8 (9)	118.4 (10.1)	0.30

72

### Return to Throwing Criteria Biodex -Isokinetics


- ER / IR ratios
  - ✓ 72 - 76%
- ER / ABD ratios
  - ✓ 68 - 73%
- Torque / BW ratios
  - ✓ ER 18 - 23%
  - ✓ IR 26 - 32%
- Bilateral comparison
  - ✓ ER 95-100%; IR 115%
  - Wilk et al. AJSM '93
  - Wilk et al. AJSM '95



73

### Return to Throwing Criteria Muscular Strength - HHD

- ER / IR ratios
  - ✓ 66-72%
- ER / ABD ratios
  - ✓ 68 - 73%
- Torque / BW ratios
  - ✓ ER 18 - 23%
  - ✓ IR 26 - 32%
- Bilateral comparison
  - ✓ ER 95-100%; IR 115%



74





75



78



79

**Scapular Strength Ratios**  
*Wilk, Reinold, Hooks...Unpublished data '07*

	Pitchers		Non-throwers	
	D	ND	D	ND
Elev / Depress	400%	480%	520%	540%
Retract / Protract	88%	71%	78%	71%

80

**Return to Throw Criteria**  
*Ball Drop Test*

- ✓ Dynamic stabilization tests
- ✓ Prone ball drops
  - ✓ 30 sec test
  - ✓ prone on plinth – No Holding On!
  - ✓ number of releases/catches
  - ✓ 3 trials – mean of 3 trials
  - ✓ compare Dom to Non Dom
  - ✓ score: %
  - ✓ Goal: 90%>
  - ✓ Expectation: 110%>

81

**Return to Throw Criteria**  
*Functional Testing*

- ✓ Three years of Testing: (9/22)
  - ✓ Healthy Professional: 193
  - ✓ Healthy College: 82
  - ✓ Healthy High School: 141
  - ✓ Healthy Totals: 416
- ✓ Patients: UCLr & Brace: 129

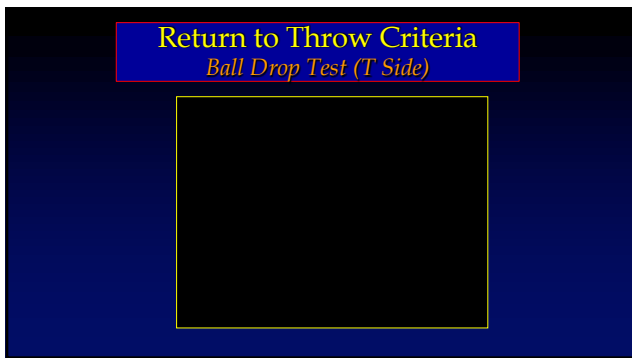
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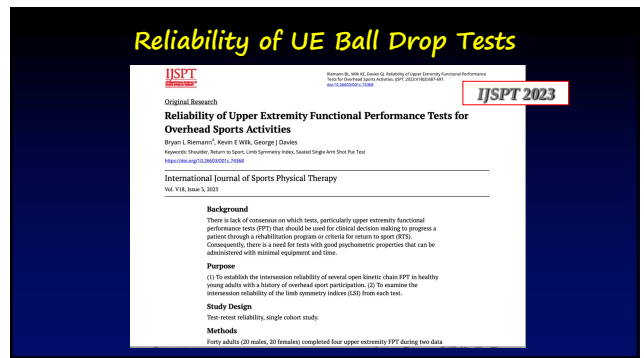
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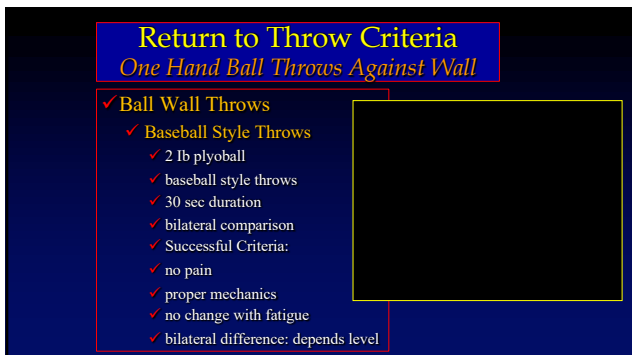
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90

**Return to Throw Criteria**  
*Single Leg Squat*

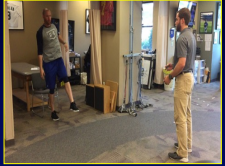
- ✓ Single leg squat test
  - ✓ Floor or 8 in step – 30 sec
  - ✓ count reps on each leg w/ 30 s
  - ✓ bilateral comparison
  - ✓ assess depth
  - ✓ assess valgus/varus
  - ✓ assess lateral trunk movt.
  - ✓ assess trunk flexion
  - ✓ looking for symmetrical motion with no pain &/or dysfunction
  - ✓ 80-85% symmetry



91

**Return to Play Criteria**  
*Single Leg Squat*

- ✓ Single leg squat test
  - ✓ Floor
  - ✓ 30 sec test on each leg
  - ✓ assess technique & numbers
  - ✓ assess valgus/varus
  - ✓ assess lateral trunk movt.
  - ✓ assess trunk flexion
  - ✓ looking for symmetrical motion with no pain &/or dysfunction
  - ✓ ability to maintain balance & form for all reps



92



94

**Closed Kinetic Chain Upper Extremity Stability Test - Davies**



95

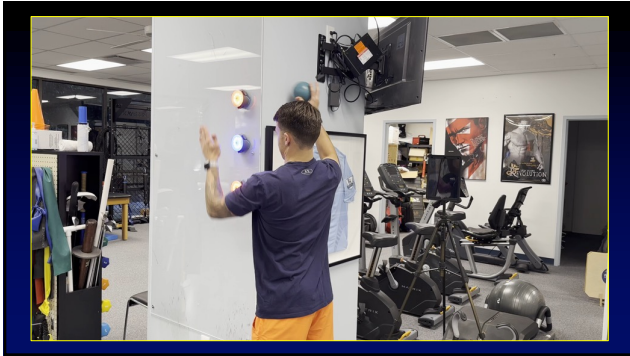


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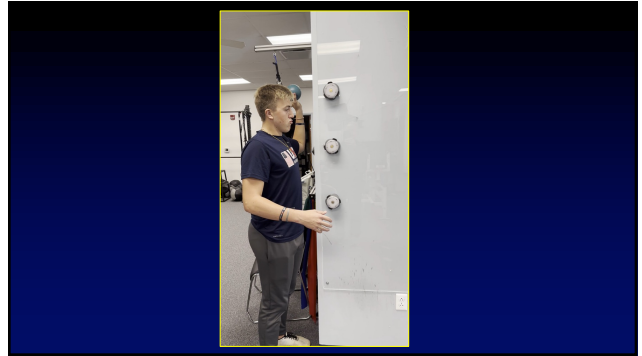
**Closed Kinetic Chain Upper Extremity Stability Test - Cognitive Motor - Color Specific**



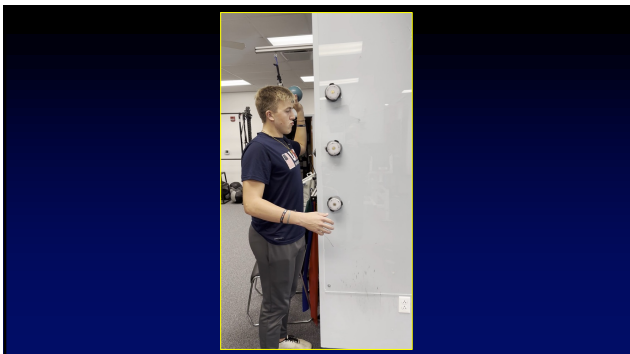
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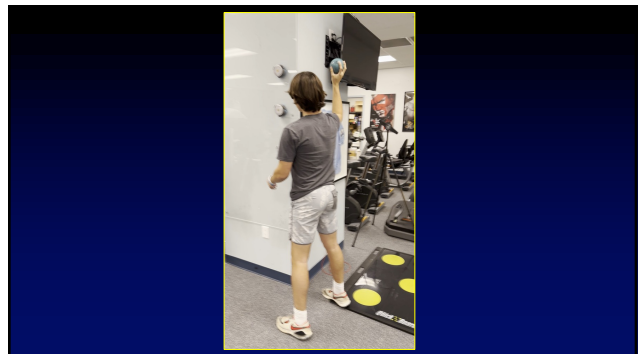
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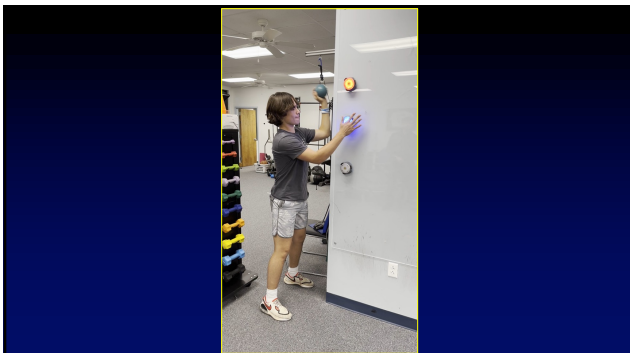
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101



102



103



104





105

### Neurocognitive Testing of the Upper Extremity in Overhead Athletes

✓ College Baseball	40
✓ College Softball	16
✓ High School Bball	74
✓ High School Sball	7
✓ Totals	137

106

### Test 1: Reactive CKQUEST

**Results by sport:**

	# of hits	Reaction Time
Baseball (n=83)	R: 17.1; L: 16.4	R: .400; L: .419
Softball (n=23)	R: 16.0; L: 15.2	R: .443; L: .483

**Results by level:**

	# of hits	Reaction Time
High School Baseball (n=43)	R: 16.6; L: 16.3	R: .406; L: .412
High School Softball (n=7)	R: 15.8; L: 15.1	R: .462; L: .495
College Baseball (n=40)	R: 17.5; L: 16.5	R: .394; L: .425
College Softball (n=16)	R: 16.2; L: 15.2	R: .425; L: .473

107

### Test 2: Reactive Triangle CKQUEST

Results by sport

	# of hits	Reaction Time	Errors
Baseball (n=83)	R: 23.8; L: 23.8	R: .575; L: .530	R: .08; L: .09
Softball (n=23)	R: 21.1; L: 21.2	R: .633; L: .635	R: 0; L: .04

Results by level

	# of hits	Reaction Time	Errors
High School Baseball (n=43)	R: 24.1; L: 24.1	R: .607; L: .513	R: .12; L: .07
High School Softball (n=7)	R: 21; L: 21.1	R: .589; L: .588	R: 0; L: .07
College Baseball (n=40)	R: 23.6; L: 23.5	R: .543; L: .548	R: .04; L: .11
College Softball (n=16)	R: 21.3; L: 21.3	R: .677; L: .682	R: 0; L: 0

108

### Test 3: Reactive Right vs. Left CKQUEST

**Results by sport**

	# of hits	Reaction Time	Errors
Baseball (n=83)	18.1	.711	.25
Softball (n=23)	14.8	.935	.12

**Results by level**

	# of hits	Reaction Time	Errors
High School Baseball (n=43)	17.9	.727	.35
High School Softball (n=7)	13.9	1.031	.21
College Baseball (n=40)	18.2	.695	.15
College Softball (n=16)	15.7	.840	.03

109

### Test 4: Reactive 90/90 Wall Throws

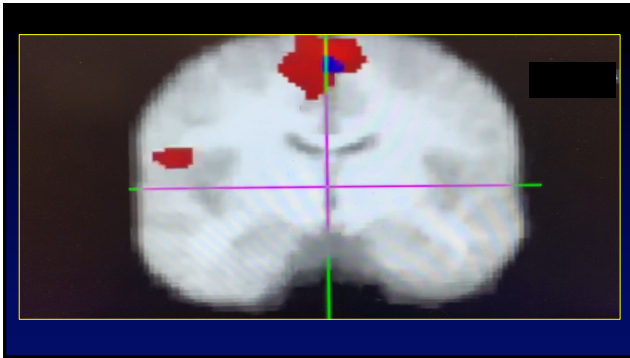
Results by sport

	# of hits	Reaction Time	Errors
Baseball (n=83)	R: 22.0; L: 22.6	R: .482; L: .550	R: .54; L: .41
Softball (n=23)	R: 21.4; L: 19.5	R: .564; L: .628	R: .77; L: 1.15

Results by level

	# of hits	Reaction Time	Errors
High School Baseball (n=43)	R: 25.3; L: 24.8	R: .503; L: .491	R: .64; L: .25
High School Softball (n=7)	R: 21.8; L: 20.8	R: .607; L: .617	R: .17; L: .42
College Baseball (n=40)	R: 20.4; L: 21.5	R: .472; L: .579	R: .50; L: .49
College Softball (n=16)	R: 21; L: 18.3	R: .521; L: .640	R: 1.38; L: 1.9

110



112

### Measuring the Brain After Injury

Rest 30 s Move 30 s Rest 30 s Move 30 s Rest 30 s Move 30 s Rest 30 s

Strand M, Dinklas J, Bonnette L, et al. Validity assessment of a single camera MR-compatible motion capture system for use with lower extremity neuroimaging paradigms. *ISPT in Press*.  
 Gagnier JK, Gray CL, Simon G, Nagarty AJ, Wolf TR. Neural Correlates of Knee Extension and Flexion Force Control: A Noninvasively Instrumented Neuroimaging Study. *Front Hum Neurosci*. 2020;14:1747. doi:10.3389/fnhum.2020.01747

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113

### Neuroplasticity Following ACL Injury

[ RESEARCH REPORT ]

Neuroplasticity Associated With Anterior Cruciate Ligament Reconstruction

Individuals who experience a primary anterior cruciate ligament (ACL) injury are at substantially increased risk of experiencing a second ACL injury, despite surgical reconstruction and rehabilitation. Moreover, while attempts to return to activity are associated with high rates of return to play, these people exhibit a lower return to play level than the population for the highest of return to play level. Factors of the physiological and behavioral changes associated with ACL injury and its reconstruction include:

- **Rehab Implications:**
  - ✓ Dual tasking
  - ✓ Blindfolded
  - ✓ Eyes closed
  - ✓ Stroboscope glasses
  - ✓ Visual elements

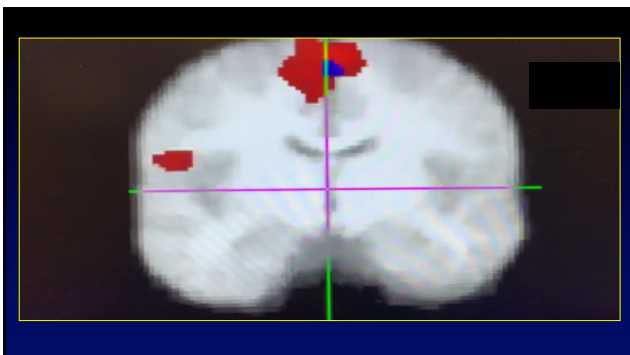
114

### Evidence of CNS Plasticity after Musculoskeletal Injury

- Δ in cross sectional area / tibial translation only modestly correlate with functional deficits
- Sensorimotor deficits appear *bilaterally*
- Deficits persist despite absence of pain, stiffness, or effusion in knee
- Reduced corticospinal excitability and sensorimotor function persist despite normalized H-reflex

H-reflex: measure of stimulus from muscle to spinal cord and back to muscle

115



116

- Frontal Lobe**  
Cognitively Demanding Activities  
Open Skill Activities  
Resistance Training  
Mind-Body Exercise
- Parietal Lobe**  
Sensory – Rich Activities  
Visual – Spatial Demands  
Object – Based Activities
- Occipital Lobe**  
Visual – Spatial Demands  
Visual – Attention Demands  
Motor Control & Stimulation
- Temporal Lobe**  
Cardiovascular Exercise  
Closed Skill Activities  
Generalized Physical Activity
- Cerebellum**  
Coordinative Exercise  
Skill & Motor Learning  
Open Skill Activities

117



118



119

### Functional Testing Overhead Athlete Specific Tests

- ✓ Range of Motion
- ✓ Manual Muscle Testing (HHD)
- ✓ Special Tests
- ✓ Functional Tests
  - ✓ Ball Drop Testing
  - ✓ Ball Wall Drizzle Testing
  - ✓ Throws
  - ✓ Single Leg Squats
- ✓ Reactive Neurocognitive Testing:
  - ✓ Target Light Testing
  - ✓ Series of 4 Tests

121

### Return to Play Criteria Collision Athlete

188

### Return to Play Criteria Collision Athlete

- Clinical Examination
- ROM
  - » Passive ROM
  - » Active ROM
- Muscular Strength
- Special Tests
- RTP Testing
- Rehab Progression
- Time from Surgery

189

### RTP Shoulder Stabilization Clinical Examination

- Range of Motion
  - » Necessary for sport/position
  - » Safe & painful
- Palpation
- Special tests
  - » Stability testing
  - » Labral tests (SLAP)
  - » Biceps tests

190



**Return to Play Criteria**  
*Collision Athlete*

- ✓ Unilateral Chest press
- ✓ Involved v Uninvolved
- ✓ 1 RM
- ✓ 50% BW – number of repetitions
- ✓ 85-90% of uninvolved
- ✓ Assess technique

Pain Free, Technique, Weight




191

**Return to Play Criteria**  
*Collision Athlete*

- ✓ CKCUEST (Davies)
- ✓ UE Stability Test
- ✓ Tape 36" apart
- ✓ 15 sec test
- ✓ Record # of touches
- ✓ 85-90%\*



*Goldbeck et al: J Spts Rehab '00*  
*Roush et al: NAJSPT '07*



192

**Return to Play Criteria**  
*Collision Athlete*

- ✓ Unilateral Prone Ball Drop Test
- ✓ Involved vs Uninvolved
- ✓ 2 lb plyoball
- ✓ 30 sec test
- ✓ Number of catches
- ✓ 90%> of UI side
- ✓ Endurance test\*

193

**Return to Play Criteria**  
*Collision Athlete*




194

**Return to Play Criteria**  
*Collision Athlete*

- ✓ Upper Quarter Y Balance Test

*Westerick et al: IJSPT '12*  
*Gorman et al: JSCR '12*  
- Quantity: 85-90%, Quality Assessment: control



195

**Return to Play Criteria**  
*Collision Athlete*



196

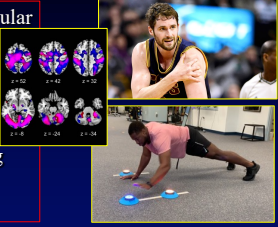


### Neurocognitive Testing & Training

*Conclusions & Key Points:*

- ✓ Injuries may result in neuromuscular deficits – neuroplasticity
- ✓ Enhanced motor control can improve performance & reduce injuries
- ✓ More to rehab than strengthening
- ✓ Neuromuscular control - Effort
- ✓ *Better Athletes*

*Are They Ready to Play Safely & Effectively*



197



198