Reactive Agility, Pupil Diameter, and Injury Associations Among College Football Players

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Introduction

- Both musculoskeletal injury (MSKI) and sport-related concussion (SRC) present risk for progressive dysfunction and disability
  - Suboptimal brain processing of neural signals may either precede injury or result from it, such as anterior cruciate ligament (ACL) rupture[1-3]
- One prior report has documented an association between perceptual-motor performance and subsequent MSKI or SRC among football players[4]
  - Potentially modifiable performance capabilities may reduce injury risk[5,6]
- Preparticipation screening to identify individuals with elevated injury risk necessary to implement risk reduction interventions

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Study Purpose

- To assess possible prospective associations between preparticipation test results and occurrences of core or lower extremity injury (CLEI) or sport-related concussion (SRC) among Division-I FCS football players over the course of one season
  - Whole-Body Reactive Agility (WBRA)
  - Smartphone Flanker Test (FL) App
  - Smartphone Pupil Light Reflex (PLR) App
  - Sport Fitness and Wellness Index Survey

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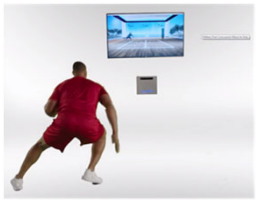
Whole-Body Reactive Agility (WBRA)

- Virtual reality displayed on monitor (TRAZER Sport Simulator)
  - Targets appear on either right or left side of monitor
  - Targets disappear when body moved to proper 3D coordinates
    - Body position tracked within 3 m X 3 m area
  - Performance metrics:
    - Reaction time
    - Speed
    - Acceleration
    - Deceleration
    - Total Distance



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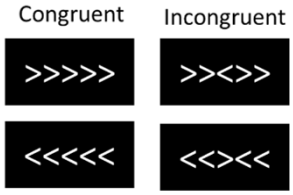
Flanker Test



- 20 trials (10 congruent and 10 Incongruent)
- 5-arrow displays present for 300 ms
- Inter-stimulus intervals 500 ms to 1500 ms

- Measurement of Perceptual-Motor Efficiency
  - Recognition of stimulus (perception)
  - Rapid cognitive processing (interpretation)
  - Muscle response (motor activation)
- Performance metrics:
  - Flanker Conflict Effect (FCE) = Incongruent Avg RT - Congruent Avg RT
  - Rate Correct Score (RCS) = Number of Correct Responses / RT Sum (sec)
  - Reaction Time Variability (RTV) = Intra-individual Std Dev of All trials

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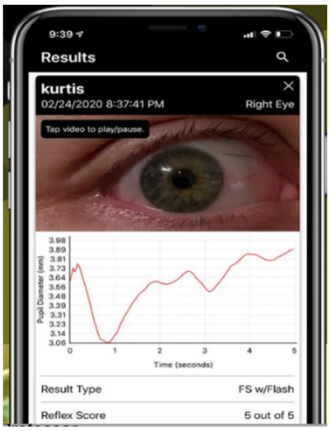
Pupil Light Reflex

- PLR recorded by 5-second video of eye response to smartphone camera flash
  - Smartphone app (BrightLamp Reflex iPhone App)
  - Left eye and Right eye measured separately
    - Constriction Time (Con Time)
    - Constriction Latency (Con Lat)
    - Minimum Diameter (Min Dia)
    - Maximum Diameter (Max Dia)
    - Average Diameter (Avg Dia)



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Procedures

- Injury definition:
  - Any core or lower extremity musculoskeletal injury (dislocation, fracture, sprain, or strain) that was evaluated and treated, regardless of whether or not time was lost from participation in a subsequent practice session or game
- Surveillance period:
  - 16 weeks from start of pre-season practices to end of 11-game season

Core and LE Injuries

Ankle:	8
Lower Leg:	1
Knee:	5
Hamstring:	2
Quadriceps:	4
Hip/Groin:	2
Low Back:	1
Abdomen:	1

* 24 Core and LE Injuries sustained by 18 players

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Core or Lower Extremity Injury (Practice Session or Game)

		CLEI Occurrence in Practice or Game		
		Yes	No	Incidence
History of ACL-R	Yes	4	3	57%
	No	14	66	18%
	Total	18	69	

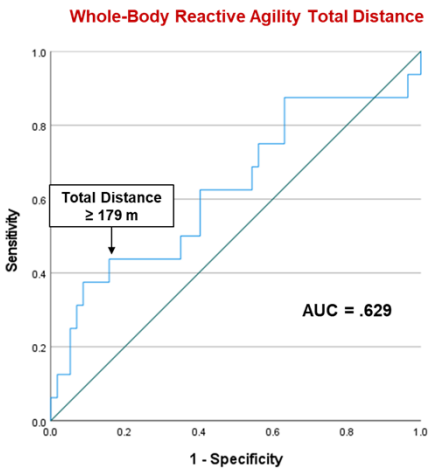
Sensitivity 22% Specificity 96%

$\chi^2(1)=6.17$ $P=.031$ **OR=6.29** 95% CI: 1.26, 31.26

		CLEI Occurrence in Practice or Game		
		Yes	No	Incidence
WBRA Total Distance ≥ 179 m	Yes	7	9	44%
	No	9	48	16%
	Total	16	57	

Sensitivity 44% Specificity 84%

$\chi^2(1)=5.71$ $P=.024$ **OR=4.15** 95% CI: 1.23, 14.02



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Prospective (Baseline Measure) Prediction: Core or Lower Extremity Sprain or Strain

Predictor	AUC	Cut Point	n	P	Sensitivity	Specificity	PPV	NPV	OR	95% CI
Hx ACL-R	-	Yes/No	6/87	.031	.22	.96	.57	.83	6.29	1.26, 31.26
WBRA Total Distance	.629	≥ 179 m	16/73*	.024	.44	.84	.44	.84	4.15	1.23, 14.02
Both Positive	-	Yes/No	3/73*	.008	.19	1.00	1.00	.81	-	-
Either Positive	-	Yes/No	16/73*	.019	.50	.81	.42	.85	4.18	1.29, 13.61
Starter Status	-	Yes/No	34/87	.091	.56	.65	.29	.85	2.34	0.82, 6.72

* WBRA data missing for 14 cases

Core or Lower Extremity Injury (Practice Session or Game)

BOTH FACTORS		CLEI Occurrence in Practice or Game: Yes	No	Incidence
Hx ACL-R AND Hi Total Dist	Yes	3	0	100%
	No	13	57	19%
	Total	16	57	

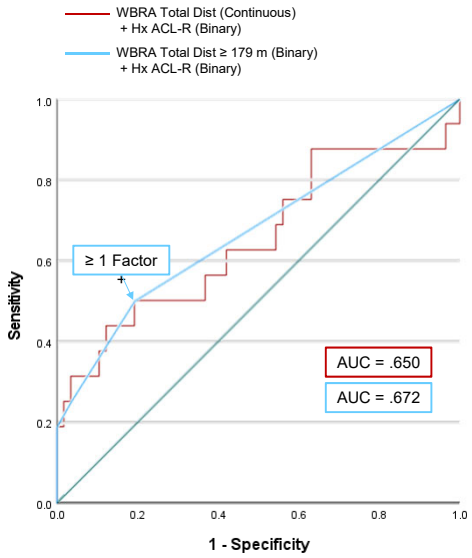
Sensitivity 19% Specificity 100%

$\chi^2(1)=11.15$ $P=.009$ **OR=*** ** 95% CI: ***

EITHER FACTOR		CLEI Occurrence in Practice or Game: Yes	No	Incidence
Hx ACL-R OR Hi Total Dist	Yes	8	11	42%
	No	8	46	15%
	Total	16	57	

Sensitivity 50% Specificity 81%

$\chi^2(1)=6.12$ $P=.019$ **OR=4.18** 95% CI: 1.29, 13.61



Prediction of Core or LE Sprain or Strain

Binary Predictor	Univariable Unadjusted Odds Ratio (95% CI)	Multivariable Adjusted Odds Ratio (95% CI)
Hx ACL-R	6.29 (1.26, 31.26)	7.24 (1.10, 47.58)
WBRA Total Dist ≥ 179 m	4.15 (1.23, 14.02)	3.46 (0.96, 12.51)

Prediction Accuracy = 81%

WBRA Total Distance Range: 129 – 207 m

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Prospective (Baseline Measure) Prediction: Sport-Related Concussion

Predictor	AUC	Cut Point	n	P	Sensitivity	Specificity	PPV	NPV	OR	95% CI
Max Pupil Diameter	.634	≤ 5.47 mm	37/84	.035	.78	.60	.19	.96	5.25	1.02, 27.01
Rate Correct Ratio	.628	≤ 0.64	32/87	.057	.67	.67	.19	.94	4.00	0.93, 17.29
Both Positive	-	Yes/No	15/84	.008	.56	.87	.33	.94	8.13	1.86, 35.47
Either Positive	-	Yes/No	53/84	.087	.89	.40	.15	.97	5.33	0.63, 44.86
Starter Status	-	Yes/No	34/87	.067	.11	.58	.03	.85	0.17	0.02, 1.43

* Max Pupil Diameter data missing for 3 cases (due to dark eye color)

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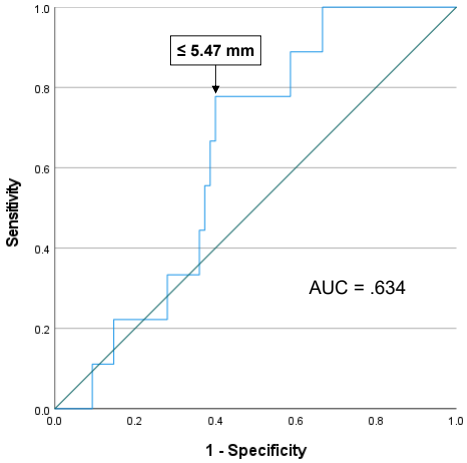
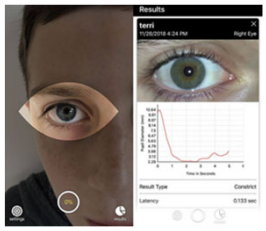
Sport-Related Concussion Occurrence (Practice Session or Game)

Maximum Pupil Diameter (Average of Right and Left)





		SRC Occurrence in Practice or Game		
		Yes	No	Incidence
Max Pupil Diameter* ≤ 5.47 mm	Yes	7	30	19%
	No	2	45	4%
	Total	9	75	

Sensitivity 78% Specificity 60%

* Average of Right and Left

$\chi^2(1)=4.65$ **OR=5.25**
P=.035 95% CI: 1.02, 27.01

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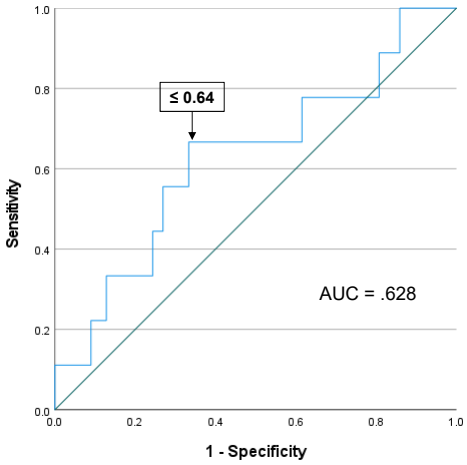
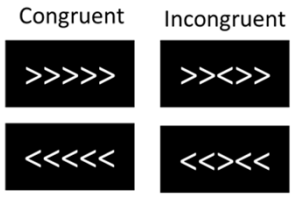
Sport-Related Concussion Occurrence (Practice Session or Game)

Rate Correct Ratio = RCS-Incongruent / RCS-Congruent





		SRC Occurrence in Practice or Game		
		Yes	No	Incidence
Flanker Test Rate Correct Ratio ≤ 0.64	Yes	6	26	19%
	No	3	52	6%
	Total	9	78	

Sensitivity 67% Specificity 67%

$\chi^2(1)=3.86$ **OR=4.00**
P=.057 95% CI: 0.93, 17.29

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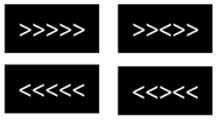
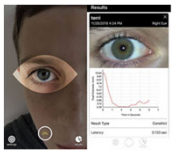
Sport-Related Concussion (Practice Session or Game)

Congruent



Incongruent



Flanker Test Rate Correct Ratio ≤ 0.64	SRC Occurrence in Practice or Game: Yes	No	Incidence
Yes	6	26	19%
No	3	52	6%
Total	9	78	

Sensitivity 67% Specificity 67%

$\chi^2(1)=3.86$ $P=.057$ **OR=4.00** 95% CI: 0.93, 17.29

Max Pupil Diameter* ≤ 5.47 mm	SRC Occurrence in Practice or Game: Yes	No	Incidence
Yes	7	30	19%
No	2	45	4%
Total	9	75	

Sensitivity 78% Specificity 60%

* Average of Right and Left

$\chi^2(1)=4.65$ $P=.035$ **OR=5.25** 95% CI: 1.02, 27.01

BOTH Lo RCR and Lo Max Pupil Diameter	SRC Occurrence in Practice or Game: Yes	No	Incidence
Yes	5	10	33%
No	4	65	6%
Total	9	75	

Sensitivity 56% Specificity 87%

$\chi^2(1)=9.77$ $P=.008$ **OR=8.13** 95% CI: 1.86, 35.47

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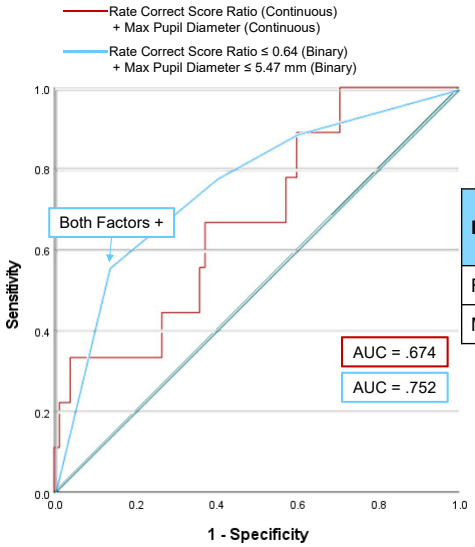

Prediction of Concussion

Binary Predictor	Univariable Unadjusted Odds Ratio (95% CI)	Multivariable Adjusted Odds Ratio (95% CI)
Rate Correct Score Ratio ≤ 0.64	4.00 (0.93, 17.29)	3.89 (0.96, 17.54)
Max Pupil Diameter ≤ 5.47	5.25 (1.02, 27.01)	5.12 (0.97, 27.08)

Prediction Accuracy = 93%*

* Binary Model (Both Factors Positive)

Rate Correct Ratio Range: 0.17 – 1.21
Maximum Pupil Diameter Range: 4.19 – 7.83

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Discussion: Core or Lower Extremity Injury

- History of ACL-R strongly associated with secondary occurrence of core or lower extremity injury over the course of a football season
  - Time since ACL-R ranged from 2 to 5 years
- Excessive WBRA Total Distance may be an indicator of suboptimal visuo-spatial calibration (i.e., imprecise 3-D virtual target location)
  - Perceptual-motor inefficiency may either precede or result from ACL injury
- 100% (3/3) who demonstrated excessive total distance (≥ 179 m) and also had a history of ACL-R sustained a core or lower extremity injury

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Discussion: Sport-Related Concussion

- Prior research has documented smaller Maximum Pupil Diameter among individuals with concussion history[7]
  - 4.75 X greater incidence of SRC with ≤ 5.47 mm at baseline
- Perceptual-motor efficiency quantified as Rate Correct Ratio at baseline also prospectively predicted occurrence of SRC
  - More errors and longer processing time for incongruent stimuli
- 33% (5/15) with both factors sustained SRC compared to 6% (4/69) who exhibited only 1 or neither of the 2 factors

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Clinical Relevance

- History of ACL-R appears to increase CLEI risk, which may be due to impaired sensorimotor control (i.e., loss of mechanoreceptors)[1,2,6]
- Visuo-spatial calibration, perceptual-motor efficiency, and maximal pupil diameter may reflect interrelated brain processes[4,5,7]
- Impairments observed at pre-participation screening may be due to asymptomatic neuroinflammation caused by past head impacts[8]
- Screening tests can identify individuals with elevated risk for CLEI or SRC, which may advance development of preventive strategies[3,4]

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