

# Association of Cumulative Training Load and Monotony on Core and Lower Extremity Injuries among College Football Players

Colt Batie and Dylan Walker

THE UNIVERSITY of TENNESSEE   
CHATTANOOGA

# Disclaimer

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- We have nothing to disclose

# Introduction

- Lack of adaptability to environmental uncertainty increases injury risk<sup>1</sup>
  - Tissue loads result from impacts and abrupt changes in movement velocity/direction<sup>2</sup>
  - Fewer motor control options available during high-demand physical activities<sup>3</sup>
  - Movement pattern monotony can concentrate load on internal body structures
  
- Some consider collision injuries unavoidable,<sup>4</sup> but “load” may be a factor
  - Training Load: Instantaneous rate of change in 3-D acceleration of body mass<sup>5</sup>
  - Monotony: Lack of load variability; inverse of load coefficient of variation<sup>6</sup>
  - Either or both factors may predict level of injury susceptibility

# Purpose

- To prospectively analyze data collected during college football practice sessions from wearable inertial measurement units (IMUs) to assess a possible relationship between training load or monotony to occurrences of core or lower extremity injury (CLEI) across pre-season practice sessions and 10 regular season games.

# Methods



- 61 Male NCAA Division-1 Football Players
  - Age range: 18-24; Mass:  $102.7 \pm 20.3$  kg; Height:  $184.6 \pm 6.2$  cm
- IMU Device: Catapult One (Catapult Sports USA, Chicago, IL)
  - Measurement validity and reliability previously established<sup>7</sup>
  - Worn within vest by expected starters and high-level non-starting players
  - IMU data aggregation: PlayerTek Software (Catapult Sports USA, Chicago, IL)
- Surveillance Period:
  - Start of preseason practice sessions through first 10 games of 13-game season
- Injury Documentation (Sportsware, CSMI, Stoughton, MA)
  - Core or lower extremity injury (CLEI): Any sprain or strain that interrupted participation



# Statistical Analysis

- Entire surveillance period: 54 recording sessions, 94 days
  - Phase 1: 16 recording sessions: 24 days (pre-season practice period, 2 scrimmages)
  - Phase 2: 19 recording sessions: 35 days (first 5 weeks of regular season)
  - Phase 3: 19 recording sessions: 35 days (second 5 weeks of regular season)
- Training Load and Monotony:
  - Uninjured (full period/phase); Injured (minimum of 4 pre-injury recordings)
    - Potential cause must precede injury to infer a contributory role
- Potential confounding factors assessed:
  - Position Category; Starter Status; Lifetime Concussion History; CLEI History (prior 12 mo)
- Receiver operating characteristic, chi-square, logistic regression, Cox regression analyses

# Pre-Season through 10<sup>th</sup> Game (13-Game Season): Classification of Injury\* vs. No Injury

\* Core or Lower Extremity Sprain or Strain  
32 Players sustained a total of 36 Injuries

Position	Injury Incidence	Position Category
OL	73% (8/11)	<b>Interior</b> 68% (19/28)
LB	71% (5/7)	
DL	64% (7/11)	
RB & QB	71% (5/7)	<b>Skilled</b> 38% (12/32)
WR & TE	42% (5/12)	
DB	15% (2/13)	

	Players	Possible Recordings	Actual Recordings	Range	Missing Data
<b>Uninjured</b>	29	1566	1183	4-54	25%
<b>Injured</b>	32	1728	785	4-54	55%

Position Category	Injury		Incidence	
	Yes	No		
Interior	20	9	69%	<b>PPV: 69%</b>
Skilled	12	20	38%	<b>NPV: 62%</b>
Total	32	29		

Pre-Season through 10 <sup>th</sup> Game of Season						
Injury Category	Hip/Groin	Thigh	Knee	Lower Leg	Ankle	Foot
<b>Number</b>	3	4	12	4	9	4

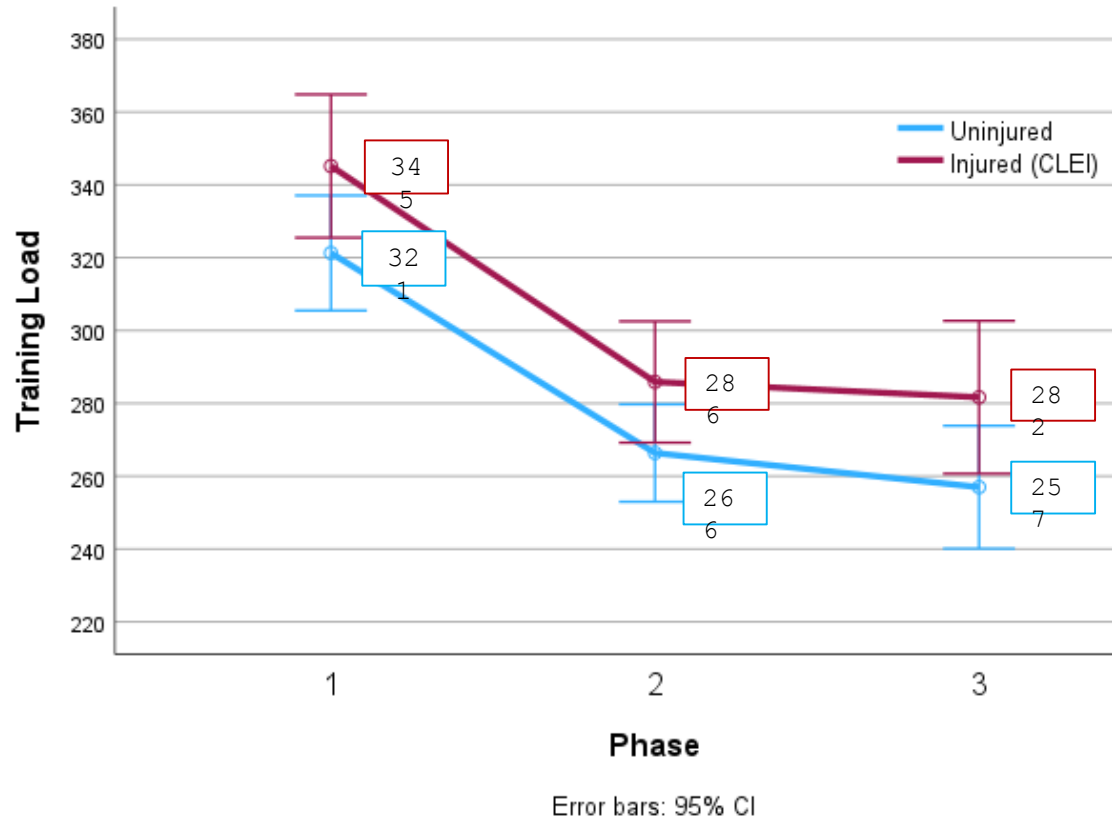
**Sensitivity: 61%**    **Specificity: 69%**

$\chi^2(1)=6.04$   
2-Sided  $P=.021$

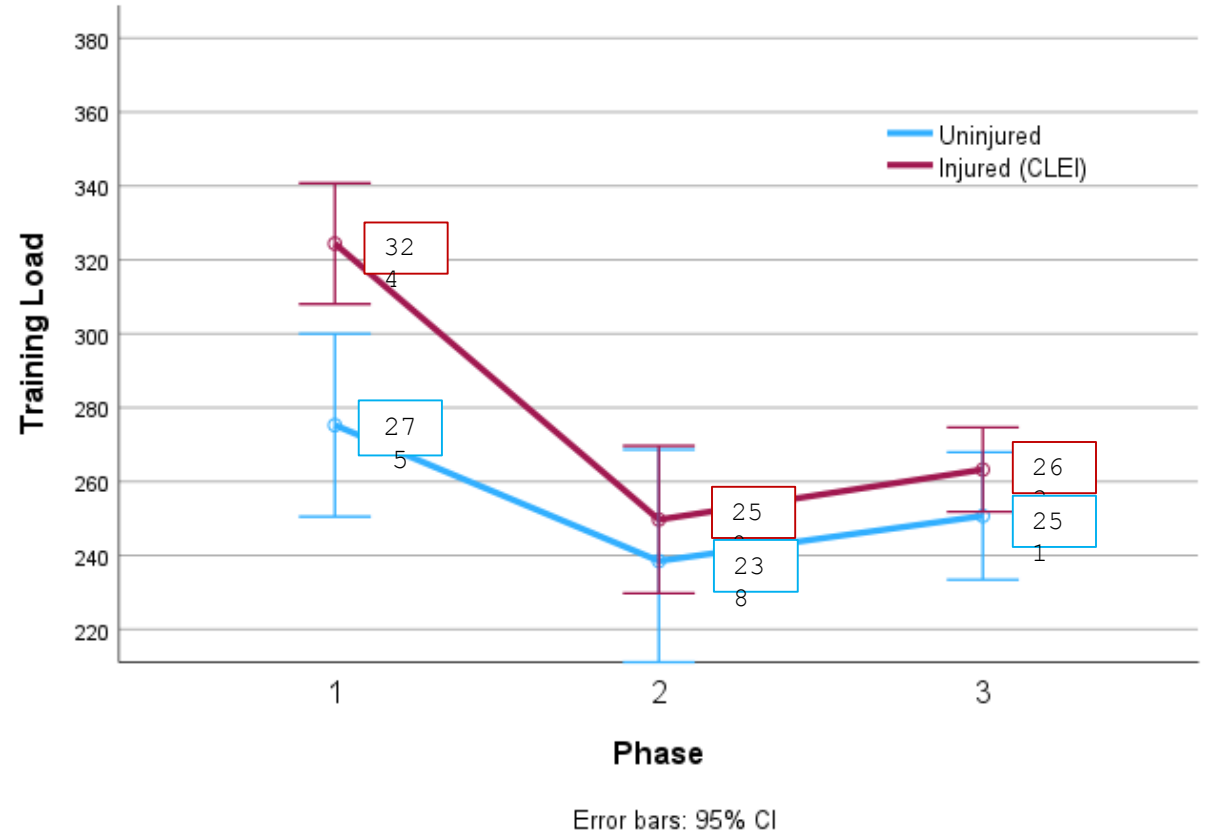
**OR=3.70**  
95% CI: 1.28, 10.73

# Training Load: Injured vs. Uninjured

## Skilled Positions (RB+QB, WR+TE, DB)



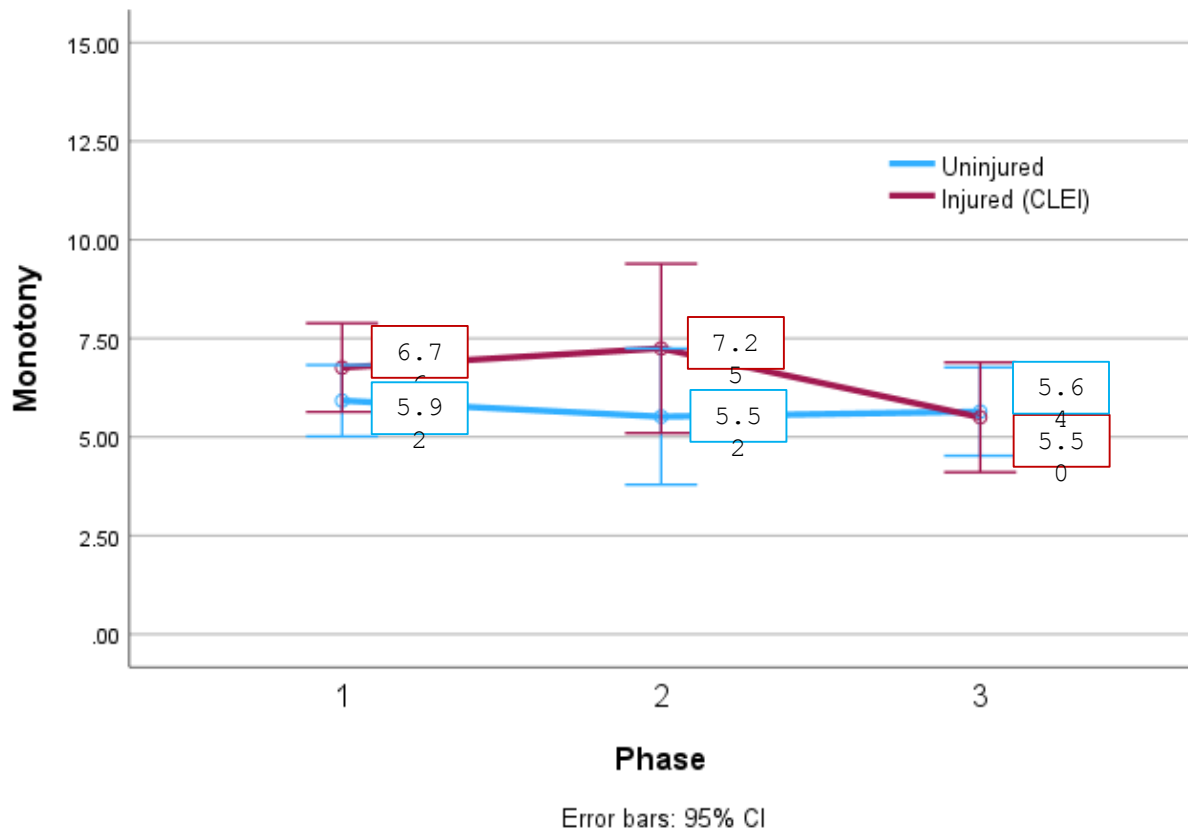
## Interior Positions (OL, DL, LB)



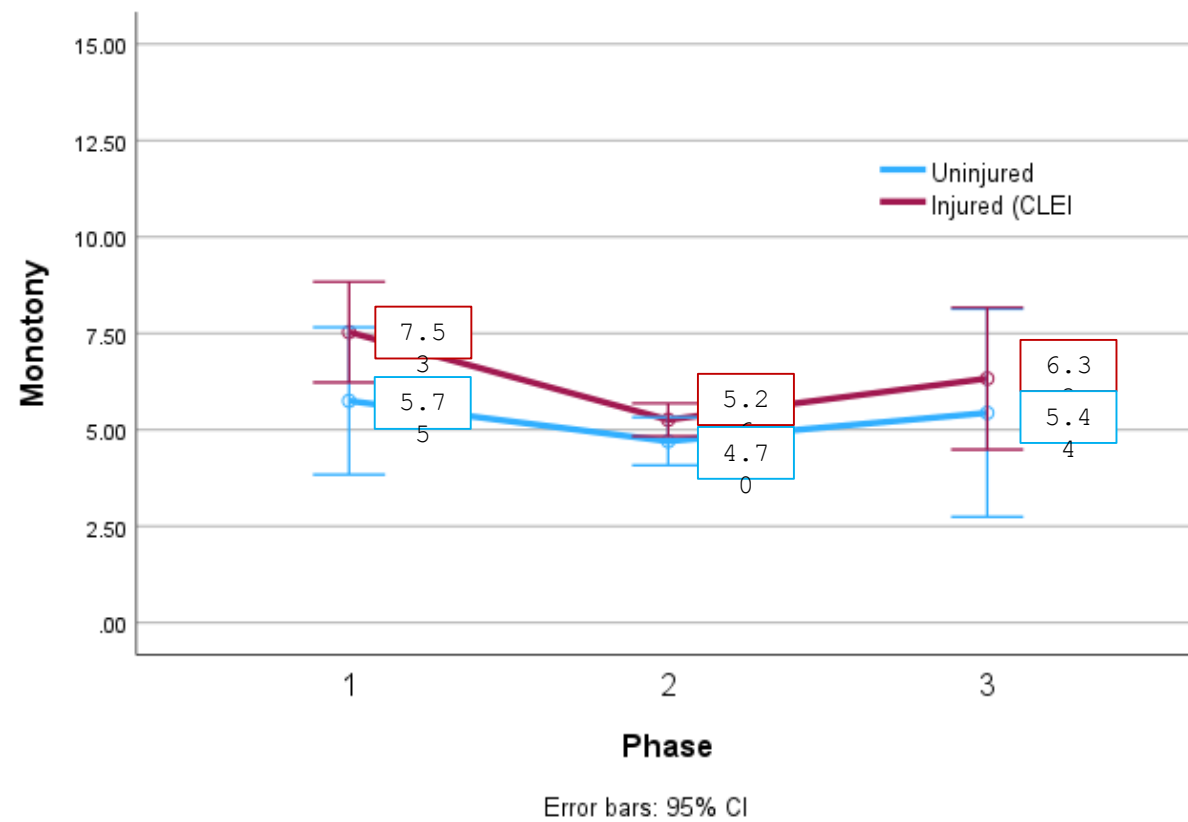


# Monotony: Injured vs. Uninjured

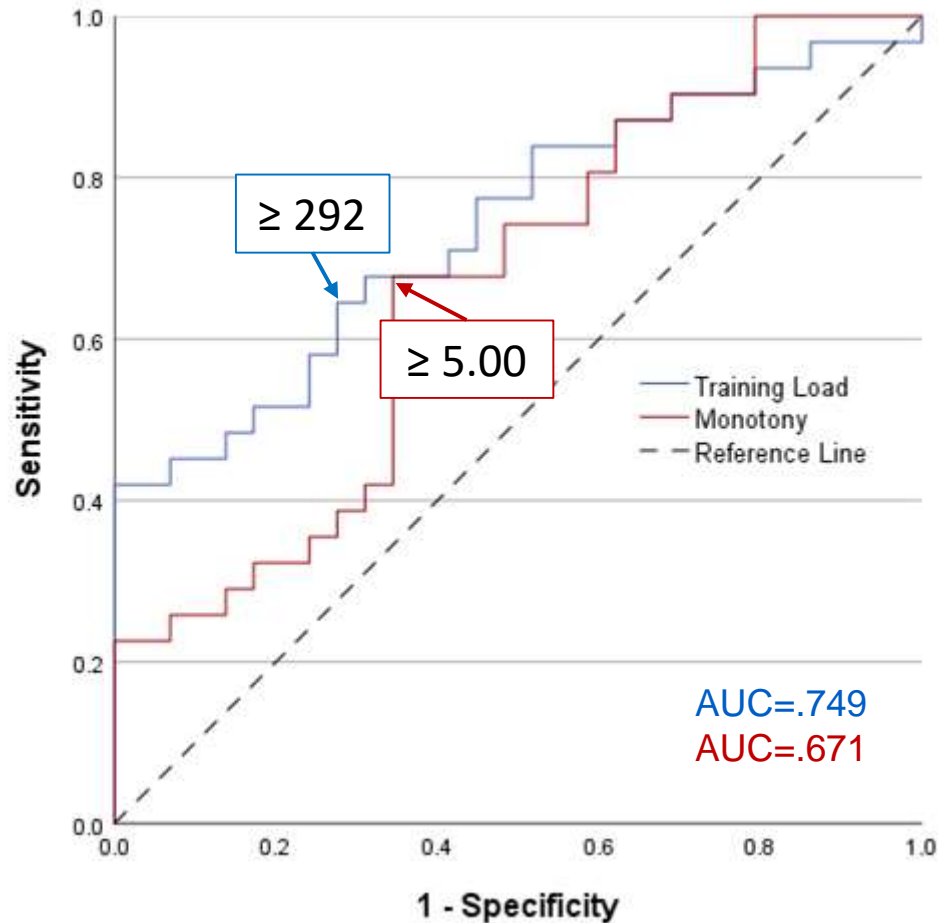
Skilled Positions (RB+QB, WR+TE, DB)



Interior Positions (OL, DL, LB)



# Pre-Season through 10<sup>th</sup> Game (13-Game Season): Classification of Injury\* vs. No Injury



\* Core or Lower Extremity Sprain or Strain

		Injury		Incidence	
		Yes	No		
Training Load	≥ 292	21	8	72%	<b>PPV: 72%</b>
	< 292	11	21	34%	<b>NPV: 66%</b>
Total		32	29		

**Sensitivity: 66% Specificity: 72%**

$$\chi^2(1)=8.83$$

2-Sided  $P=.005$

**OR=5.01**

95% CI: 1.68, 14.95

		Injury		Incidence	
		Yes	No		
Monotony	≥ 5.00	22	10	69%	<b>PPV: 69%</b>
	< 5.00	10	19	34%	<b>NPV: 66%</b>
Total		32	29		

**Sensitivity: 68% Specificity: 66%**

$$\chi^2(1)=7.16$$

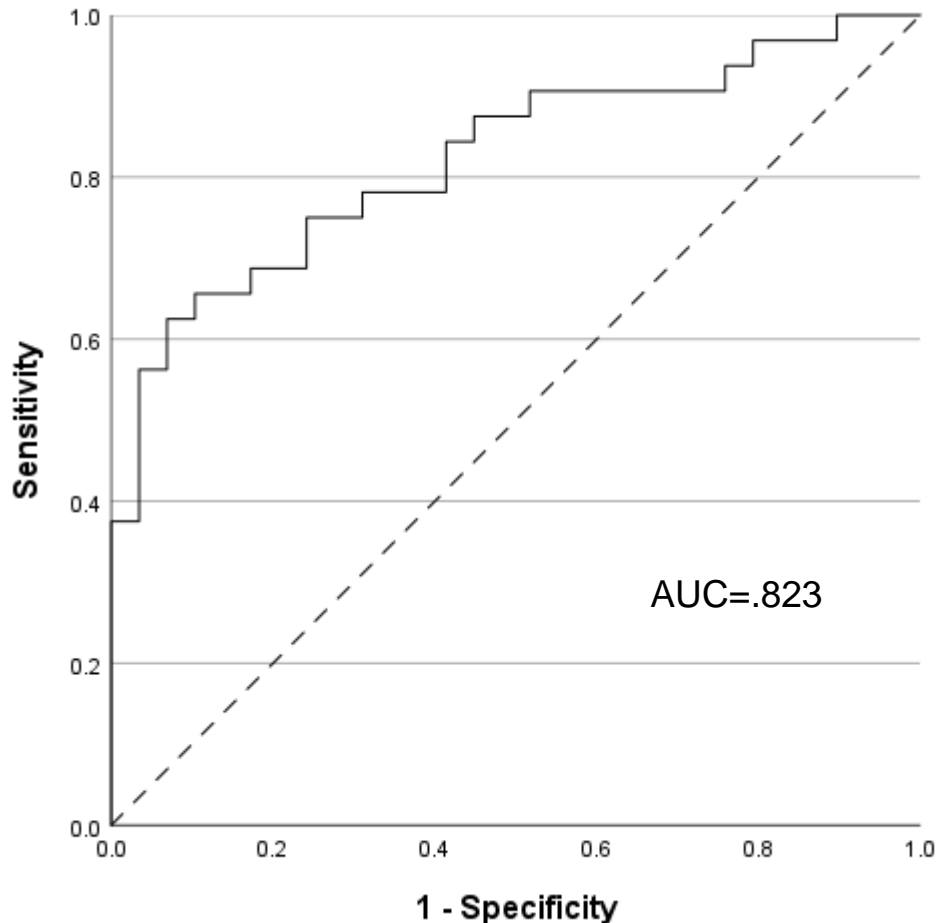
2-Sided  $P<.011$

**OR=4.18**

95% CI: 1.43, 12.19

# Pre-Season through 10<sup>th</sup> Game (13-Game Season): Classification of Injury vs. No Injury

Logistic Regression Model of Injury Probability  
Combination of Position Category + Training Load



Logistic Regression Output 2-Factor Prediction Model

	B	Sig.	Exp(B)	95% C.I. for EXP(B)	
				Lower	Upper
Position Category	1.922	.006	6.836	1.725	27.082
Training Load	.032	.001	1.032	1.012	1.052
Constant	-9.873	.001	.000		

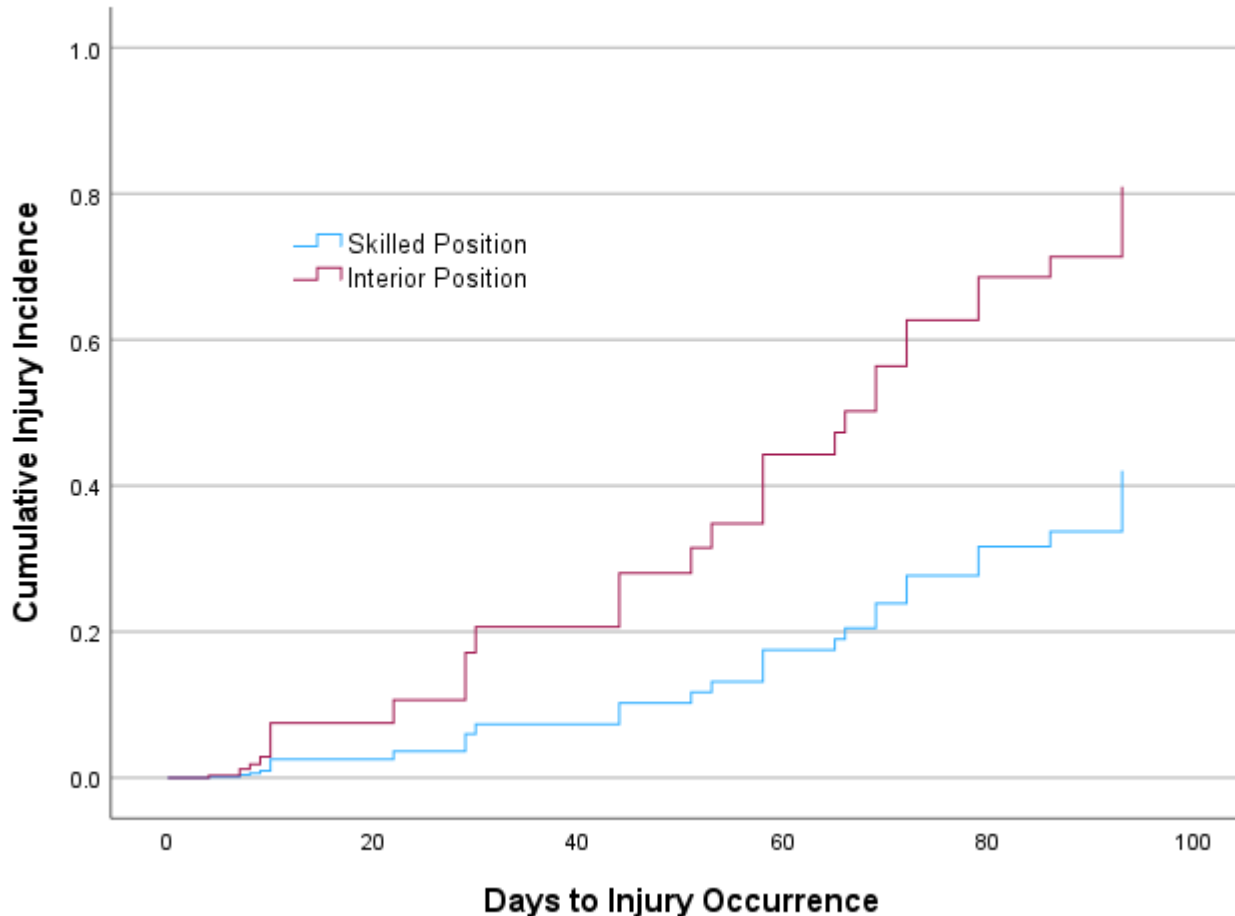
Potential Confounding Factors Excluded from Model\*

Factor	$\chi^2$ (df=1)	2-Sided <i>P</i>
Concussion History (Lifetime)	0.24	.796
Starter Status (Game 1 Depth Chart)	1.00	.427
Previous CLEI (Prior 12-Month Period)	0.03	1.00

\* Univariable Analyses

# Pre-Season through 10<sup>th</sup> Game (13-Game Season): Classification of Injury vs. No Injury

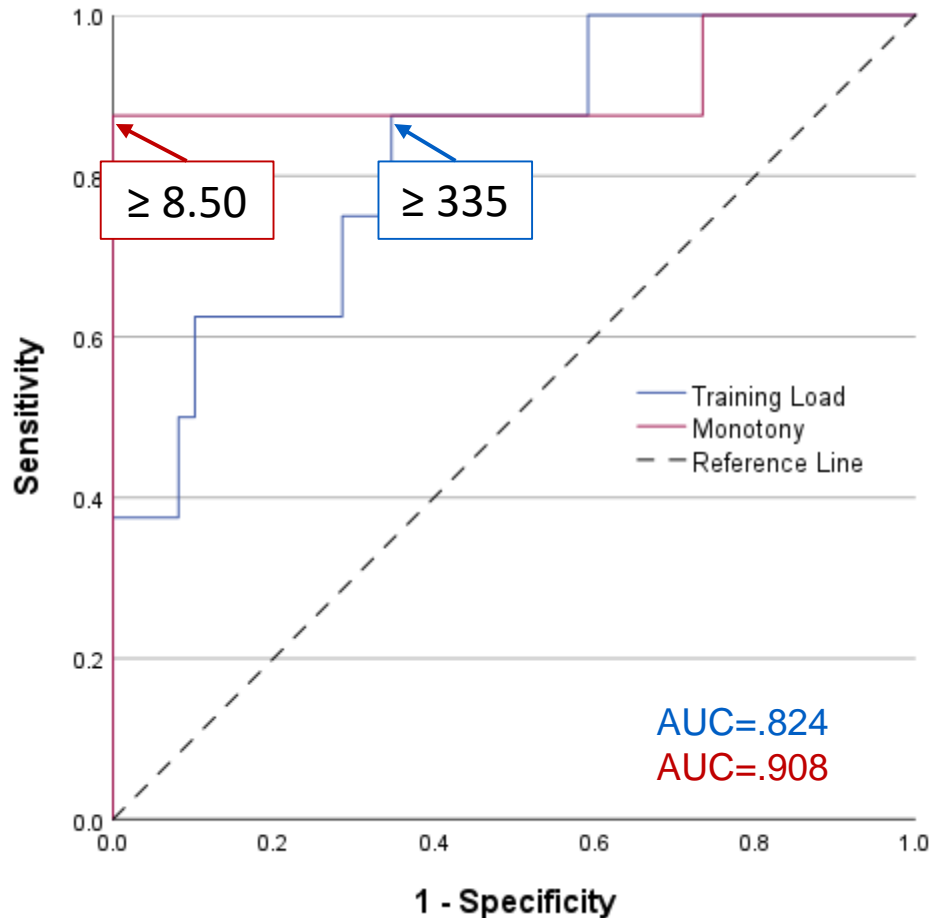
Cox Regression Model of Time to Event  
Combination of Position Category + Training Load + Monotony



Cox Regression Output 3-Factor Prediction Model

	B	Sig.	Exp(B)	95.0% CI for Exp(B)	
				Lower	Upper
Training Load	.025	<.001	1.026	1.011	1.040
Monotony	.269	.020	1.308	1.044	1.639
Position Category	1.112	.007	3.040	1.356	6.817

# Phase 1: Classification of Injury\* vs. No Injury



\* Core or Lower Extremity Sprain or Strain

		Injury		Incidence	
		Yes	No		
Training Load	$\ge 335$	7	17	29%	<b>PPV: 29%</b>
	$< 335$	1	32	3%	<b>NPV: 97%</b>
Total		8	49		

**Sensitivity: 88% Specificity: 65%**

$$\chi^2(1)=7.87$$

2-Sided  $P=.007$

**OR=13.18**

95% CI: 1.50, 116.13

		Injury		Incidence	
		Yes	No		
Monotony	$\ge 8.50$	7	0	100%	<b>PPV: 100%</b>
	$< 8.50$	1	49	2%	<b>NPV: 98%</b>
Total		8	49		

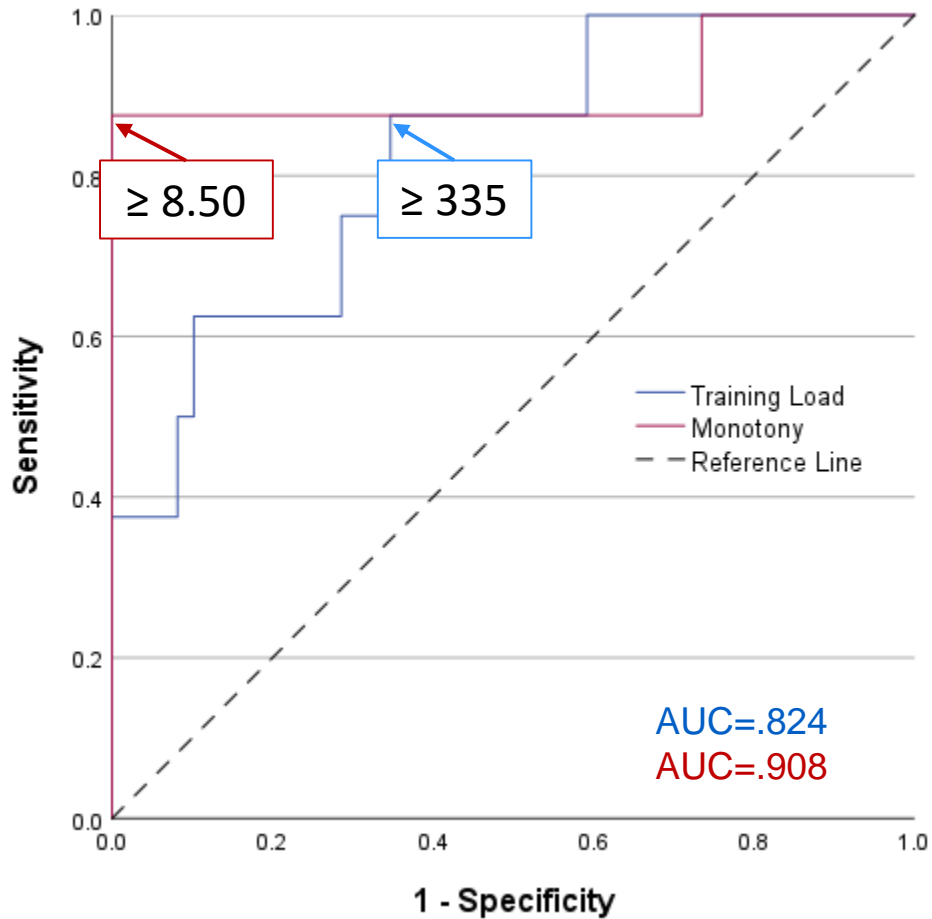
**Sensitivity: 88% Specificity: 100%**

$$\chi^2(1)=48.88$$

2-Sided  $P<.001$

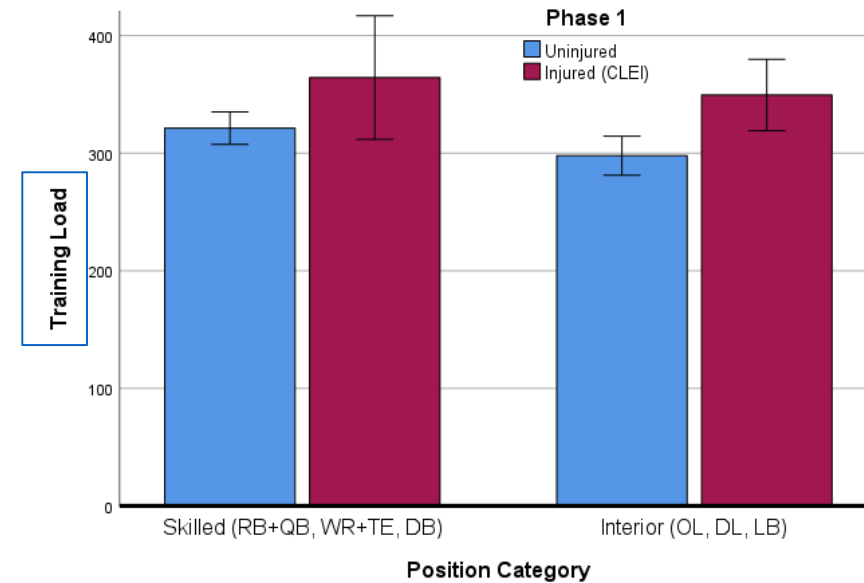
**OR= $\infty$**

# Phase 1: Classification of Injury vs. No Injury

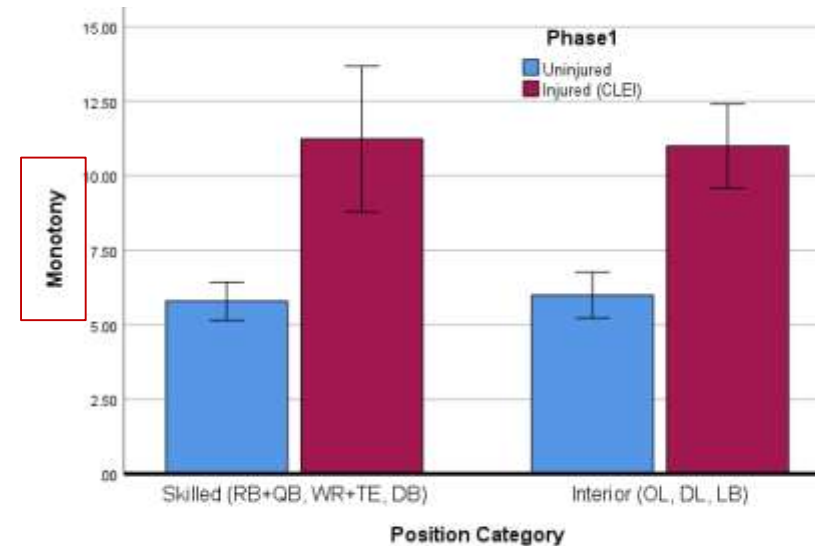


Skilled: 7% Injured (2/31)  
 Interior: 23% Injured\* (6/26)

\* 3 OL & 3 LB

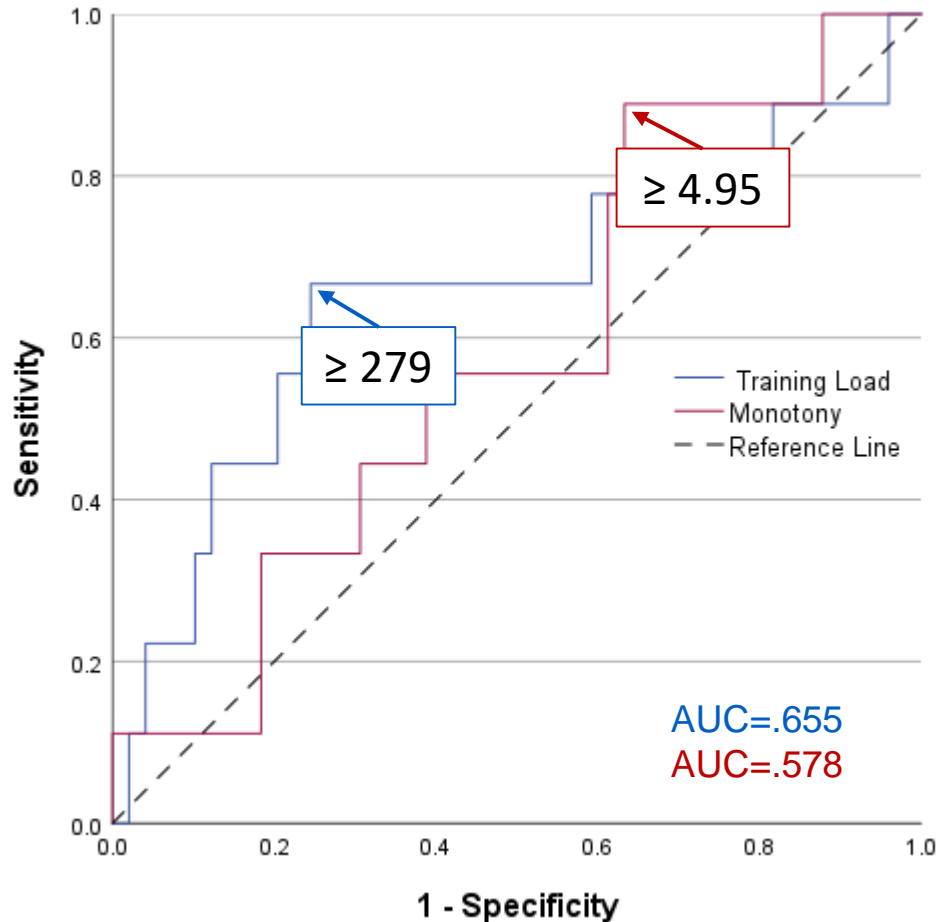


Error bars: 95% CI



Error bars: 95% CI

# Phase 2: Classification of Injury\* vs. No Injury



\* Core or Lower Extremity Sprain or Strain

		Injury		Incidence	
		Yes	No		
Training Load	$\geq 279$	6	12	29%	<b>PPV:29%</b>
	$< 279$	3	37	11%	<b>NPV:89%</b>
Total		9	49		

**Sensitivity: 67% Specificity: 75%**

$$\chi^2(1)=6.32$$

2-Sided  $P= 0.020$

**OR= 6.17**

95% CI: 1.33, 28.51

		Injury		Incidence	
		Yes	No		
Monotony	$\geq 4.95$	8	31	26%	<b>PPV: 26%</b>
	$< 4.95$	1	18	5%	<b>NPV: 95%</b>
Total		9	49		

**Sensitivity: 89% Specificity: 37%**

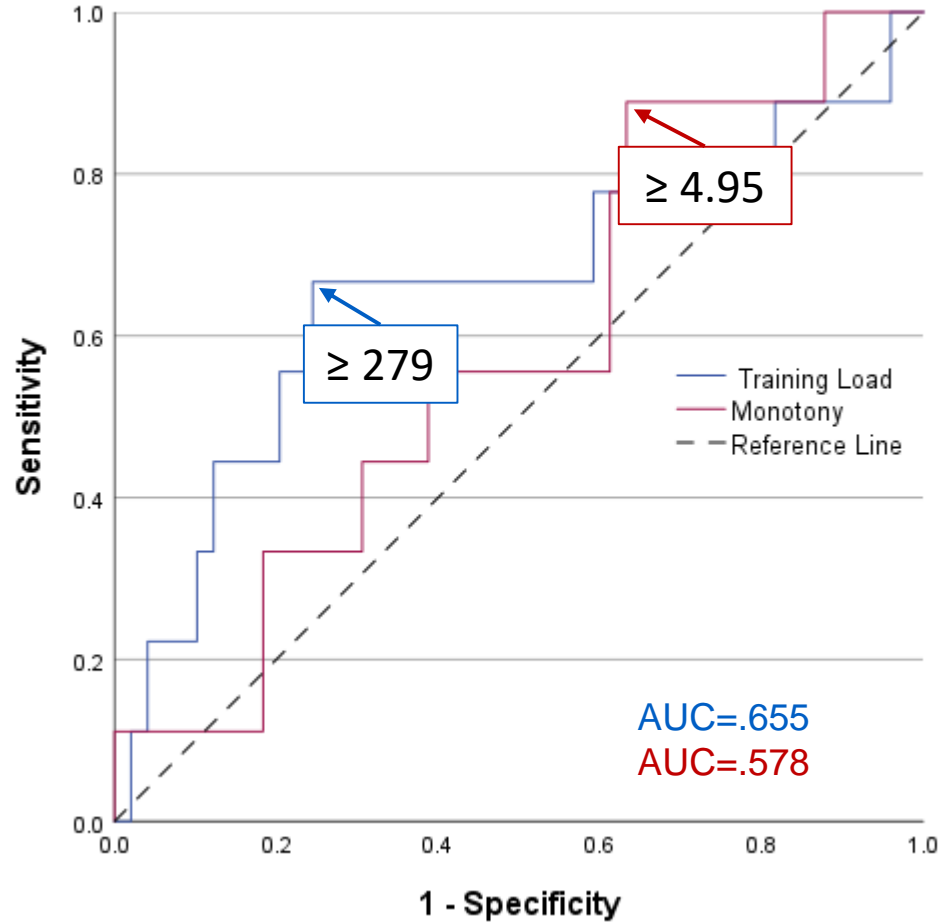
$$\chi^2(1)= 2.27$$

2-Sided  $P= 0.25$

**OR= 4.65**

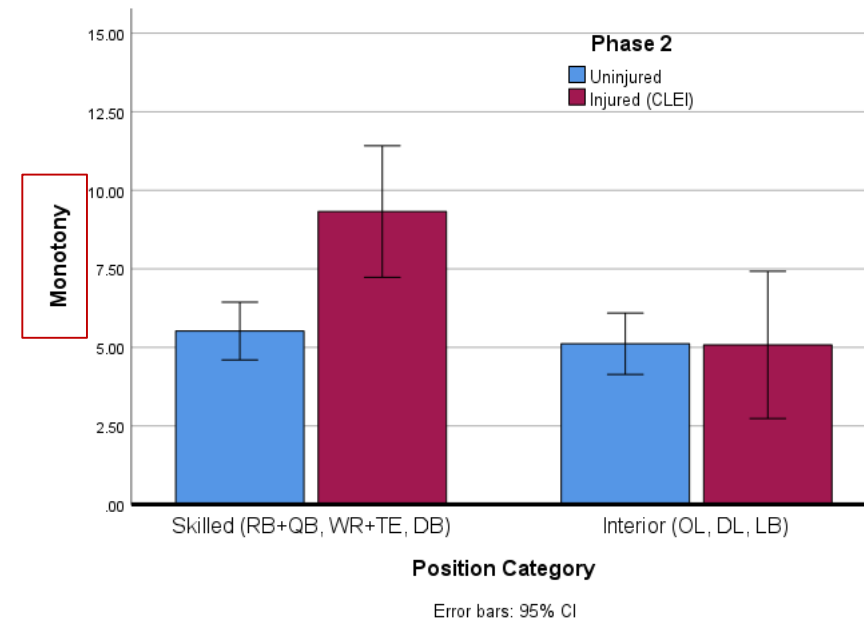
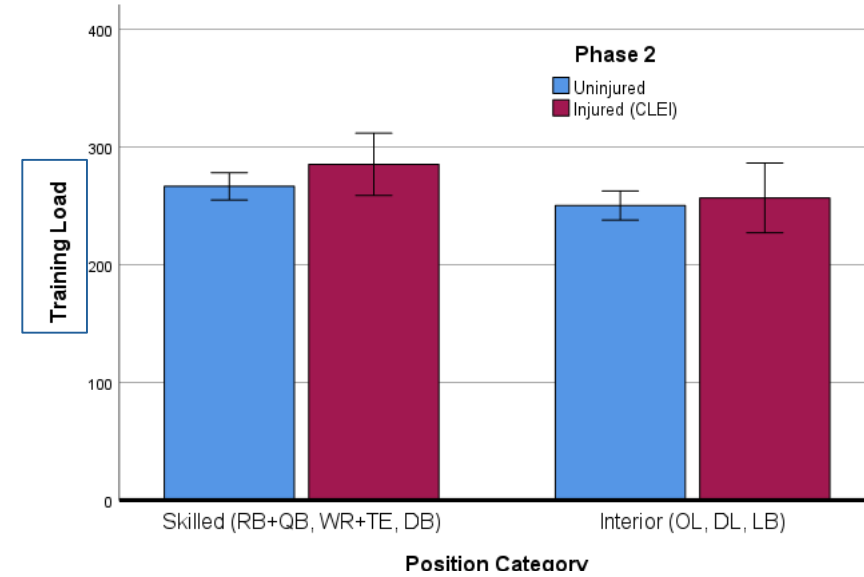
95% CI: 0.53, 40.22

# Phase 2: Classification of Injury\* vs. No Injury



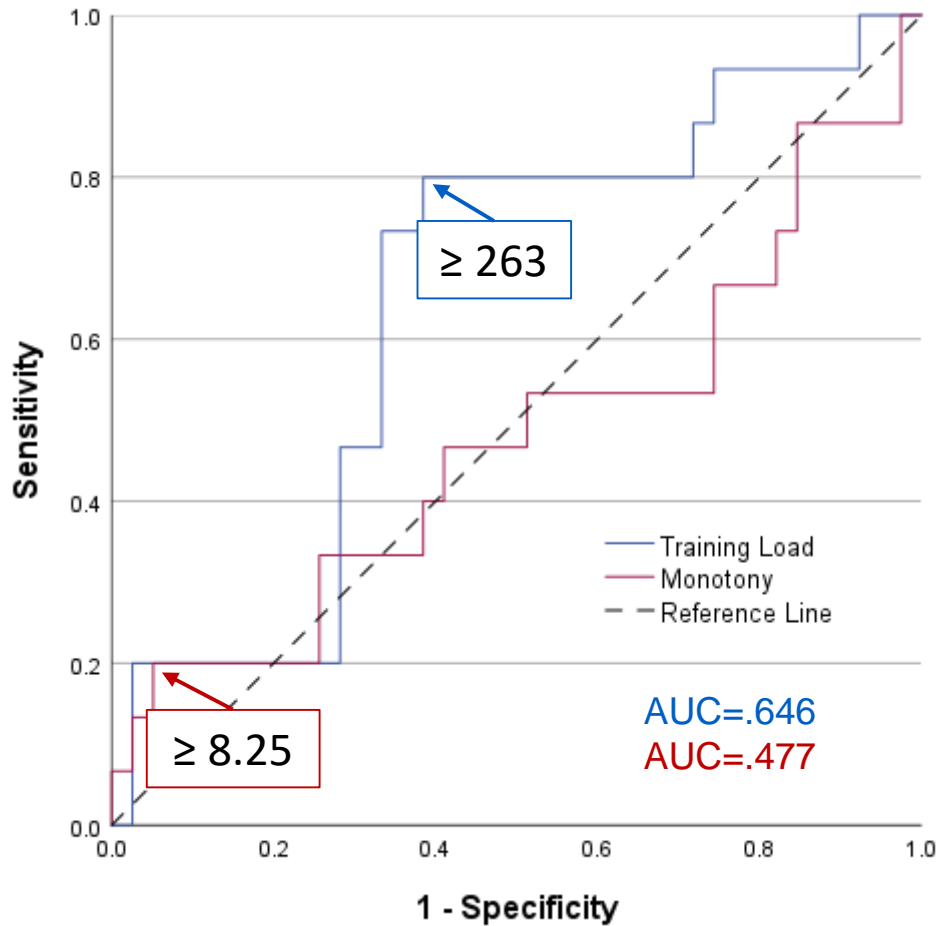
Skilled: 16% Injured\* (5/31)  
 Interior: 15% Injured (4/27)

\* 3 RB+QB & 2 DB





# Phase 3: Classification of Injury\* vs. No Injury



		Injury		Incidence	
		Yes	No		
Training Load	$\ge 263$	12	15	44%	<b>PPV:44%</b>
	$< 263$	3	24	11%	<b>NPV:89%</b>
Total		15	39		

**Sensitivity: 80% Specificity: 62%**

$$\chi^2(1) = 7.48$$

2-Sided  $P = 0.014$

**OR = 6.40**

95% CI: 1.55, 26.48

		Injury		Incidence	
		Yes	No		
Monotony	$\ge 8.25$	3	2	60%	<b>PPV:60%</b>
	$< 8.25$	12	37	24%	<b>NPV:76%</b>
Total		15	39		

**Sensitivity: 20% Specificity: 95%**

$$\chi^2(1) = 2.85$$

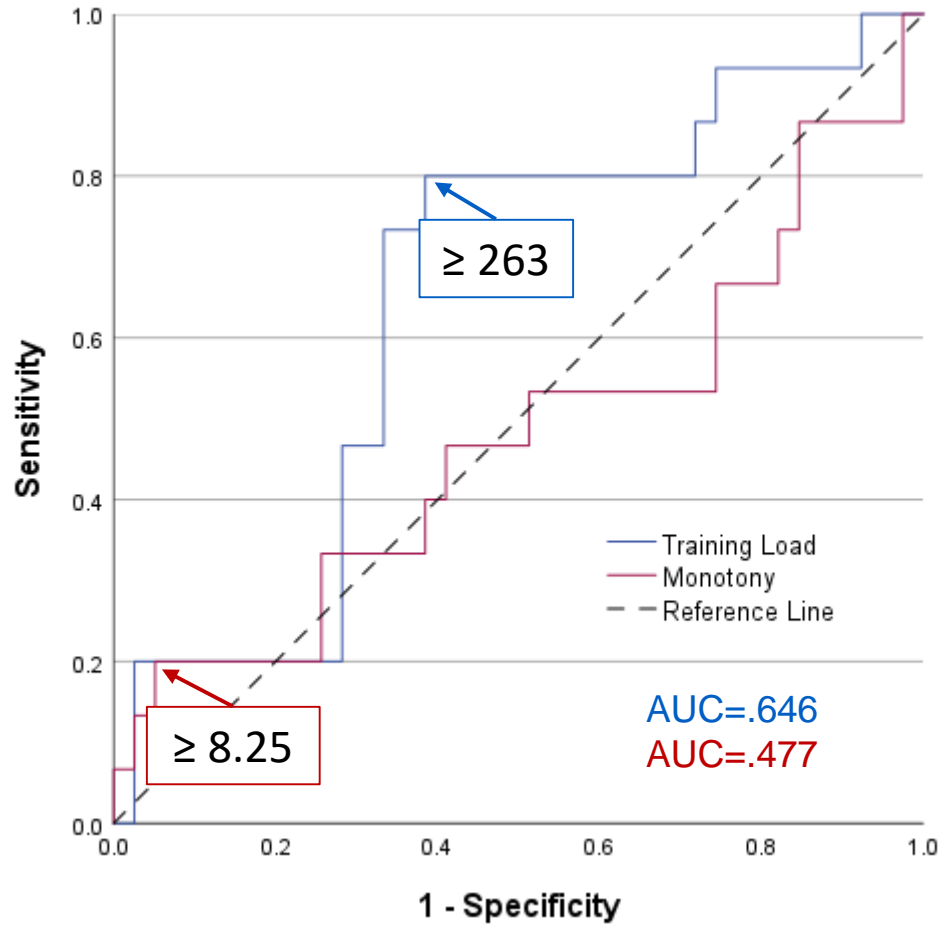
2-Sided  $P = 0.124$

**OR = 4.63**

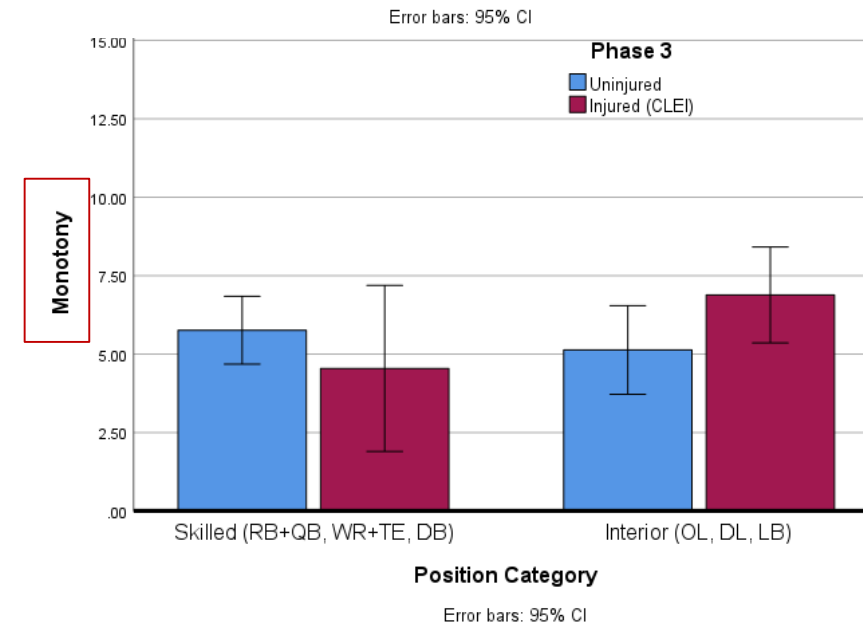
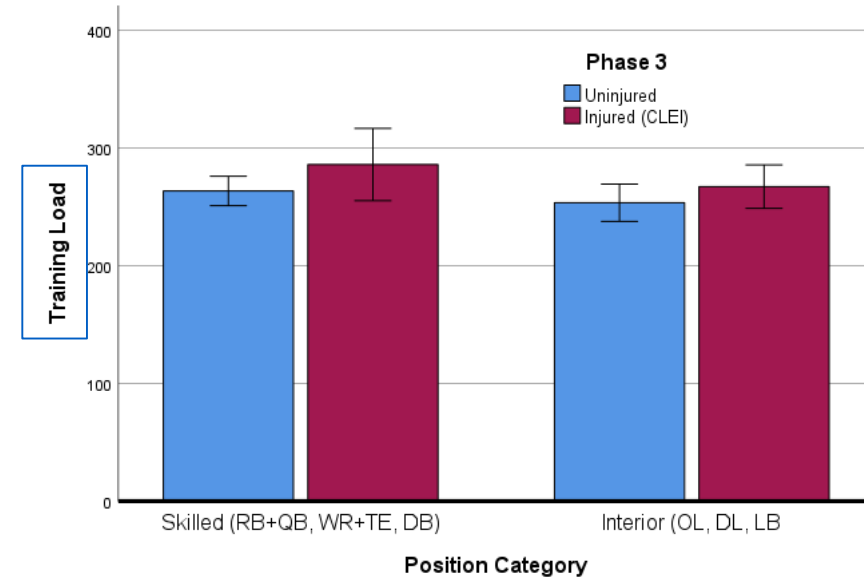
95% CI: 0.69, 31.05

\* Core or Lower Extremity Sprain or Strain

# Phase 3: Classification of Injury vs. No Injury

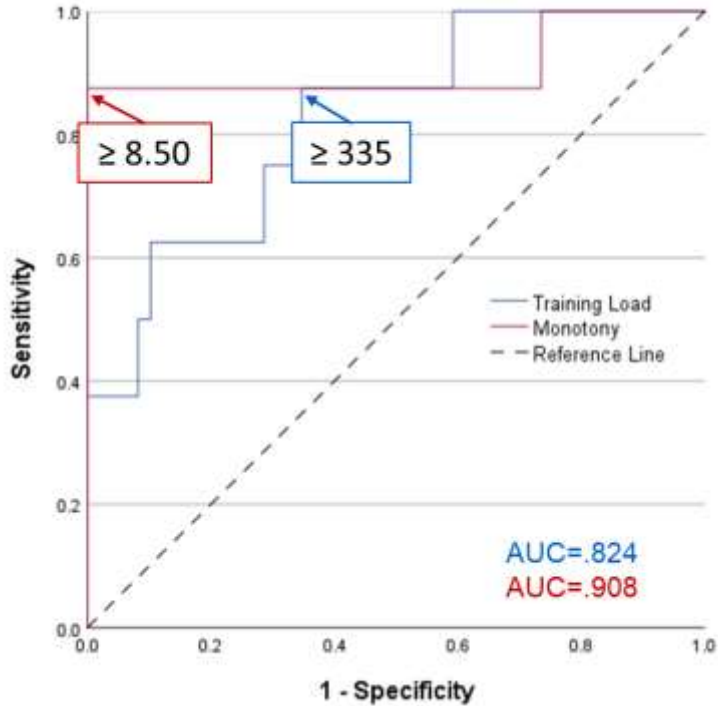


Skilled: 14% Injured (4/28)  
 Interior: 42% Injured\* (11/26)  
 \* 4 OL, 5 DL, & 2 LB

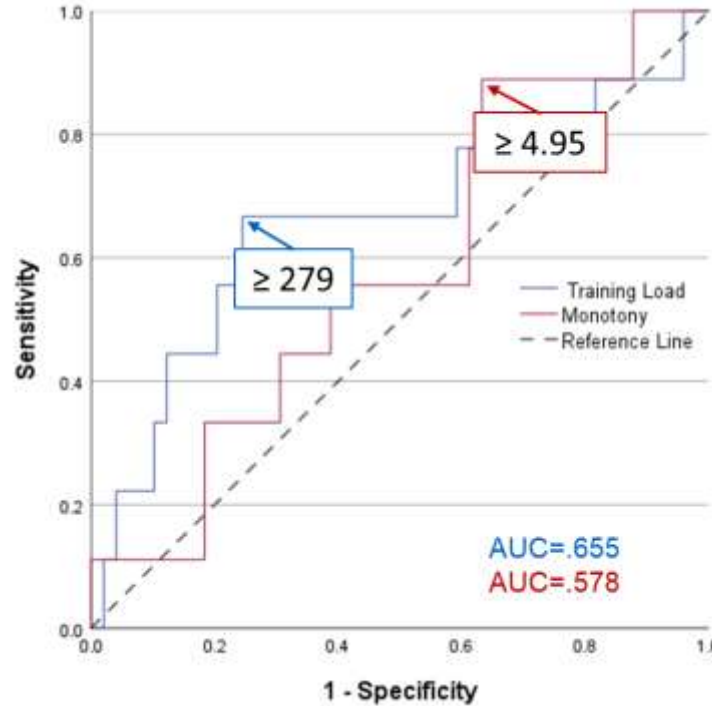


# Phase 1 – Phase 2 – Phase 3\*

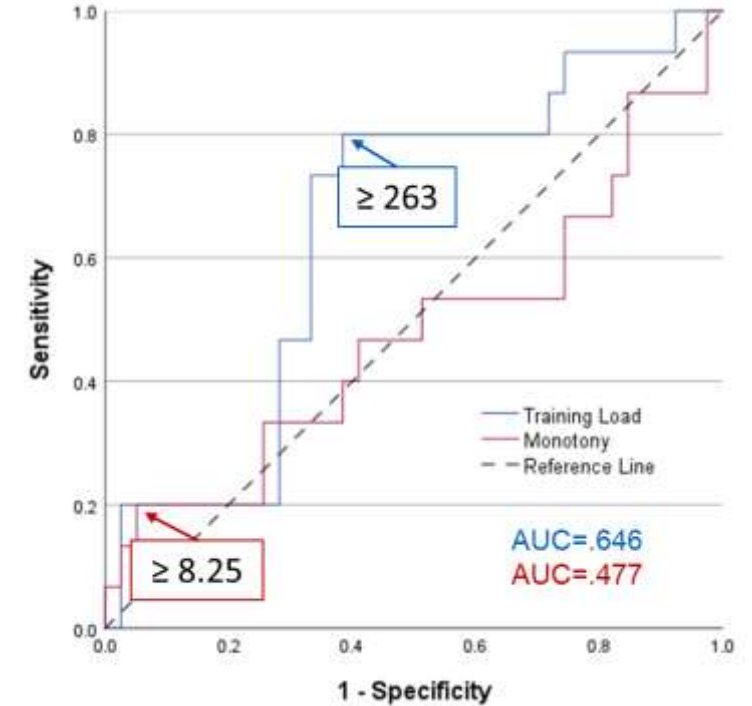
\* Injury sustained subsequent to an injury that occurred during a prior phase included



16 Recording Sessions (2 Scrimmages)  
24 Days  
14% (8/57) Injury Incidence



19 Recording Sessions (5 Games)  
35 Days  
16% (9/58) Injury Incidence

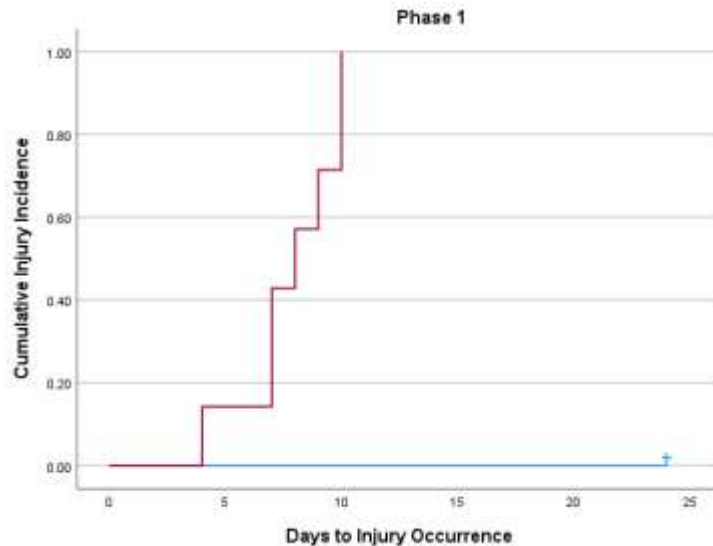


19 Recording Sessions (5 Games)  
35 Days  
28% (15/54) Injury Incidence

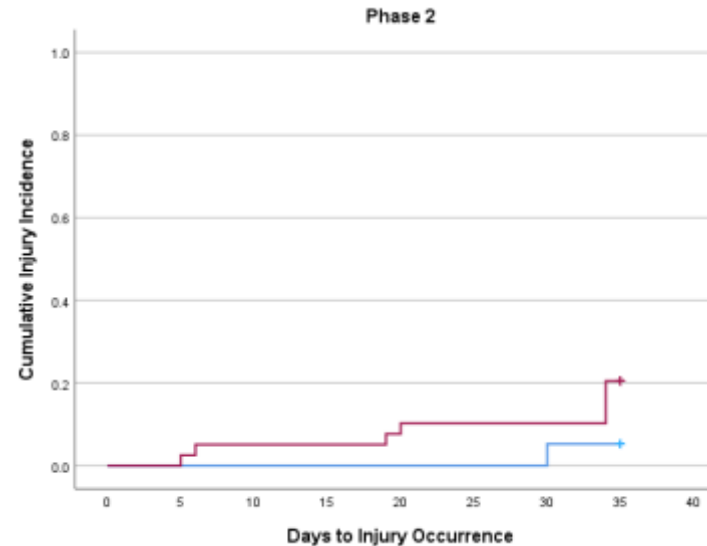
# Monotony: Phase 1 – Phase 2 – Phase 3\*

\* Injury sustained after an injury that occurred during a prior phase included

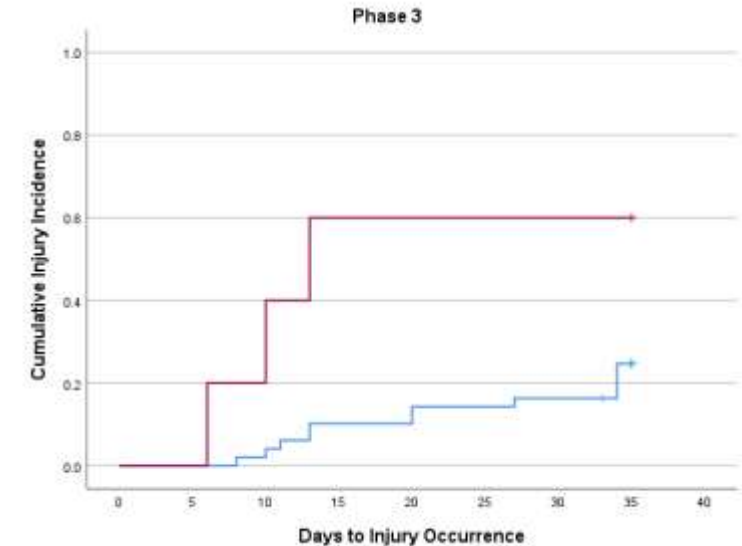
$\geq 8.50$     $< 8.50$



$\geq 4.95$     $< 4.95$



$\geq 8.25$     $< 8.25$



16 Recording Sessions (2 Scrimmages)  
24 Days  
14% (8/57) Injury Incidence

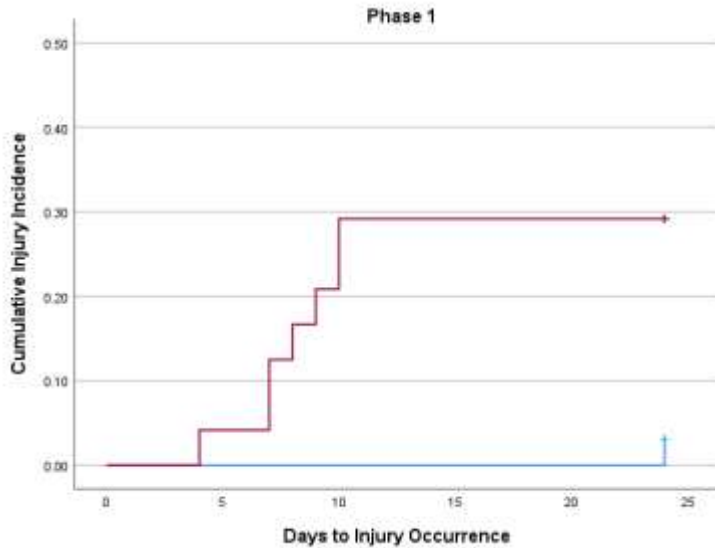
19 Recording Sessions (5 Games)  
35 Days  
16% (9/58) Injury Incidence

19 Recording Sessions (5 Games)  
35 Days  
28% (15/54) Injury Incidence

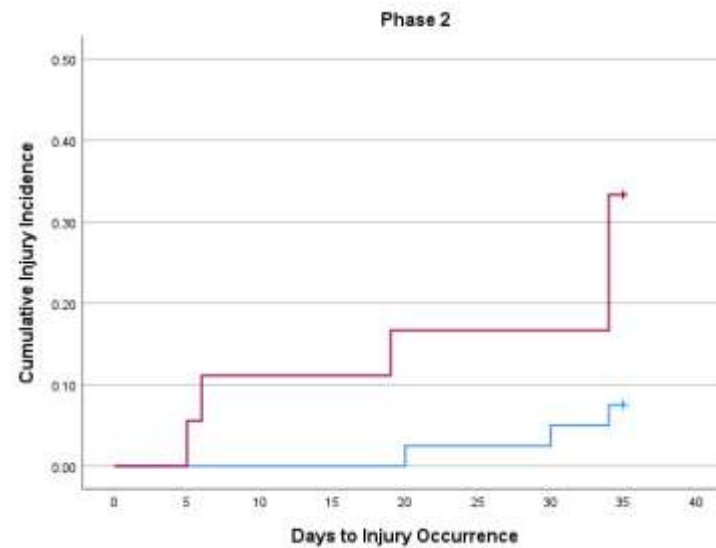
# Training Load: Phase 1 – Phase 2 – Phase 3\*

\* Injury sustained after an injury that occurred during a prior phase included

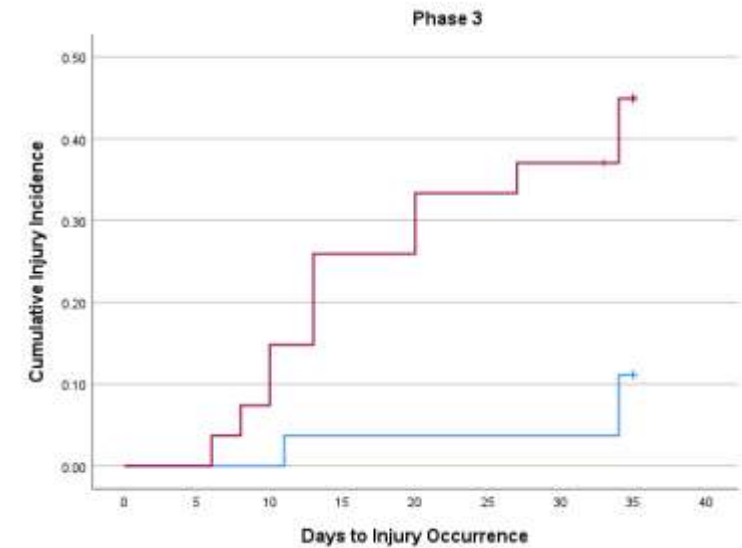
$\geq 335$   $< 335$



$\geq 279$   $< 279$



$\geq 263$   $< 263$



16 Recording Sessions (2 Scrimmages)  
24 Days  
14% (8/57) Injury Incidence

19 Recording Sessions (5 Games)  
35 Days  
16% (9/58) Injury Incidence

19 Recording Sessions (5 Games)  
35 Days  
28% (15/54) Injury Incidence

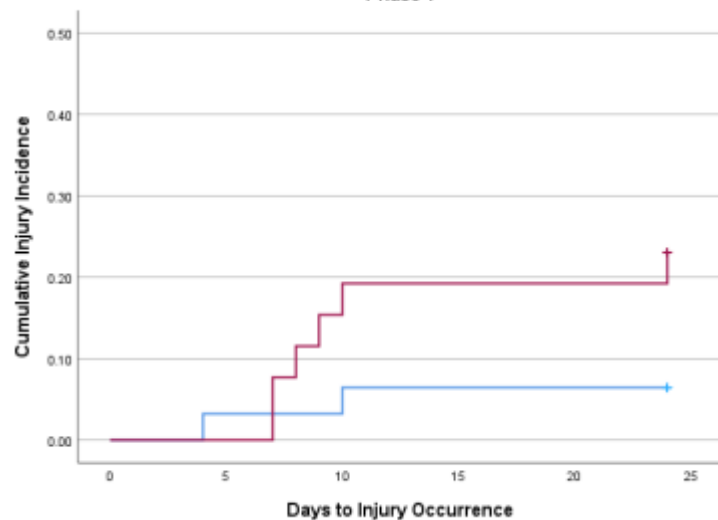
# Position Category: Phase 1 – Phase 2 – Phase

## 3\*

\* Injury sustained after an injury that occurred during a prior phase included

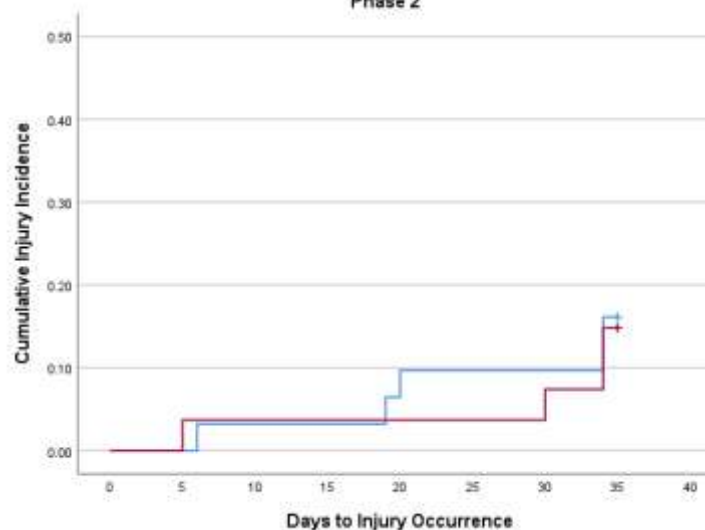
Interior Skilled

Phase 1



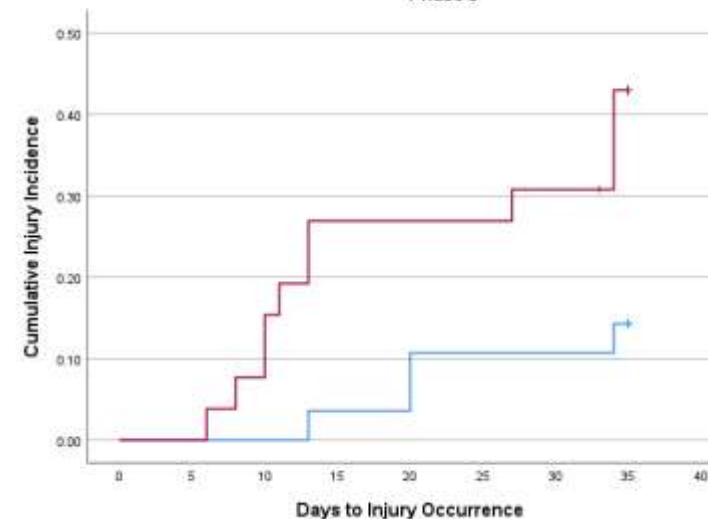
Interior Skilled

Phase 2



Interior Skilled

Phase 3



16 Recording Sessions (2 Scrimmages)  
24 Days  
14% (8/57) Injury Incidence

19 Recording Sessions (5 Games)  
35 Days  
16% (9/58) Injury Incidence

19 Recording Sessions (5 Games)  
35 Days  
28% (15/54) Injury Incidence

# Discussion

- Risk status found to change over time, which appears to alter injury incidence<sup>8,9</sup>
- High load could be an indicator of superior performance capabilities<sup>10</sup>
- Limitation: Possible effects of upper extremity injury or concussion on IMU data
- Collisions required in practice sessions to develop skill (blocking, tackling)<sup>2</sup>
- Accumulation of training load appears to be associated with increased injury risk<sup>11</sup>
  - Neuromuscular fatigue and/or microstructural tissue damage from overtraining

# Clinical Relevance

- Despite widespread use of IMUs, practical application of the data is lacking<sup>12</sup>
  - Training Load and Monotony measures may be beneficial for individualized risk mitigation
  - IMU data combined with consideration of Position Category and Phase may better estimate injury risk
  - High Training Load could be an indicator of superior collision sport performance capabilities
- Low Monotony may compensate for high Training Load to lower risk level
  - Enhanced movement variability (increased Coefficient of Variation) may better distribute loads
  - Previously reported cut point for elevated college football injury risk:  $\text{CoV} \leq 0.15$  ( $\text{Monotony} \geq 6.67$ )<sup>11</sup>
  - Cut points ranged from  $\geq 8.50$  ( $\text{CoV} \leq 0.12$ ) to  $\geq 4.95$  ( $\text{CoV} \leq 0.20$ ) across 3 Phases



# References

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