Association of Perceptual-Response Training with Injury Incidence among Secondary School Athletes

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Introduction

- Performance and injury avoidance rely on speed and accuracy[1]
  - Detection and remediation of perceptual-motor deficits essential
- Training and injury prevention remain focused on physical factors[2]
  - Potential for training-induced neural adaptation is promising
- Virtual reality (VR) metrics may reflect neural processing efficiency[3]
  - Response time viewed as duration of perceptual-cognitive processing

Introduction

- Concussion history linked to subsequent musculoskeletal injury[4]
  - Diffuse axon injury may disrupt brain functional connectivity
  - Impaired neural processing efficiency may elevate injury risk
  - Asymptomatic post-concussion effects can persist for months or years
- Prediction models typically quantify risk without any intervention[5]
  - Dynamic models assess change in risk status over surveillance period
  - Inferring causation from observational data known to be problematic
  - Analysis of potential confounding factors essential

Introduction

- VR perceptual-response training may yield valuable adaptations[6]
  - Perceptual detection and interpretation of visual stimuli
  - Cognitive conflict resolution and decision making
  - Programming, execution, and adjustments of motor responses
- Potential benefits of improved integration of brain processes:[6]
  - Sport-related injury avoidance
  - Sport performance capabilities

Study Purpose

To assess the potential value of virtual reality for assessment and training of perceptual-response efficiency, including the analysis of a possible relationship to injury occurrences among trained and untrained female high school soccer athletes.

Methods

- VR Perceptual-Response Tests*
  - Baseline (Pre-participation) Assessment
    - Assignment based on low vs high performance
    - N=50 (Training n=25 & Control n=25)
  - Follow-up (Post-Training) Assessment
    - 8 cases lost between baseline and follow-up
    - N=42 (Training n=19 & Control n=23)
- Injury Documentation
  - Core or lower extremity injury (CLEI)
    - Acute strain or sprain that interrupted practice or game participation and received treatment
  - Concussion

- Baseline n=50
  - Age: 15.2 $\pm$ 1.2 years
  - Height: 164.6 $\pm$ 5.6 cm
  - Weight: 56.9 $\pm$ 6.7 kg

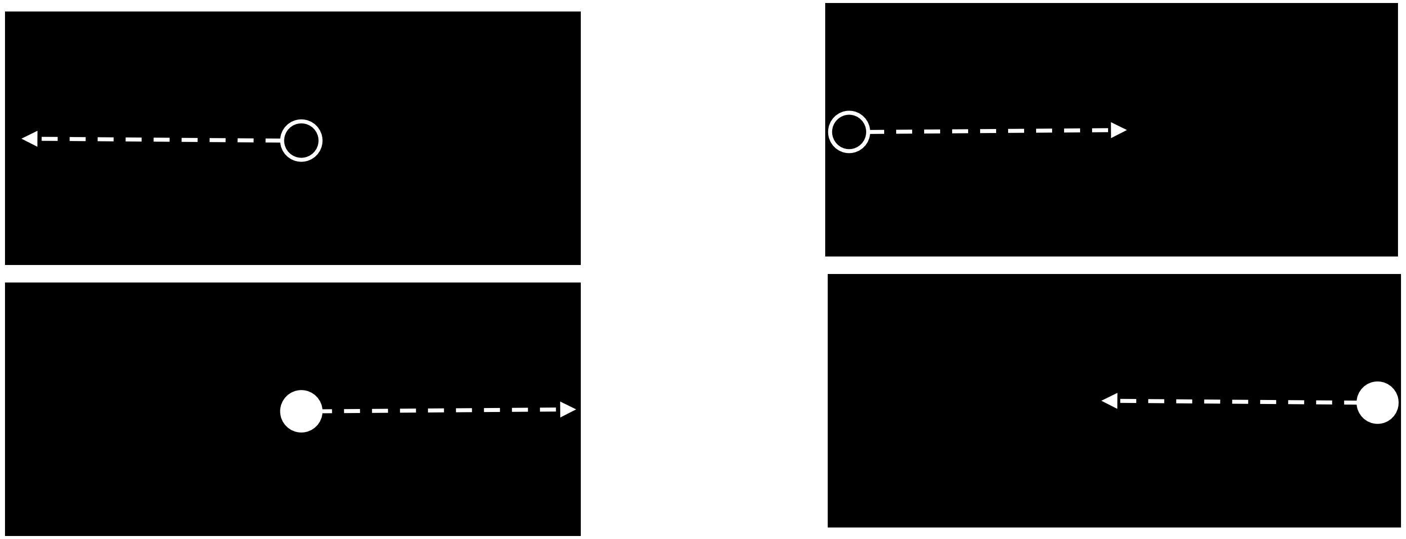
- Follow-Up n=42
  - Age: 15.1 $\pm$ 1.2 years
  - Height: 165.1 $\pm$ 5.6 cm
  - Weight: 57.6 $\pm$ 7.0 kg

* 3 Private HS Programs

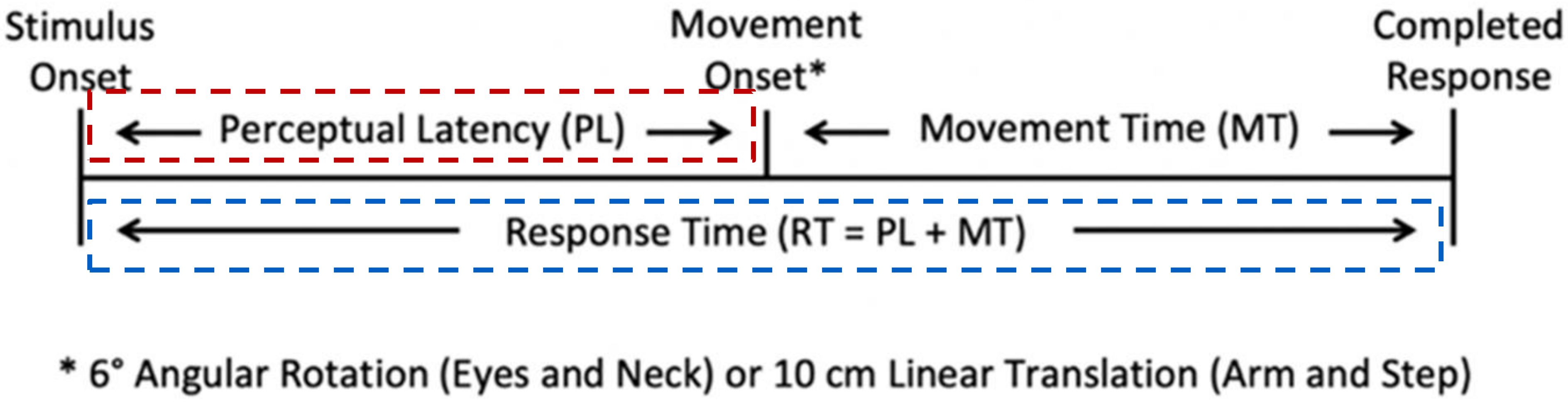
Exclusionary Criterion: Current Injury

Baseline and Follow-Up Assessments

- Visual stimuli (white circles or white rings) move in right or left directions across display
- Instruction: “Move in same direction as circles; Move in opposite direction of rings”
- Contact virtual response targets with either right and left hand controllers
- Auditory tone and hand controller vibration upon virtual target contact
- 40 trials (20 congruent circles; 20 incongruent rings)



Operational Definitions



Rate Correct per Second = # Correct Responses / Sum of **<u>Response Time</u>** for 40 Trials

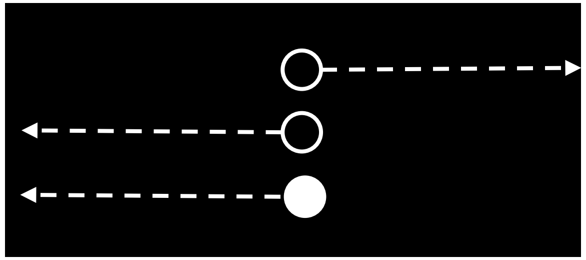
Arm **<u>Perceptual Latency</u>** Intra-Individual Variability = Standard Deviation of 40 Trials

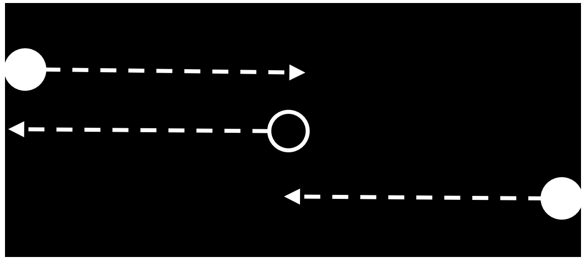
Methods: VR Metrics

- Speed-Accuracy Composite Metric: Rate Correct Score (RCS)
  - Training vs. Control condition based on Arm RCS-RT median
  - < 0.800 assigned to training program
- 40-Trial Mean and Trial-to-Trial Intra-Individual Variability (IIV)
  - Perceptual Latency (PL): Neck, Arm, Step
  - Response Time (RT): Neck, Arm, Step

VR Perceptual Response Training

- Training program: 2 sets of 20 repetitions per session
  - Horizontally moving circles: circles (congruent) or rings (incongruent)
  - Peripheral response targets located outside field of view
- Progression: ≥ 90% correct responses (18/20)
  - Levels 1-6
    - Initial stimulus location
    - Addition of visual distractors
    - Movement speed



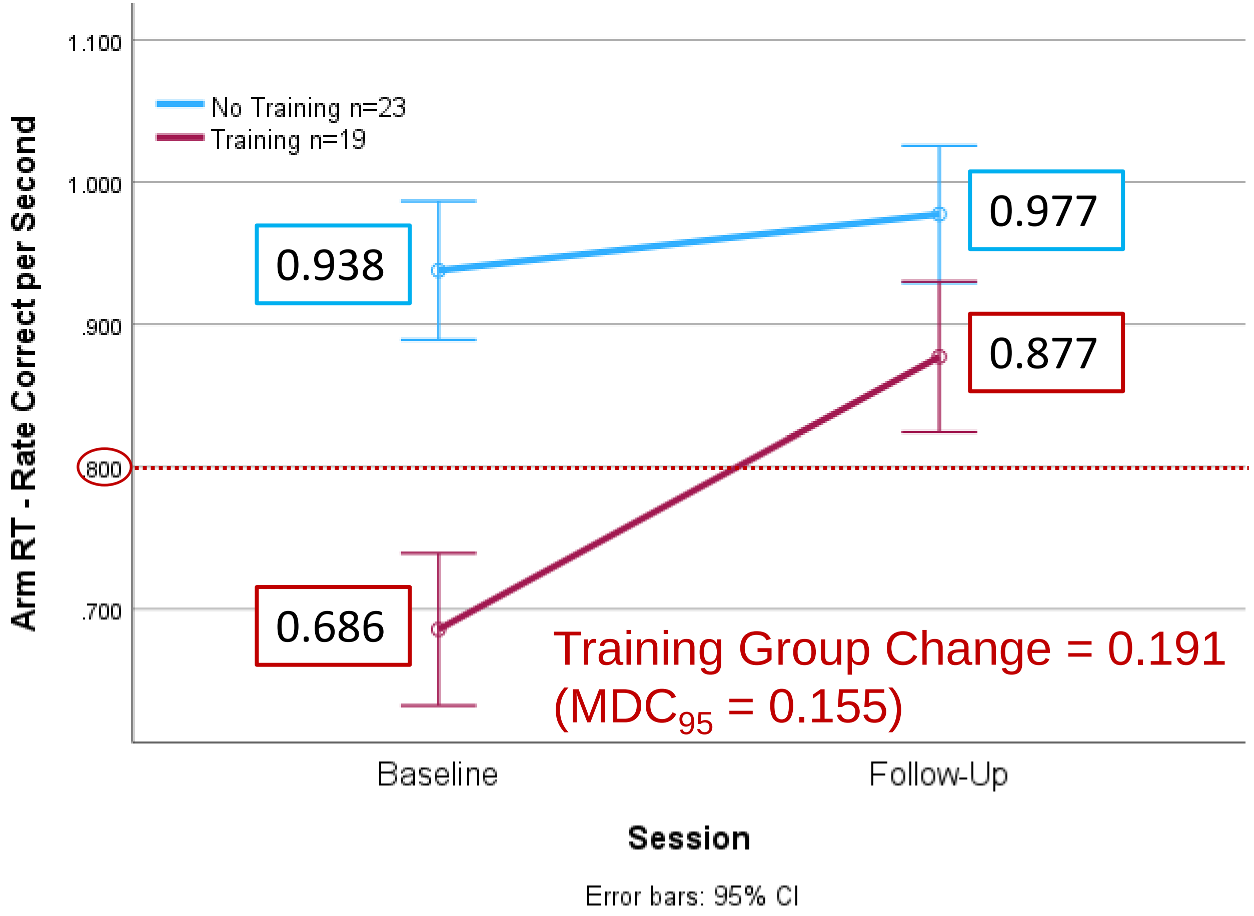


- Training program availability
  - 21-52 days after first practice (31-day period)
  - ≥ 3 training sessions completed by 19 players
    - Median number of sessions = 5 (Range: 3 – 13)
    - Median difficulty level achieved = 5 (Range: 3 – 6)

High School Girls' Soccer VR Training Effect

Rate Correct per Second (RCS) of Total Response Time*

Group Assignments Based on RCS Median (≥ 0.800 vs. < 0.800)



Group	Pre	Post
No Training (n=23)	0.938	0.977
Training (n=19)	0.686	0.877

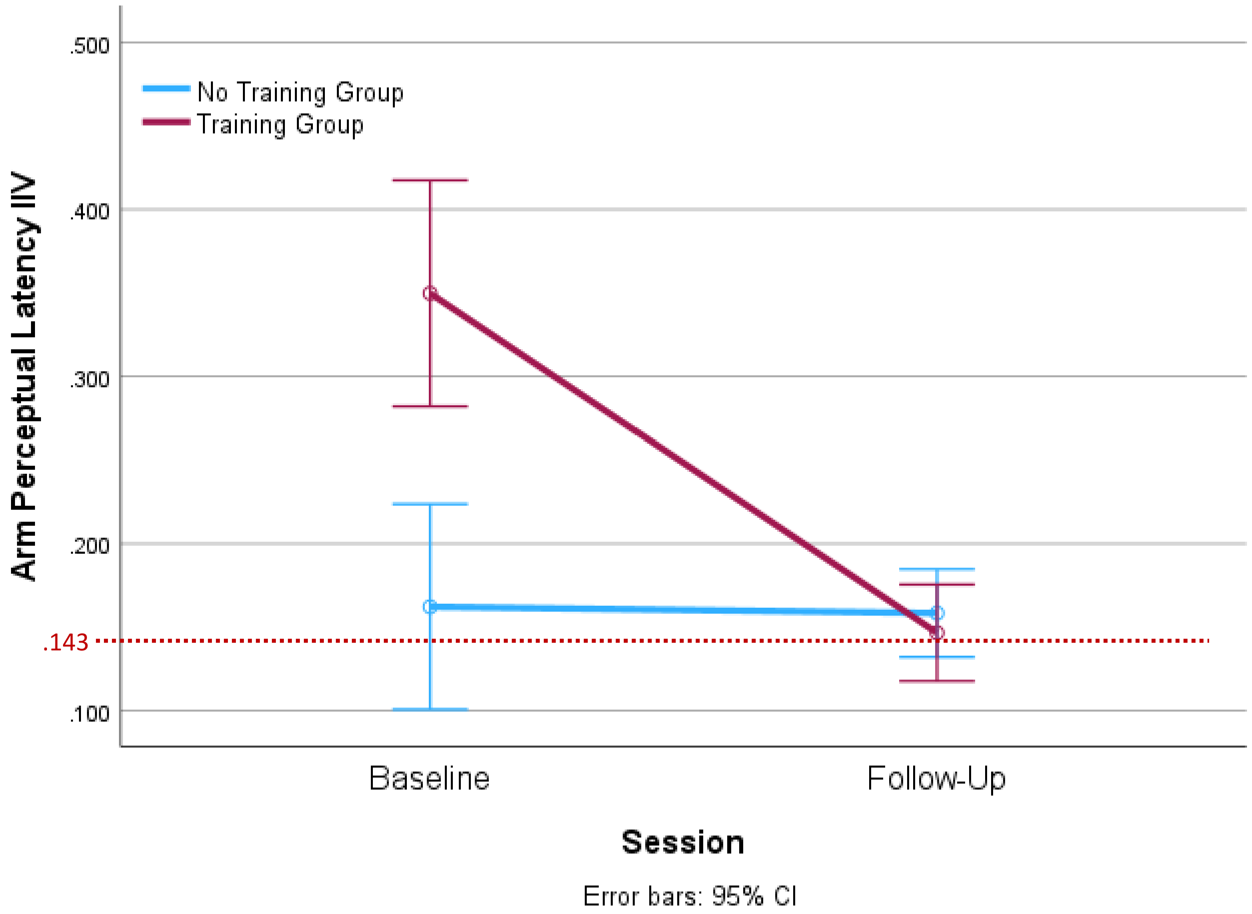
Pre-Training Cut Point: Median = 0.800

Effect	*P*	η_p^2
Group X Session	>.001	.422
Session Difference	>.001	.628
Group Difference	>.001	.420

Number Correct of 40 Trials / Sum of 40 RT Values

High School Girls' Soccer VR Training Effect

Arm Perceptual Latency Intra-Individual Variability



Group	Pre	Post
Training (n=19)	0.350	0.147
No Training (n=23)	0.162	0.158

Effect	*P*	η_p^2
Group X Session	<.001	.338
Session Difference	<.001	.355
Group Difference	.002	.210

Injury Documentation

Injury Occurrences:

Concussion: 4

Ankle: 2

Low Back: 2

Knee: 1

Hip/Groin: 1

Total: 10*

* 2 players sustained both Concussion and CLEI

Surveillance:

Phase 1: 1st Practice to Follow-Up

3 Concussion + 2 CLEI

Phase 2: Follow-Up to Season End

1 Concussion + 4 CLEI

Period (Days)	Median	Range
BL – First Practice	26	25-26
Phase 1: BL – Injury	42	33-85
First Practice – FU	57	56-69
Phase 2: FU – Injury	27	6-34
First Practice – Season End	102	88-102
Training End – Season End	43	36-50

BL: Baseline FU: Follow-Up

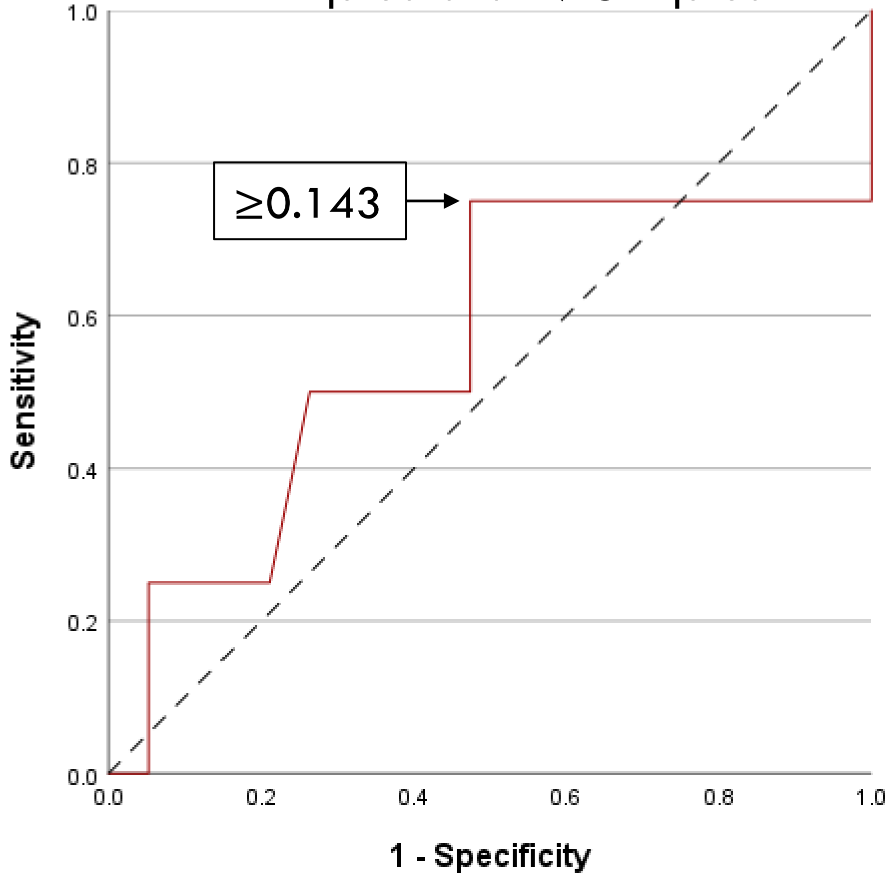
Arm Perceptual Latency Intra-Individual Variability

Injury versus No Injury (Concussion or Core/LE Injury)

Phase 1: 1st Practice to Follow-Up VR Testing

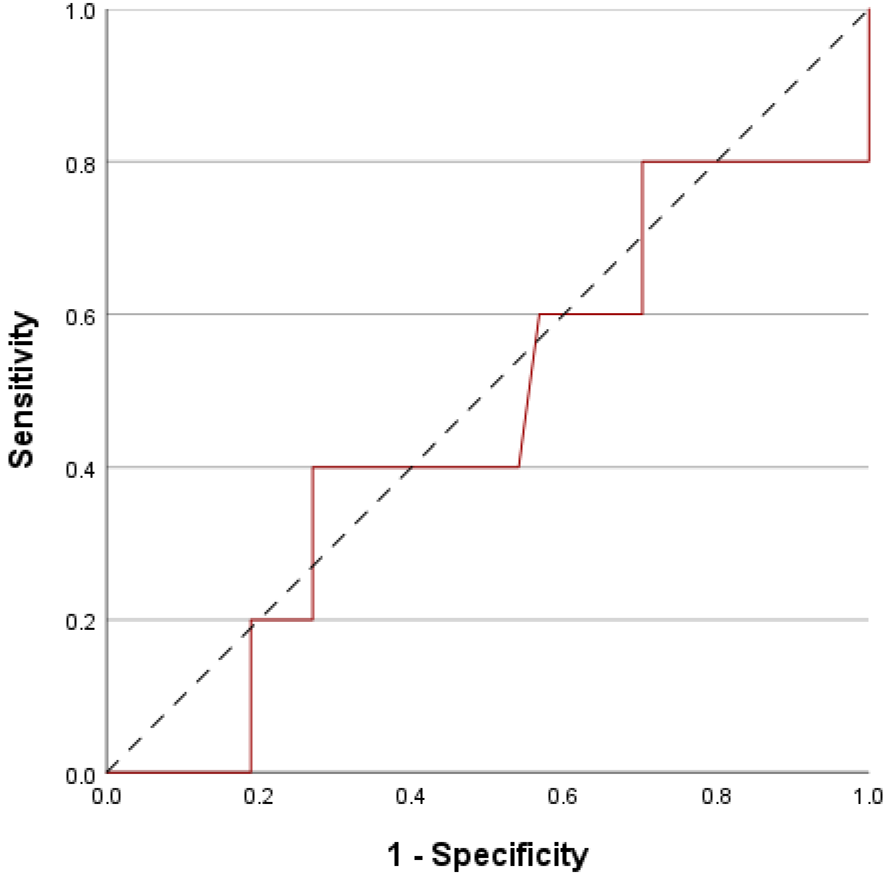
No Training (n=23)

4 Injured and 19 Uninjured



Training + No Training (n=42)

5 Injured and 37 Uninjured



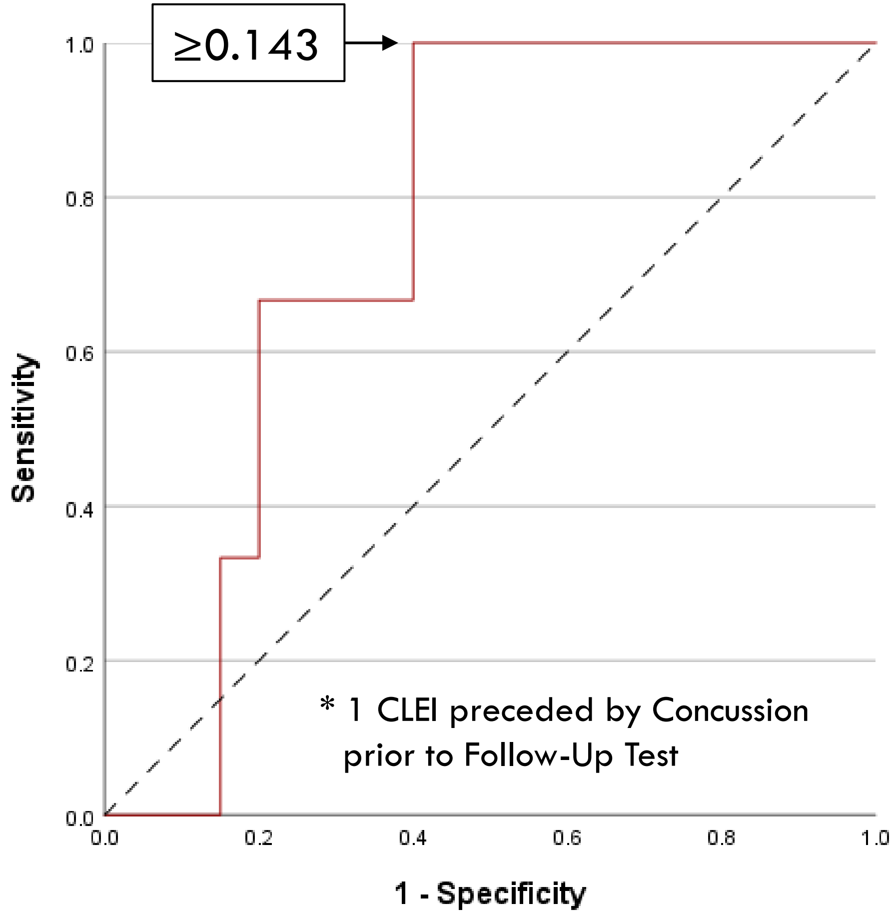
Arm Perceptual Latency Intra-Individual Variability

Injury versus No Injury (Concussion or Core/LE Injury)

Phase 2: Follow-Up VR Testing to Season End

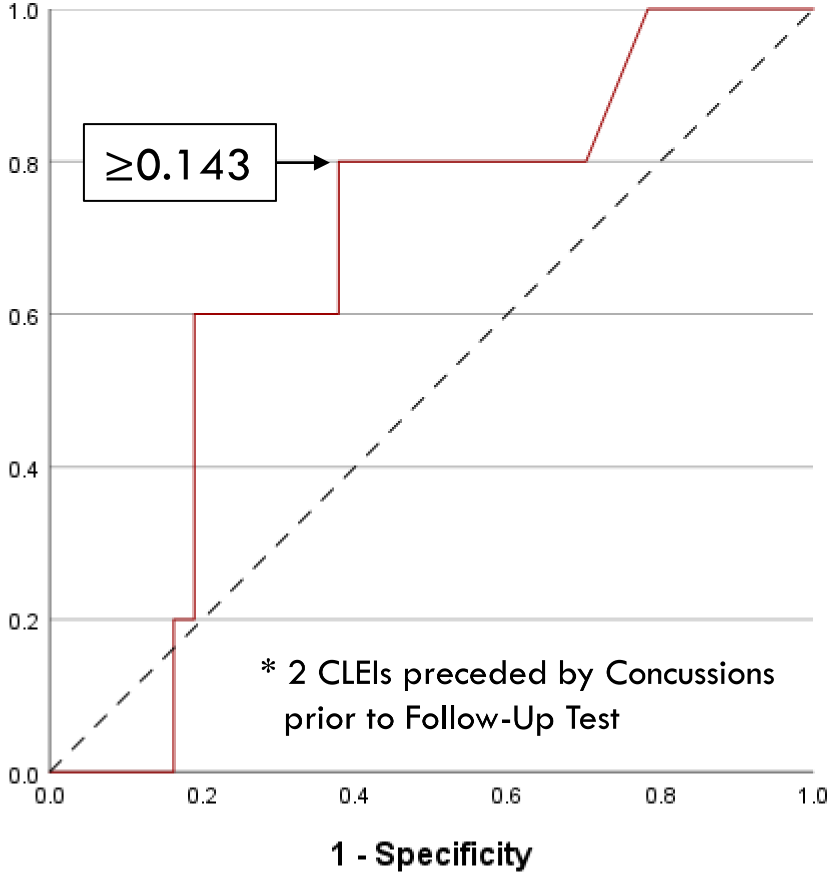
No Training (n=23)

3 Injured* and 20 Uninjured



Training + No Training (n=42)

5 Injured* and 37 Uninjured

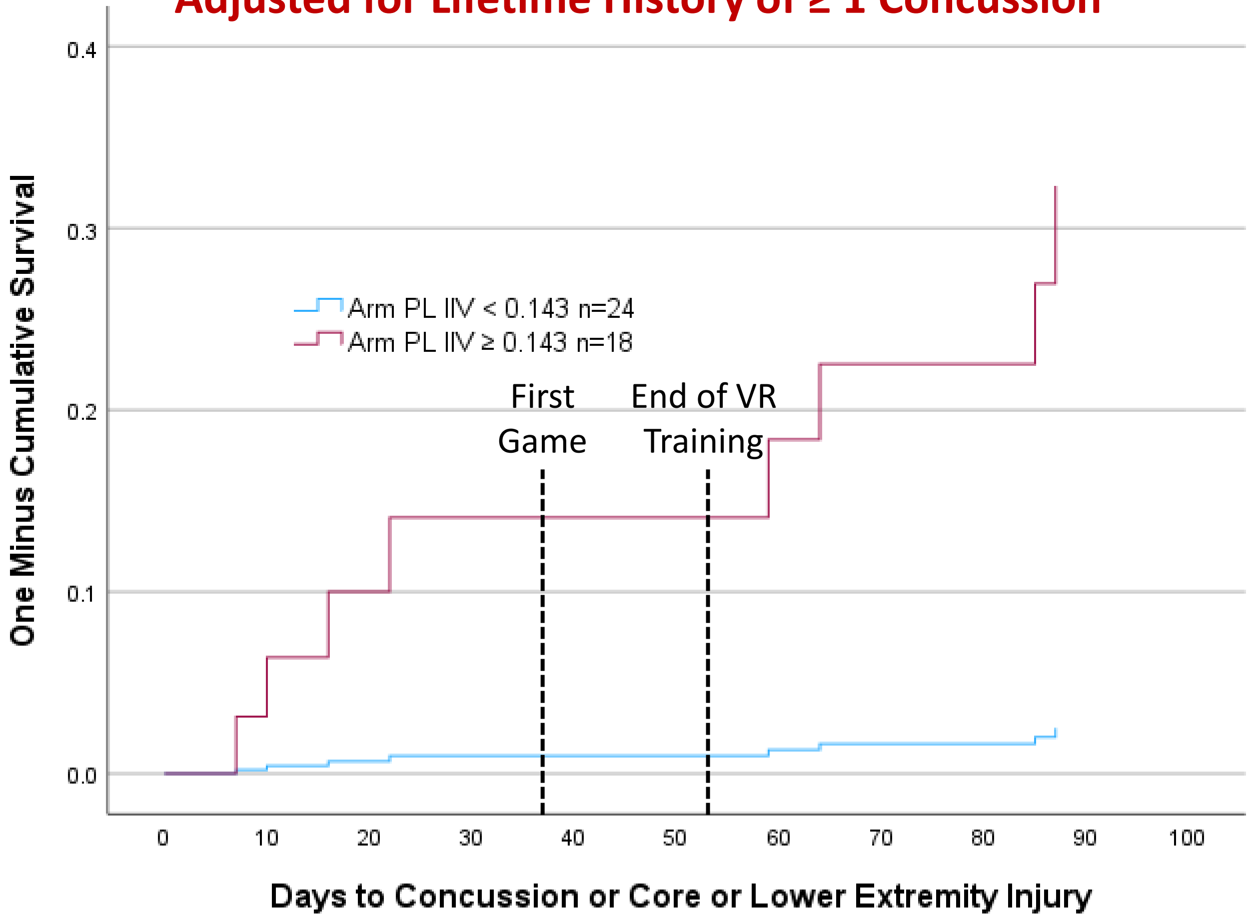


High School Girls' Soccer VR Training Effect

Arm Perceptual Latency Intra-Individual Variability (≥ 0.143 versus < 0.143)

Cox Regression 2-Factor Prediction Model for Injury Hazard

Adjusted for Lifetime History of ≥ 1 Concussion



Univariable Cox Regression Analyses

Binary Classification	Cut Point	*P*	Hazard Ratio (95% CI)
High Game Exposure	≥ 19	.137	3.02 (0.72, 12.65)
History of CLEI Prior 12 Mo	Yes/No	.079	4.36 (0.88, 21.62)
Lifetime History of Concussion	Yes/No	.032	5.54 (1.12, 27.51)
Arm Perceptual Latency IIV	≥ 0.143	.031	10.09 (1.24, 82.08)

Multivariable Backward-Stepwise Cox Regression*

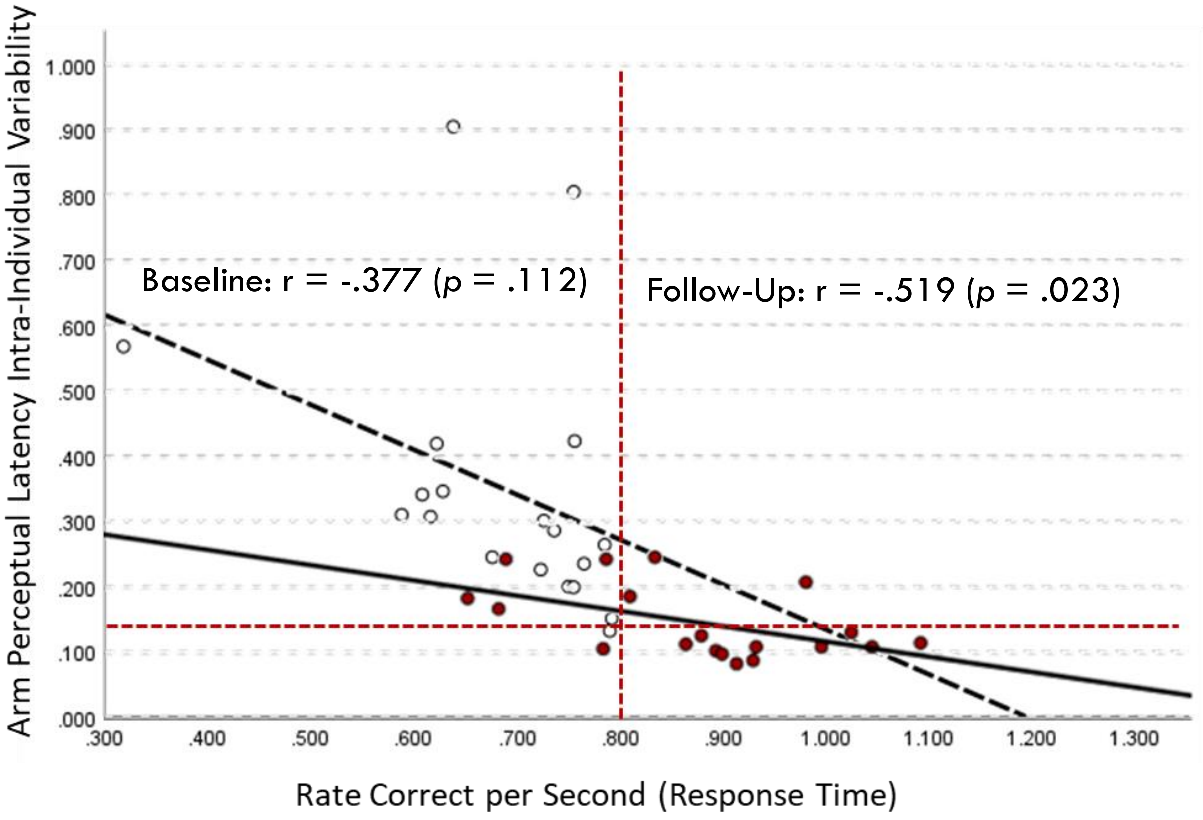
2-Factor Model $\chi^2(2)$=15.55; *P*<.001

Binary Classification	Cut Point	*P*	Adj. Hazard Ratio (95% CI)
Lifetime History of Concussion	Yes/No	.008	8.84 (1.74, 44.77)
Arm Perceptual Latency IIV	≥ 0.143	.011	15.43 (1.86, 127.99)

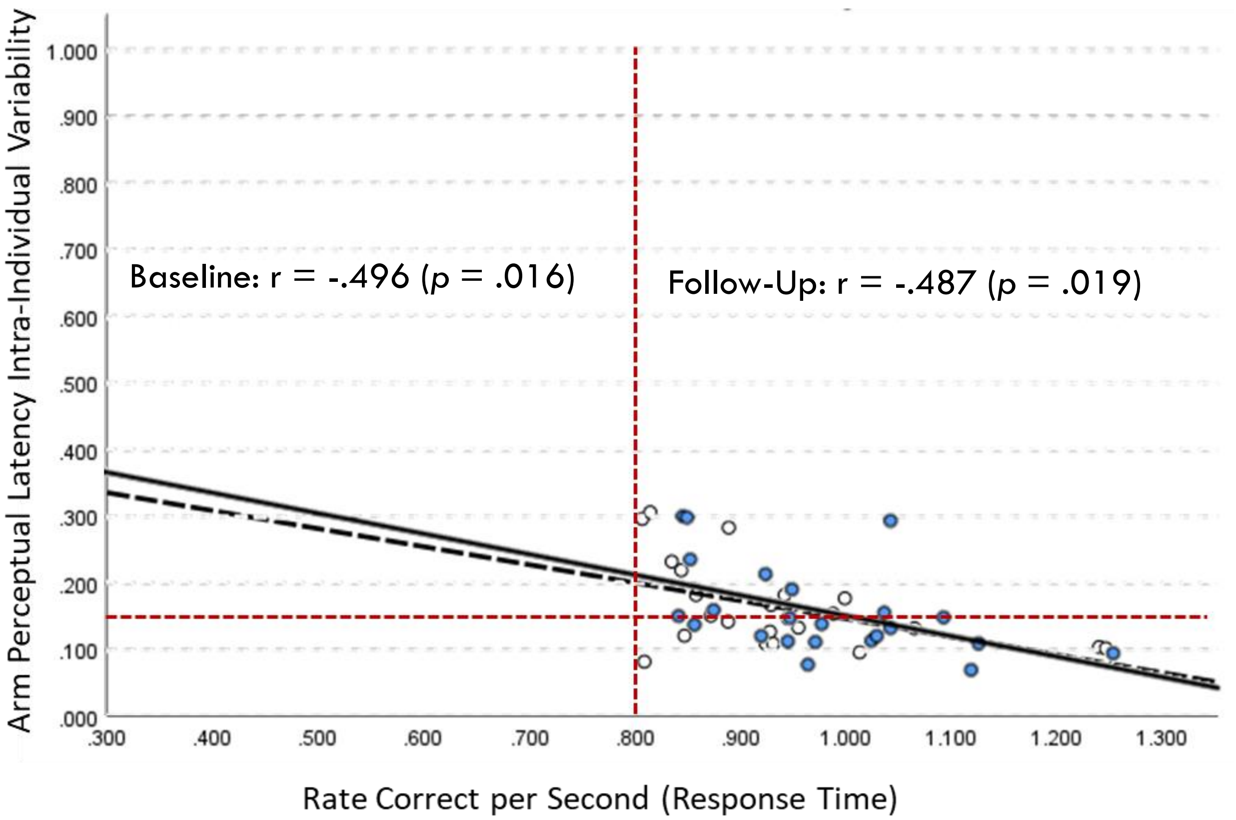
* High Game Exposure modeled both as count of Games Played (0-22) and binary factor (≥ 19) in separate analyses (both dropped from model in first step).

Baseline (Pre-Participation) versus Follow-Up (Post-Training)

Training Group (< .800 RCS at Baseline)



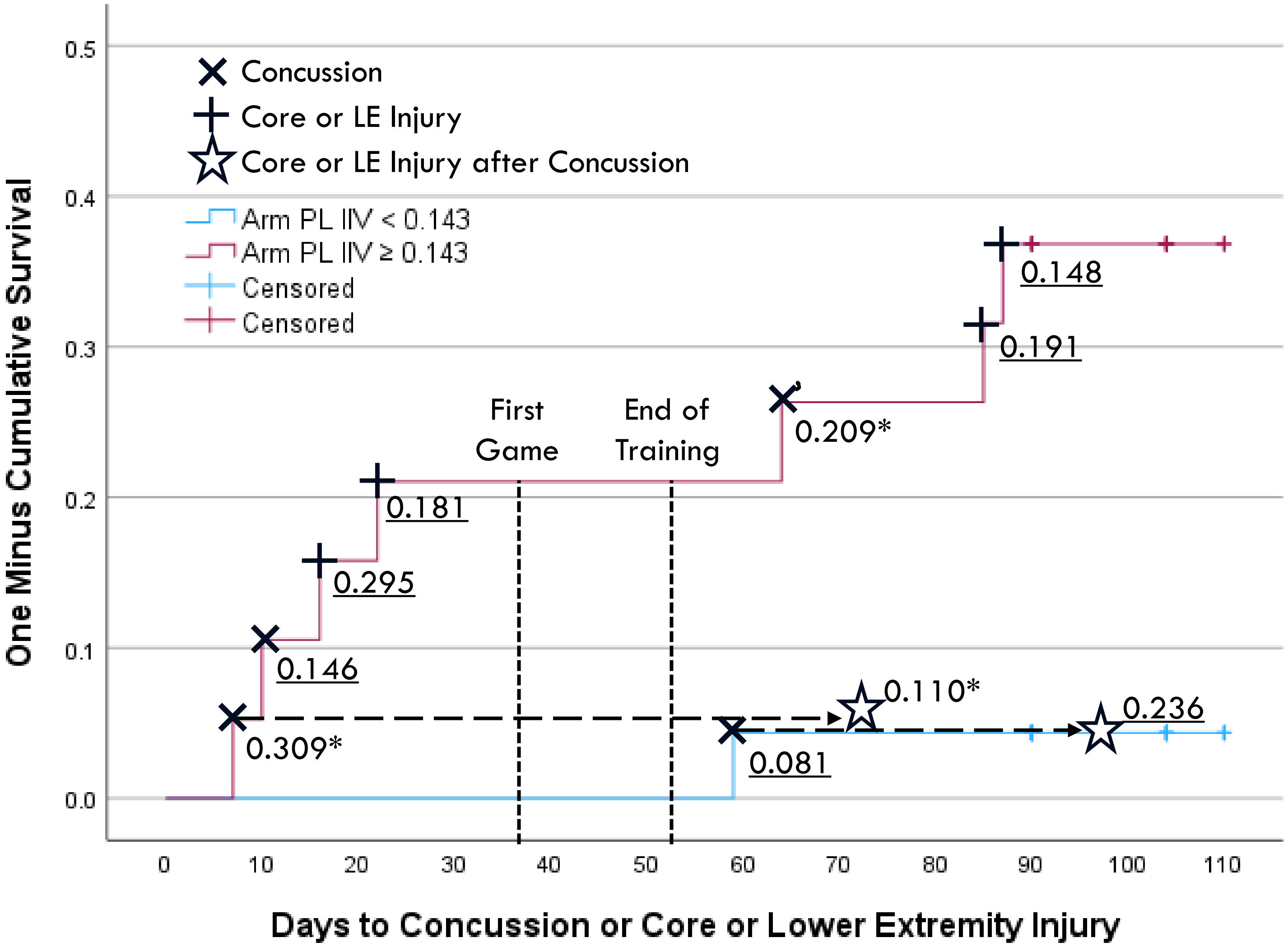
No Training Group (≥ .800 RCS at Baseline)



Baseline: Open Circles and Dashed Line of Best Fit
Follow-Up: Filled Circles and Solid Line of Best Fit

Arm Perceptual Latency IIV: < 0.143 versus ≥ 0.143

(Pre-Injury Value for 8 Injured Cases and Follow-Up Value for 34 Non-Injured Cases)



Trained cases marked with asterisk (2/19 Injured); Untrained cases underlined (6/23) Injured

Discussion

- Arm PL-IIV (initial movement inconsistency) a key metric
  - Correlated with RCS-RT, but provided better injury prediction
  - VR training produced substantial improvement in both metrics
    - BL Arm PL-IIV > 0.143 95% (18/19) to FU Arm PL-IIV > 0.143 32% (7/19)
    - BL Arm RCS-RT < 0.800 100% (19/19) to FU Arm RCS-RT < 0.800 26% (5/19)
- Lifetime Concussion History also a strong injury predictor[4]
  - Concussion History HR=8.84; Arm PL-IIV HR=15.53

Discussion

- Although the findings appear strong, limitations included:
  - No randomized group assignment (possible confounding effects)
  - Relatively small cohort (n=50) with loss of 8 participants (n=42)
  - Inconsistent number of training sessions completed (Range: 3-13)
  - Relatively low injury incidence of 19% (8/42)

Clinical Relevance

- Behavioral IIV inversely related to brain signal variability[6]
  - Both PL-IIV and RCS-RT may be indicators of neural efficiency
- 2-Phase analysis permitted assessment of change in risk status[7]
  - Counterfactual estimation of injury likelihood without VR training
- VR appears to have unique value for reduction of injury risk[8]
  - Relatively low training volume may provide substantial benefit

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