Associations of Virtual Reality Metrics and Self-Reported Well-Being with Injury Occurrences among High School Athletes

Wynn KR & Dill PW, Acocello SN, and Wilkerson GB

THE UNIVERSITY of TENNESSEE CHATTANOOGA

1

Background

- Injury risk reduction depends on the ability to identify individuals who have elevated susceptibility[1]
  - Slow neurocognitive reaction time appears to increase risk for a lower extremity sprain/strain during sport participation[1]
  - Strong association identified between asymmetrical whole body reactive movement responses and history of self-reported concussion[2]
  - Evidence exists for an association between psychosocial stress and brain information processing efficiency ,[3,4] as well as injury incidence[5,6]

2

2

Purpose

- To identify any prospective association of perceptual-motor function, suboptimal well-being, and/or concussion history with the occurrence of a core or lower extremity sprain or strain among male and female high school athletes

3

3

Methods

- Participants: 68 high school athletes
  - 41 Girls' varsity soccer players
  - 27 Boys' varsity football players
    - Exclusion criterion: current injury

IRB #22-071

- Pre-Season Performance Test
  - Virtual Reality Perceptual-Motor Efficiency
    - Whole-Body Reactive Response
      - Eyes – Neck – Arm – Step
- Pre-Season Survey Administration
  - Global Well-Being Index (GWBI)
- Injury Documentation
  - Electronic injury record
    - Core or Lower Extremity Injury (CLEI)
      - Any acute sprain or strain that received treatment
      - Surveillance across pre-season and regular season

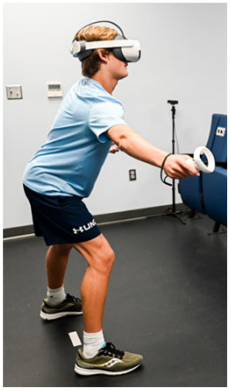
4

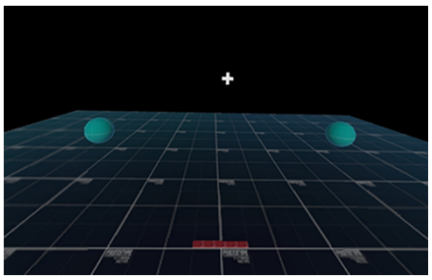
4

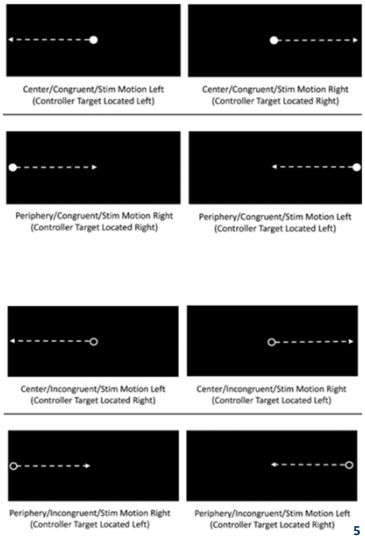
Pre-Season Performance Test

Immersive Virtual Reality Test

- 40 trials requiring lunging/reaching responses to horizontally moving dots
- Auditory tone and controller vibration feedback provided when target contacted



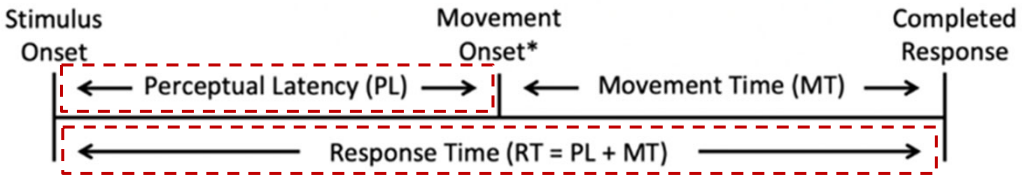




5

5

Virtual Reality Measurements



* 6° Angular Rotation (Eyes and Neck) or 10 cm Linear Translation (Arm and Step)

Operational Definitions of Perceptual Latency and Response Time

6

Methods: VR Test Metrics

- 40-Trial Mean and Trial-to-Trial Intra-Individual Variability (IIV)
  - Perceptual Latency (PL): Eyes, Neck, Arm, Step
  - Response Time (RT): Eyes, Neck, Arm, Step
- Speed-Accuracy Composite Metric: Rate Correct Score (RCS)
  - Calculated from Arm Movements (Hand Controller)
    - RCS-PL = Number Correct / Sum of PL Values
    - RCS-RT = Number Correct / Sum of RT Values

7

Pre-Season Survey: Global Well-Being Index (GWBI)

Check (√) each of the problems listed below that have affected your ability to function or derive maximum enjoyment of life activities in the past couple of years.

1. **General Pain or Discomfort**
   - ❑ Headaches/Pressure in Head ❑ Neck Pain ❑ Non-Specific Body Discomfort
2. **Sleep-Related Problems**
   - ❑ Trouble Falling Asleep ❑ Sleeping Less ❑ Fatigue/Drowsiness
3. **Mood-Related Problems**
   - ❑ Nervousness/Anxiety ❑ Sadness/Depression ❑ Irritability/Stress
4. **Musculoskeletal Problems** (During Activities of Daily Living)
   - ❑ Aching Discomfort ❑ Joint Stiffness ❑ Muscle Spasms/Tightness
5. **High-Intensity Performance Limitations**
   - ❑ Running Speed Limitation ❑ Explosive Power Limitation ❑ Endurance Limitation

Follow-up questions appear if at least 1 problem selected within a given category:

How frequently has the worst problem been experienced over the past couple of years?

0 ○ None – Not at all | 1 ○ Rare to Occasional | 2 ○ Occasional to Frequent | 3 ○ Frequent to Persistent

When was the most recent occurrence of the worst problem among those that were selected?

1 ○ > 1 Year Ago | 2 ○ > 6 Months Ago | 3 ○ > 1 Week Ago | 4 ○ Current Week

Estimate the severity of the worst problem at any point over the past couple of years?

1 ○ Mild to Moderate | 2 ○ Moderate to Severe | 3 ○ Severe

8

Injury Surveillance

- **Injury definition:**
  - Any core or lower extremity sprain or strain that was evaluated, regardless of whether or not time was lost from participation

CLEI: Core or Lower Extremity Injury	Female CLEIs: Occurrence:	Male CLEIs: Occurrence:	All Recorded CLEIs:
	Ankle: 7	Ankle: 5	Ankle: 12
	Knee: 4	Knee: 1	Knee: 5
	Hip/Groin: 1	Hip/Groin: 1	Hip/Groin: 2
	Low Back: 1	Low Back: 0	Low Back: 1
	Total: 13	**Total: 7**	**Total: 20**
	32% (13/41)	26% (7/27)	29% (20/68)

- Receiver operating characteristic and cross-tabulation analyses used to quantify strength of associations between predictors and outcome (CLEI)

9

Core or Lower Extremity Injury

N=68 (Male=27 + Female=41) Injured: 29% (20/68)

Results of Univariable Cross-Tabulation Analyses of Binary Predictors						
Variable	**AUC**	**Cut-Point**	**P***	**Sensitivity**	**Specificity**	**OR (95% CI)**
Hx SRC ≥ 2	–	yes/no	.016	0.30	0.94	6.43 (1.42, 29.10)
Arm Response Time Avg	.690	≥ 1.258	.004	0.70	0.69	5.13 (1.65, 15.96)
Step Response Time IIV	.652	≥ 0.301	.005	0.75	0.63	5.00 (1.55, 16.09)
RCS Response Time Avg	.618	≤ 0.694	.060	0.55	0.69	2.69 (0.92, 7.85)
Neck Perceptual Latency IIV	.613	≥ 0.321	.076	0.60	0.63	2.50 (0.86, 7.28)
Neck Perceptual Latency Avg	.610	≥ 0.673	.240	0.65	0.48	1.71 (0.58, 5.03)
Arm Perceptual Latency Avg	.593	≥ 0.811	.044	0.50	0.75	3.00 (1.01, 8.96)

AUC: Area Under Curve P*: Fisher's Exact 1-Sided P-Value OR: Odds Ratio CI: Confidence Interval
Hx SRC: History of Sport-Related Concussion RCS: Rate Correct Score IIV: Intra-Individual Variability

Core or Lower Extremity Injury

Male=27 Injured: 26% (7/27)

Results of Univariable Cross-Tabulation Analyses of Binary Predictors						
Variable	**AUC**	**Cut-Point**	**P**	**Sensitivity**	**Specificity**	**OR (95% CI)**
Neck Perceptual Latency Avg	.764	≥ 0.654	.048	0.86	0.60	9.00 (0.90, 89.61)
Arm Response Time Avg	.721	≥ 1.257	.024	0.57	0.90	12.00 (1.48, 97.18)
Step Response Time IIV	.721	≥ 0.282	.048	0.86	0.60	9.00 (0.90, 89.61)
Neck Perceptual Latency IIV	.679	≥ 0.330	.088	0.57	0.80	5.33 (0.83, 34.09)
Arm Perceptual Latency Avg	.629	≥ 0.742	.088	0.57	0.80	5.33 (0.83, 34.09)
RCS Response Time Avg	.621	≤ 0.83	.161	0.86	0.45	4.91 (0.50, 48.62)

AUC: Area Under Curve P*: Fisher's Exact 1-Sided P-Value OR: Odds Ratio CI: Confidence Interval
RCS: Rate Correct Score IIV: Intra-Individual Variability

11

Core or Lower Extremity Sprain or Strain

Female=41 Injured: 32% (13/41)

Results of Univariable Cross-Tabulation Analyses of Binary Predictors						
Variable	**AUC**	**Cut-Point**	**P**	**Sensitivity**	**Specificity**	**OR (95% CI)**
Hx SRC ≥ 2	–	yes/no	.008	0.39	0.96	16.88 (1.71, 166.21)
Arm Response Time Avg	.695	≥ 1.385	.029	0.62	0.75	4.80 (1.18, 19.61)
GWBI Mood-Related Problems	.643	≥ 7	.045	0.54	0.79	4.28 (1.04, 17.62)
Step Response Time IIV	.615	≥ 0.301	.043	0.77	0.57	4.44 (1.00, 19.75)
RCS Response Time Avg	.615	≤ 0.67	.048	0.62	0.71	4.00 (1.00, 15.99
Arm Perceptual Latency Avg	.573	≥ 0.881	.066	0.46	0.82	3.94 (0.92, 16.94)
Neck Perceptual Latency IIV	.549	≥ 0.347	.113	0.62	0.64	2.88 (0.74, 11.21)
Neck Perceptual Latency Avg	.497	≥ 0.702	.163	0.54	0.68	2.46 (0.64, 9.49)

AUC: Area Under Curve P*: Fisher's Exact 1-Sided P-Value OR: Odds Ratio CI: Confidence Interval
Hx SRC: History of Sport-Related Concussion RCS: Rate Correct Score IIV: Intra-Individual Variability

12

Cross-Tabulation Analyses

Males

		Core or LE Injury		
		Yes	No	Incidence
Concussion History ≥ 2	Yes	1	2	33%
	No	6	18	25%
	Total	7	20	

Sensitivity 14% Specificity 90%

$\chi^2(1)= .096$ 1-Sided $P=.610$ **OR=1.50** 95% CI: 0.12, 19.64

Males + Females

		Core or LE Injury		
		Yes	No	Incidence
Concussion History ≥ 2	Yes	6	3	67%
	No	14	45	24%
	Total	20	48	

Sensitivity 30% Specificity 94%

$\chi^2(1)=6.93$ 1-Sided $P=.016$ **OR=6.43** 95% CI: 1.42, 29.10

Females

		Core or LE Injury		
		Yes	No	Incidence
Concussion History ≥ 2	Yes	5	1	83%
	No	8	27	15%
	Total	13	28	

Sensitivity 39% Specificity 96%

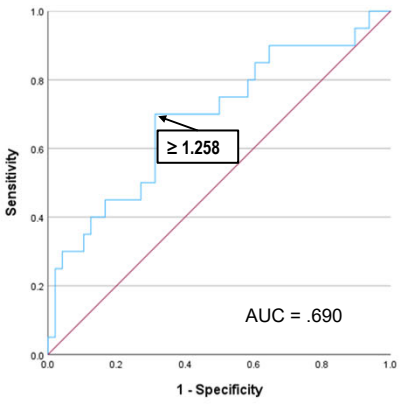
$\chi^2(1)=8.65$ 1-Sided $P=.008$ **OR=16.88** 95% CI: 1.71,166.21

13

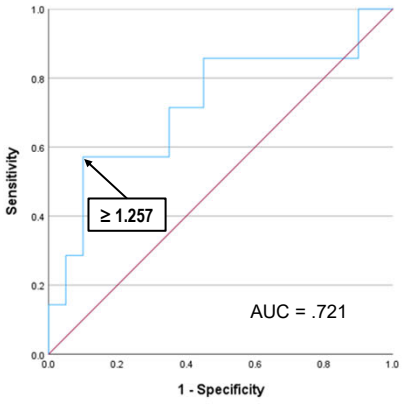
Arm Response Time (40-Trial Average [seconds])

Males: 1.186 ± .134 Females: 1.326 ± .251 Diff: 0.140 P = .004

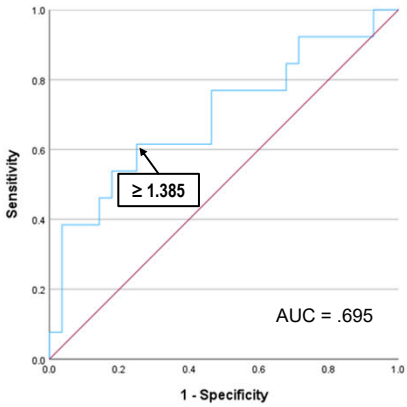
Male + Female (N = 68)



Male (N = 27)



Female (N = 41)

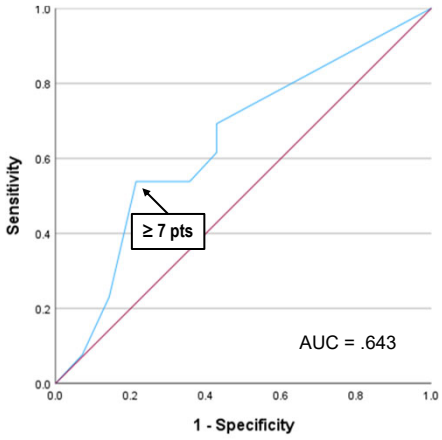


14

14

Females: GBWI Mood-Related Problems (Category 3)

(Nervousness/Anxiety – Sadness/Depression – Irritability/Stress)



Females

GWBI Category 3 ≥ 7 points		Core or LE Injury: Yes	Core or LE Injury: No	Incidence
	Yes	7	6	54%
	No	6	22	21%
	Total	13	28	

Sensitivity 54% Specificity 79%

$\chi^2(1)=4.31$ 1-Sided P=.045

OR=4.28 95% CI: 1.04,17.62

15

Discussion

- Both sex-specific and sex-combined analyses included Arm Response Time Avg and Step Response Time IIV among strongest predictors of CLEI
- Arm Response Time Avg 140 ms faster for Males than Females (P=.004)
- Neck Perceptual Latency Avg strongest predictor of CLEI for Male athletes
- History of ≥ 2 SRCs strongest predictor of CLEI for Female athletes
- GWBI Mood-Related Problems also important for Female athletes

16

Discussion

- Each of the factors associated with CLEI occurrence may relate to impaired functional connectivity within and between brain networks[3]
  - Slowed information processing – prolonged Arm and Neck Perceptual Latency Avg and Arm Response Time Avg
  - Impaired cognitive flexibility – elevated trial-to-trial performance inconsistency (Step Response Time IIV and Neck Perceptual Latency IIV)
- Immersive VR may provide a means to identify a subtle perceptual-motor processing deficiency that otherwise remain undetected[2]

Clinical Relevance

- Injury risk reduction may need to address sex-specific considerations
  - Male Neck Perceptual Latency Avg may relate to vestibular dysfunction[8]
  - Sex-specific Arm Response Time Avg cut points needed to estimate risk
  - Intervention for Mood-Related Problems especially important for Females[3]
- VR assessment of perceptual-motor function appears to provide data relevant to interrelated manifestations of impaired brain connectivity

References

1. Wilkerson GB, Bruce JR, Wilson AW, et al. Perceptual-motor efficiency and concussion history are prospectively associated with injury occurrences among high school and collegiate American football players. *Orthop J Sports Med.* 2021;9(10):23259671211051722.
2. Wilkerson GB, Colston MA, Acocello SN, Hogg JA, Carlson LM. Subtle impairments of perceptual-motor function and well-being are detectable among military cadets and college athletes with self-reported history of concussion. *Front Sports Act Living.* 2023;5:1046572. doi:10.3389/fspor.2023.1046572
3. Wong JKY, Churchill NW, Graham SJ, Baker AJ, Schweizer TA. Altered connectivity of default mode and executive control networks among female patients with persistent post-concussion symptoms. *Brain Inj.* 2023;37(2):147-158.
4. Stawski RS, Cerino ES, Witzel DD, MacDonald SW. Daily stress processes as contributors to and targets for promoting cognitive health in later life. *Psychosom Med.* 2019;81(1):81-89.
5. Singh H, Conroy DE. Systematic review of stress-related injury vulnerability in athletic and occupational contexts. *Psychol Sport Exerc.* 2017;33:37-44.
6. Ivarsson A, Johnson U, Lindwall M, Gustafsson H, Altemyr M. Psychosocial stress as a predictor of injury in elite junior soccer: a latent growth curve analysis. *J Sci Med Sport.* 2014;17(4):366-370.
7. Edmed S, Sullivan K. Depression, anxiety, and stress as predictors of post-concussion-like symptoms in a non-clinical sample. *Psychiatr Res.* 2012;200(1):41-45.
8. Loyd BJ, Dibble LE, Weightman MM, et al. Volitional head movement deficits and alterations in gait speed following mild traumatic brain injury [published online ahead of print, Oct 14]. *J Head Trauma Rehabil.* 2022; doi:10.1097/HTR.0000000000000831.