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Prediction of Sport-Related Concussion and Musculoskeletal Injury Occurrences among High School Football Players

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BACKGROUND AND PURPOSE

- Current clinical procedures for prevention and management of sport-related concussion (SRC) may not yield optimal outcomes¹
- SRC symptoms typically resolve within 7 to 14 days, but persist for more than 2 weeks for approximately 15-20% of cases²
 - Growing evidence indicates that delayed effects of a secondary neurometabolic injury process persists for months or years
- Neurophysiological studies suggest that recovery is often incomplete upon return to sport, which probably elevates injury risk³
 - Subsequent incidence of musculoskeletal injury is as much as 2 X greater, and as much as 3-5 X greater for another SRC⁴
 - Advanced neuro-diagnostic test results suggest that multiple SRC occurrences increase risk for neurodegenerative conditions⁵
- Little research has assessed the predictive validity of risk screening assessments for identification of athletes who possess high risk
 - Football has the greatest SRC incidence rate among all high school sports played in the US; 9.21 per 10,000 athlete-exposures⁶
 - Among high school football players, core or lower extremity injury (CLEI) is most common; > 50% of all musculoskeletal injuries⁷
- Long-term effects of mTBI can adversely affect cognitive-motor neural processing, which appears to worsen over time⁸
 - Current assessment tools that identify such brain alterations are expensive, complex, and not feasible options for risk screening⁹
 - Inexpensive and easily administered clinical tests for detection of asymptomatic mTBI effects would be exceptionally valuable¹⁰
- The purposes of this study were to assess retrospective and prospective associations of risk screening metrics (survey responses and cognitive-motor test results) with SRC and CLEI for estimation of injury risk level for individual high school football players

PARTICIPANTS AND PROCEDURES

- 92 high school football players from 14 different programs received a pre-participation exam (PPE) from the same medical provider
 - 15.6 ± 1.1 years of age (range 13 – 18); 15 players who left team before end of season were excluded from original cohort of 107
- PPE included electronic injury history/symptoms surveys and administration of smartphone test of perceptual-motor efficiency
 - 10-item Overall Wellness Index (OWI): 0–100 score for frequency and temporal proximity of 82 physical or mental problems
 - List of 82 problems derived from recognized symptoms of post-concussion syndrome grouped into 10 categories (Figure 1)
 - 10-item Sport Fitness Index (SFI): 0–100 score for persisting effects of prior musculoskeletal injuries sustained at any time in past
 - Frequency or severity of persisting effects on sport performance capabilities; 10 categories of adverse effects (Figure 2)
- Flanker Test smartphone app measured perceptual-motor efficiency from rapid tilt of device in center arrow's direction (Figure 3)
 - 20 Flanker Test 5-arrow trials displayed for 300 ms, with 500–1500 ms inter-stimulus intervals (<<<<<, >>>>>, <<><<, >>>>>)
 - Conflict Effect (CE): incongruent (>><>>, <<><<) minus congruent (<<<<<, >>>>>) average response time difference
 - Efficiency Index (EI): average response time divided by proportion of correct responses (speed versus accuracy trade-off)
 - EI Ratio (EIR): incongruent EI divided by congruent EI (relative efficiency for complex versus simple visual stimuli)
- Prospective analysis of CLEI: injuries documented from start of pre-season practice sessions through end of season
 - Any core or lower extremity sprain or strain that resulted in evaluation and treatment, regardless of time loss from participation
- Retrospective analysis of CLEI: (HxCLEI) self-reported core or lower extremity sprain or strain sustained within previous 12-months
- Prospective analysis of SRC: occurrence during practice session or game; diagnosed by healthcare provider
- Retrospective and prospective analyses of SRC history (HxSRC): self-reported occurrence any time in the past
- Receiver operating characteristic (ROC) analysis quantified associations by area under curve (AUC) and defined binary cut-points
 - Cross-tabulation analysis used to calculate positive predictive value (PPV), negative predictive value (NPV), and odds ratio (OR)

RESULTS

- A total of 64 CLEIs were sustained (Table 1); 43% (40/92) sustained at least 1 CLEI; 26 sustained 1 CLEI; 14 sustained ≥ 2 CLEIs
 - Self-reported HxSRC 15% (14/92); 12-month HxCLEI 23% (21/92); HxSRC – HxCLEI association: OR=2.15 (95% CI: 0.63, 7.32)
 - No prospective association of self-reported HxSRC with CLEI occurrence apparent: OR=0.97
- Retrospective associations of OWI symptoms, OWI score, SFI score, and Flanker Test CE with HxSRC presented in Table 2
- ROC curves with AUC values presented for each of the 10 items of OWI (Figure 4) and for each of the 10 items of SFI (Figure 5)
- Prospective associations of OWI symptoms, OWI score, SFI score, and Flanker Test EIR with SRC occurrence presented in Table 3
- Diagnosed SRC incidence 8% (7/92); among 14 players with HxSRC, 29% (4/14) sustained another SRC during surveillance period
- ROC curves with AUC values presented for each of the 10 items of OWI (Figure 6) and for each of the 10 items of SFI (Figure 7)
- HxSRC prospective associations of OWI symptoms, OWI score, SFI score, and Flanker Test EIR with new SRC presented in Table 4
- ROC curves with AUC values presented for each of the 10 items of OWI (Figure 8) and for each of the 10 items of SFI (Figure 9)
- Among 14 HxSRC cases, prospective associations with CLEI occurrence identified for SFI (Figure 10) and Flanker Test EIR (Figure 11)
- Cascaded classification tree for prospective association of SFI ≤ 92 and EIR ≥ 2.0 with CLEI occurrence presented in Figure 12

Figure 1

Item	Overall Wellness Index
1	Physical Problems (11 Symptoms)
2	Sleep/Stamina Problems (6 Symptoms)
3	Muscle Control Problems (10 Symptoms)
4	Balance/Perception Problems (7 Symptoms)
5	Altered Sensations (5 Symptoms)
6	Mood Problems (6 Symptoms)
7	Behavioral Control (13 Symptoms)
8	Memory-Related Problems (4 Symptoms)
9	Thinking-Related Problems (9 Symptoms)
10	Language-Related Problems (11 Symptoms)

Figure 2

Item	Sport Fitness Index
1	Previous Limitation in Sport Participation
2	Pain Limitation of Performance Capabilities
3	Speed-Power-Endurance Limitations
4	Pain Limitation of Explosive Power Output
5	Pain Limitation of a Sport-Specific Skill
6	Spasms-Stiffness-Aching During ADLs
7	Rapid-Forceful Movement Apprehension
8	Aching-Stiffness-Swelling After Activity
9	Joint Locking-Catching-Grinding-Aching
10	Negative Impact of Personal Life Events

Figure 3



Table 1. Core/LE Injuries

Foot/Ankle	28
Lower Leg	4
Knee	15
Thigh/Hip/Groin	10
Low Back/Abdomen	7

Table 2	AUC	Cut Point	PPV	NPV	OR	90% CI
OWI Symptoms	.685	≥ 4	47%	91%	8.75	2.44, 31.40
OWI Score	.656	≤ 88	32%	91%	4.78	1.46, 15.68
SFI Score	.576	≤ 88	23%	89%	2.52	0.79, 8.01
Flanker Test CE (ms)	.607	≥ 52	22%	93%	3.86	1.00, 14.91

Table 3	AUC	Cut Point	PPV	NPV	OR	90% CI
OWI Symptoms	.671	≥ 7	47%	91%	36.44	5.51, 240.99
OWI score	.658	≤ 76	33%	96%	12.83	2.43, 67.81
SFI Score	.684	≤ 78	31%	97%	16.82	2.90, 97.55
Flanker Test EIR	.585	≥ 1.7	15%	95%	3.82	0.79, 18.42

Figure 4

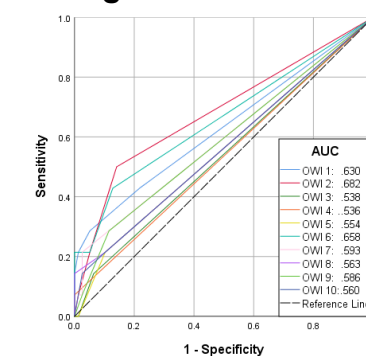


Figure 5

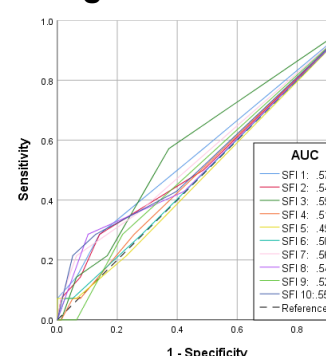


Figure 6

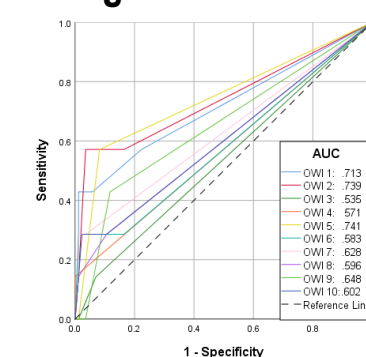


Figure 7

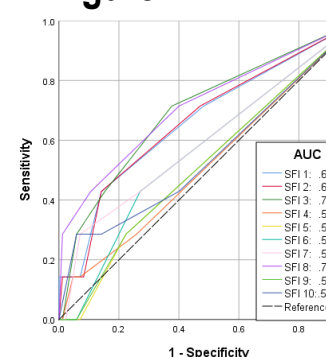


Table 4	AUC	Cut Point	PPV	NPV	OR	90% CI
OWI Symptoms	.750	≥ 3	71%	86%	15.00	1.03, 218.30
OWI Score	.729	≤ 86	67%	75%	6.00	0.58, 61.84
SFI Score	.802	≤ 92	75%	100%	33.80*	2.26, ∞
Flanker Test EIR	.667	≥ 2.0	100%	73%	17.00*	1.15, ∞

* OR estimated: 0.5 added to each 2 X 2 cell to avoid division by zero

Figure 10

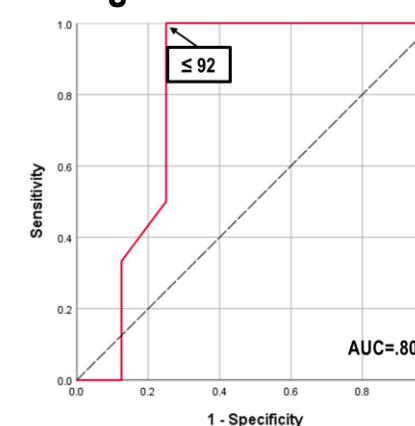


Figure 11

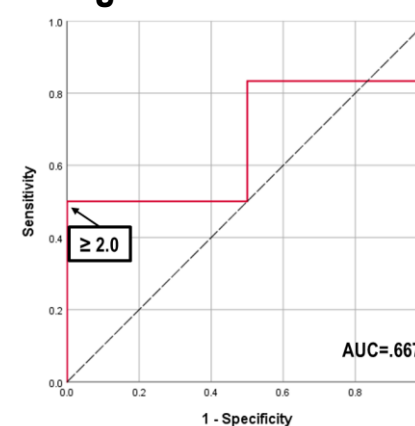


Figure 8

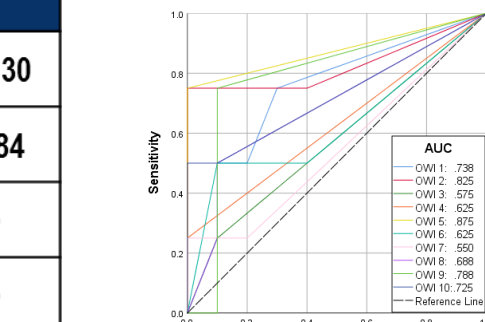


Figure 9

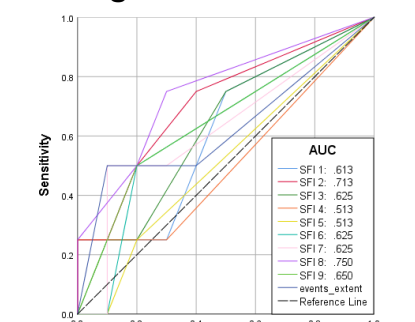
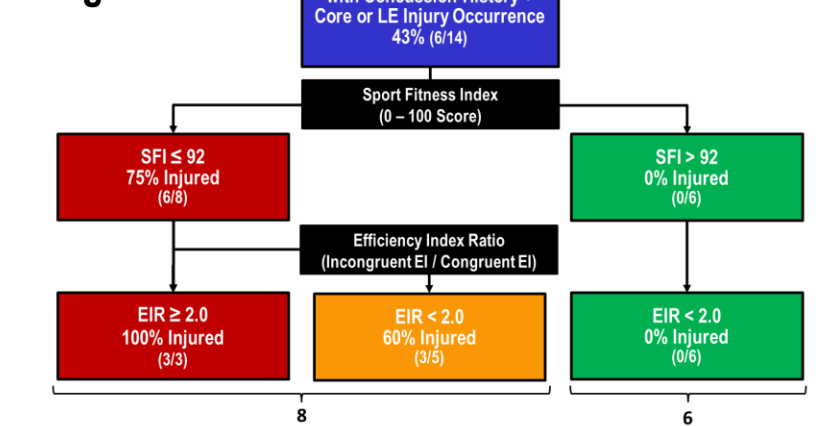


Figure 12



CLINICAL RELEVANCE

- The sensitivity of current clinical tests for detection of subtle impairment of brain functional connectivity has been questioned⁹
 - Standardized Assessment of Concussion and Balance Error Scoring System may be inadequate for cognitive-motor assessment
- OWI and SFI demonstrated strong retrospective association with HxSRC and strong prospective association with SRC occurrence
 - Flanker Test CE retrospectively associated with HxSRC and Flanker Test EIR prospectively associated with SRC occurrence
- HxSRC was retrospectively associated with HxCLEI, but was not prospectively associated with CLEI occurrence during surveillance
 - Analysis limited to 14 players with HxSRC demonstrated strong prospective association of SFI and Flanker Test EIR with CLEI
- HxSRC is known to elevate risk for CLEI and SRC recurrence, but more sensitive clinical tests are needed to detect high-risk status
 - OWI and SFI responses, combined with Flanker Test metrics, may identify specific risk factors for guidance of clinical management
- Our findings strongly support utilization of the OWI, SFI, and Flanker Test to identify individual high school football players who are likely to derive greatest benefit from focused efforts to further assess cognitive-motor function and potentially reduce injury risk

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