Modifiable Neuromechanical Impairments among Elite Athletes with Sport-Related Concussion History

Tyler S. Perry, Ryan M. Lipe, Michael T. Brooks, Gary B. Wilkerson, EdD, ATC; Dustin C. Nabhan, DC, DACBSP, FACSM

THE UNIVERSITY of TENNESSEE CHATTANOOGA

BACKGROUND AND PURPOSE

- Susceptibility to neurodegeneration has been linked to the cumulative effects of mild traumatic brain injury (mTBI) episodes[1]
  - Diagnosed concussion and/or repetitive subconcussive head impacts appear to initiate a neuroinflammatory response[2]
    - Absence of sport-related concussion (SRC) clinical symptoms does not necessarily exclude diffuse axon injury
- Microstructural disruption of white matter tracts within and between brain networks can produce subtle effects on function[3]
  - Impaired functional connectivity may elevate susceptibility to musculoskeletal injury and may affect psychological status[4,5]
    - Clinical tests are needed to identify individuals who may be experiencing persisting subtle effects of previous SRC[6]
- Self-reported frequency and temporal proximity of SRC symptoms may be a better indicator than history of concussion
  - Complete resolution of SRC symptoms may not necessarily correspond to restoration of normal neural processing
    - Athletes who are reluctant to acknowledge SRC occurrence may be more willing to report persisting symptoms
- If perceptual-motor neural processing is impaired, the potential for improvement through training needs to be documented
  - Whole-body reactive agility (WBRA) offers a means to assess, and potentially remediate, perceptual-motor deficiencies
    - Current standards for return-to-play following SRC may not identify subtle long term effects that elevate injury risk[7]
- The purposes of this study were to: 1) identify persisting effects of SRC through analysis of survey responses and WBRA metrics, and 2) assess the potential for remediation of WBRA performance deficiencies among athletes with SRC history

PARTICIPANTS AND PROCEDURES

- A cohort of 35 elite athletes provided responses to surveys pertaining to physical and mental status (Table 1)
  (24.0 ±5.1 years; 17 males: 68.4 ±3.6 cm, 154.0 ±24.8 kg; 18 females: 64.5 ±2.0 cm, 140.5 ±21.4 kg)
  - 10-item Overall Wellness Index (OWI) generates 0-100 score for frequency and recency of 82 physical/mental problems
    - List of 82 problems derived from recognized symptoms of post-concussion syndrome grouped into 10 categories
  - 10-item Sport Fitness Index (SFI) generates a 0-100 score for persisting effects of prior musculoskeletal injuries
  - Depression, Anxiety, and Stress Scale (DASS): 42-item survey measures the 3 domains of depression, anxiety, and stress
- A subset of 16 athletes participated in 12 WBRA training sessions (10-12 minutes each) over a period of 26 ±9 days
  (25.3 ±5.8 years; 10 males: 69.0 ±3.8 cm, 160.7 ±27.4 kg; 6 females: 63.8 ±2.0 cm, 144.5 ±28.7 kg)
  - A virtual reality motion analysis system (TRAZER™, Westlake, OH): 8 lateral and 8 diagonal WBRA responses (Figure 1)
    - Targets located at margins of 3-m X 3-m area; targets presented on either right or left side of virtual reality display
      - Single-task (ST): targets presented on either right or left side of virtual reality display (lateral or diagonal-back)
      - Dual-task (DT): targets presented on both sides, with proper movement direction indicated by Flanker Test arrows
        - 4 possible Flanker Test 5-arrow displays (<<<<<, >>>>>, <<><<, >><>>) presented in random order
    - WBRA metrics: Total Distance, Reaction Time (RT), Speed (Spd), Acceleration (Acc), and Deceleration (Dec)
      - Right versus left asymmetry (Asym) assessed, including averaged RT, Spd, Acc, and Dec Asym (AvgAsym)
- Data analyzed with receiver operating characteristic (ROC), cross-tabulation, and logistic regression analyses
  - Training effect assessed with repeated measures ANOVA and calculation of standardized response mean (SRM)
    - Data from 12 training sessions grouped to create 3 training phases of 4 sessions each

RESULTS

- History of sport-related concussion (HxSRC) reported by 46% (16/35) of cohort and 56% (9/16) of training subgroup (Table 1)
  - Full cohort most recent SRC: 3.0 ±2.2 yr; range 0.3 – 8.0 yr; subgroup most recent SRC: 2.3 ±2.4 yr; range 0.3 – 8.0 yr
- Strong associations between HxSRC and survey scores; very similar findings for full cohort and training subgroup (Table 2)
  - HxSRC related to persisting effects of prior musculoskeletal injuries (SFI) and physical/mental problems (OWI and DASS)
- Phase 1 WBRA metrics demonstrated good discrimination between HxSRC and athletes who denied SRC history (NoSRC)
  - Lateral ST-WBRA AvgAsym: AUC=.698; ≥ 13.4%; OR=5.00 (Figure 2)
    - ≥10% and ≥15% thresholds similar to prior study findings with elite athlete cohorts (Table 3; A: 2017; B: 2018; C: 2019)
  - Lateral DT-WBRA Total Distance: AUC=.714; ≥ 27.3 m; OR=7.50 (Figure 3)
- Phase 1 to Phase 3 comparisons of WBRA performance metrics demonstrated substantial improvements
  - A significant group X phase interaction effect (*P*=.038) was evident for Lateral DT-WBRA Total Distance (Figure 4)
    - Greater improvement for HxSRC (28.6 ±4.0 to 24.4 ±2.5; SRM=2.06) than NoSRC (25.9 ±1.5 to 24.2 ±1.1; SRM=0.93)
  - Significant Lateral ST-WBRA AvgAsym reduction main effect (*P*=.049; SRM=0.57), but no significant interaction effect
    - Magnitude similar for HxSRC (15.7 ±4.7% to 12.6 ±2.4%) and NoSRC (12.9 ±3.7% to 10.2 ±2.5%)

Figure 1

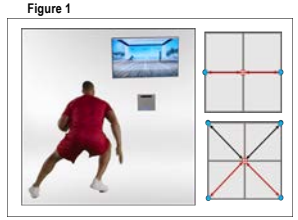


Table 1

HxSRC: Full Cohort (FC) vs. Training Group (TG)

Sport	Male		Female		Total	
	TG	FC	TG	FC	TG	FC
Boxing	0/0	0/3	0/0	1/3	0/0	1/6
Figure Skating	1/2	1/4	0/0	0/1	1/2	1/5
Gymnastics	2/2	2/3	0/0	0/0	2/2	2/3
Marathon	1/1	1/2	0/0	0/0	1/1	1/2
Shooting	0/3	0/3	0/2	0/2	0/5	0/5
Sledding	0/0	0/0	0/0	1/2	0/0	1/2
Wrestling	0/2	0/2	4/4	6/10	4/6	6/12
Total	10	17	6	18	16	35

Table 2

Survey	Group	N	AUC	Cut-Pt	PPV	NPV	OR	90% CI
Sport Fitness Index	FC	35	.711	≤ 64	64%	67%	3.60	1.09, 11.86
	TG	16	.817	≤ 64	88%	75%	21.00	2.30, 191.94
Overall Wellness Index	FC	35	.724	≤ 76	67%	77%	6.50	1.86, 22.67
	TG	16	.730	≤ 76	78%	71%	8.75	1.30, 58.86
Depression, Anxiety, and Stress Survey	FC	35	.709	≥ 11	67%	70%	4.67	1.40, 15.60
	TG	16	.635	≥ 17	80%	55%	4.80	0.59, 38.86

Table 3

Asymmetry*	Cohort	PPV	NPV	+LR	-LR	OR	90% CI
≥ 10%	A	62%	68%	1.80	0.51	3.52	1.17, 10.56
	B	64%	70%	1.50	0.36	4.15	1.10, 15.62
	C	64%	100%	1.40	0.00	8.64†	0.58, ∞
	Pooled	63%	71%	1.62	0.38	4.22	1.92, 9.27
≥ 15%	A	75%	59%	3.32	0.76	4.39	1.01, 19.03
	B	72%	65%	2.19	0.46	4.77	1.43, 15.87
	C	75%	50%	2.33	0.78	3.00	0.36, 25.08
	Pooled	73%	59%	2.57	0.65	3.96	1.78, 8.84

*Composite Asymmetry for Reaction Time, Speed, Acceleration, and Deceleration
†Estimated by adding 0.5 to each cell of 2x2 cross-tabulation to avoid division by zero

Figure 2

Phase 1 Lateral ST-WBRA AvgAsym

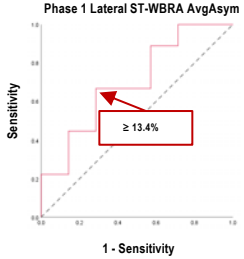


Figure 3

Phase 1 Lateral DT-WBRA Total Dist

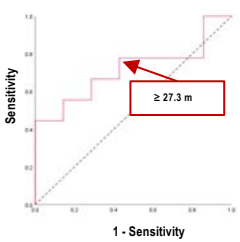
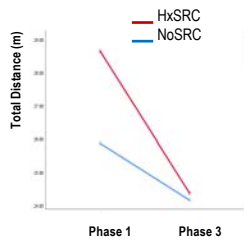


Figure 4

Phase 1-3 Lateral DT-WBRA Total Dist



CLINICAL RELEVANCE

- Consistent with prior research,[4,5] athletes with HxSRC reported more physical and mental problems than NoSRC athletes
  - SFI, OWI, and DASS scores demonstrated exceptionally strong differentiation between HxSRC and NoSRC athletes
    - Existence of problems prior to SRC or following SRC is unknown, but risk for future injury is almost certainly elevated
- Consistent with prior research,[6] Lateral ST-WBRA AvgAsym ≥ 10% and ≥ 15% were strongly associated with HxSRC
  - Asymmetries could be due to diffuse axon injury within brain networks, which disrupt inter-hemispheric neural processing[3]
    - Subtle disruption of perceptual-motor efficiency may not be identified by standard clinical assessment methods[7]
- Movement control training has been shown to substantially reduce the incidence of both musculoskeletal injury and SRC[8]
  - Greater reduction of Lateral DT-WBRA Total Distance for HxSRC likely due to improved visual-spatial movement control
    - Significantly reduced Lateral ST-WBRA AvgAsym for both groups suggests that neuroplastic adaptation occurred
- Our findings support use of the SFI, OWI, and DASS surveys and WBRA testing to identify athletes who possess elevated risk for future injury, as well as the potential for reduction of risk through training that improves perceptual-motor efficiency

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