Association of Repetitive Head Impact with Neuromechanical Test Metrics of College Football Linemen

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BACKGROUND AND PURPOSE

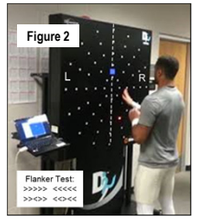
- Repetitive head impact (RHI) may lead to long-term neurological impairment,[1] possibly due to disruption of the blood-brain barrier[2]
  - Because subconcussive RHI is not associated with overt symptoms, perceived harmlessness may have serious consequences
    - Neuroimaging has demonstrated changes in white matter integrity proportional to cumulative exposure to RHI[3]
- Subtle neurological impairment of visual-motor control may result from RHI, which could elevate risk for subsequent injury
  - Performance tests are needed to identify subtle deficiencies documented by neuroimaging and electroencephalography[4]
    - Altered coupling of visual, cognitive, and motor processes may adversely affect neuromechanical responsiveness[5]
- The purpose of this study was to assess the possible association of RHI with various measures of visual-motor reaction time (VMRT) and whole-body reactive agility (WBRA) for identification of college football linemen who may possess subtle impairments

PARTICIPANTS & PROCEDURES

- 10 NCAA Division I-FCS offensive linemen (20.7 ±1.1 yrs; 139.9 ±13.6 kg; 192.5 ±4.8 cm) monitored for RHI with helmet sensors
  - Head Health Network sensors (Baton Rouge, LA); metrics included linear (g) and angular (rad/s^2) accelerations
    - Contact practice sessions and games: Mean g, Mean rad/s^2, Number of Hits ≥ 80 g, and Number of Hits ≥ 25 g (if ≥ 28 Hits)
      - ProTech helmet pad (Chester Springs, PA) worn by all players during monitored contact practice sessions (Figure 1)
- Post-season assessment included 2 VMRT tests (Figure 2) and 2 WBRA tests (Figure 3) administered 4 days after final game
  - VMRT measured by computerized light board Dynavision D2 system (Dynavision International, West Chester, OH)
    - Single Task (ST) mode (proactive): target buttons illuminated until hit; 60-s test without any secondary task requirement
    - Dual Task (DT) mode (flanker test): center arrow direction motor responses (<<<<<, >>>>>, >><>>, <<><<); 48 displays
      - Left vs. Right VMRT difference (L-R Diff) and outer 2-ring to inner 2-ring VMRT ratio (O/I Ratio) calculated for both modes
  - WBRA assessed by lateral (Lat) and diagonal (Diag) tests (TRAZER® Sports Stimulator, Traq Global Ltd, Westlake, OH)
    - Movement direction guided by appearance of virtual reality target on large monitor (Lat 20 targets; Diag 12 targets)
    - Start position 3.12 m from monitor; 0.91 m movement to deactivate Lat targets; 1.29 m movement to deactivate Diag targets
      - Reaction time (RT), speed (Spd), acceleration (Acc), deceleration (Dec), distance (Dist) and Time quantified
        - Average (Avg) value, left-right asymmetry (Asym), and assessed for each performance variable
  - Angular and linear acceleration values recorded by helmet sensors averaged for number of sessions recorded for a given player
    - Median value used to categorize cases as High or Low RHI for each of the 4 metrics derived from helmet sensors
      - Receiver-operating characteristic analysis used to define optimal cut-points for each WBRA and VMRT metric
        - Cross-tabulation analysis used to calculate sensitivity, specificity, and odds ratio (OR) for each metric
          - Credible lower limit (CLL) for 90% confidence interval calculated for each OR value

RESULTS

- Median number of helmet sensor recording sessions (contact practice sessions and 11 games) was 36; range 15-54
- VMRT and WBRA metrics exhibiting strong associations (OR ≥ 3) with helmet sensor RHI measures presented in Tables 1-4
  - Data acquisition malfunctions resulted in missing data; all WBRA Lat metrics for 1 case and WBRA Lat RT only for another case
    - WBRA Lat values presented in Tables 1-4 include 10 cases, unless designated by ¥ symbol (9 cases) or † symbol (8 cases)
      - For 100% sensitivity and/or 100% specificity, OR value estimated by adding 0.5 to each 2X2 cell; designated by * symbol
- Univariable analysis results for associations with high linear and rotational acceleration (OR ≥ 3) included in Tables 1-2
  - For Linear Acc. ≥ 40 g, 8/10 variables had OR ≥ 10 and 8/10 variables had either 100% sensitivity or 100% specificity
  - For Rotational Acc. ≥ 815 m/s^2, 9/11 variables had OR ≥ 10 and 11/11 variables had either 100% sensitivity or 100% specificity
- Univariable analysis results for associations with number of hits per session ≥ 80 g and ≥ 25 g (OR ≥ 3) included in Tables 3-4
  - For number of hits ≥ 80 g, 8/15 variables had OR ≥ 10 and 12/15 variables had either 100% sensitivity or 100% specificity
  - For number of hits ≥ 25 g, 10/15 variables had OR ≥ 10 and 11/15 variables had either 100% sensitivity or 100% specificity
- VMRT ST (2 different cut-points) and WBRA Diag RT exhibited exceptionally strong associations (OR ≥ 15) with all RHI measures
  - VMRT ST ≥ 805 ms exhibited 100% sensitivity and 100% specificity for Avg Number of Hits per session; ≥ 80 g and ≥ 25 g
  - VMRT DT L-R Diff ≥ 45 ms exhibited exceptionally strong association with high Angular Acc (≥ 815 rad/s^2 Session Avg)



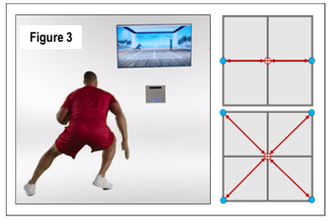


Table 1. High Linear Acc (g) ≥ 40 Session Avg

Metric	AUC	Cut-Point	Sensitivity	Specificity	OR	CLL
WBRA Diag Dist (m)	.820	≥ 26.05	80	80	16.0	1.2
VMRT ST (ms)	.780	≥ 805	80	80	16.0	1.2
WBRA Diag RT (ms)	.700	≥ 795	60	100	15.4*	1.0
VMRT ST L-R Diff (ms)	.640	≥ 40	60	100	15.4*	1.0
VMRT DT (ms)	.600	≥ 835	100	60	15.4*	1.0
WBRA Diag RT Asym (%)	.680	≥ 62	40	100	7.9*	0.5
WBRA Diag Time (s)	.560	≥ 62	40	100	7.9*	0.5
VMRT DT L-R Diff (ms)	.680	≥ 45	60	80	6.0	0.6

Table 2. High Angular Acc (rad/s^2) ≥ 815 Session Avg

Metric	AUC	Cut-Point	Sensitivity	Specificity	OR	CLL
VMRT DT L-R Diff (ms)	.820	≥ 45	80	100	33.0*	1.8
VMRT DT (ms)	.800	≥ 895	100	80	33.0*	1.8
VMRT ST (ms)	.820	≥ 760	100	60	15.4*	1.0
WBRA Diag RT (ms)	.820	≥ 795	60	100	15.4*	1.0
WBRA Diag Spd (m/s)	.720	≤ 0.93	100	60	15.4*	1.0
WBRA Diag Time (s)	.680	≥ 59	60	100	15.4*	1.0
WBRA Lat Spd (m/s)¥	.725	≤ 0.76	100	60	12.6*	0.8
WBRA Lat Dec (m/s^2)¥	.700	≤ 2.1	100	60	12.6*	0.8
WBRA Lat Acc (m/s^2)¥	.625	≤ 2.5	100	60	12.6*	0.8
WBRA Diag Dist (m)	.660	≥ 24.9	100	40	7.9*	0.5
WBRA Diag Acc (m/s^2)	.600	≤ 2.38	100	40	7.9*	0.5

Table 3. High Linear Acc (80 g) Hits ≥ 0.12 per Session

Metric	AUC	Cut-Point	Sensitivity	Specificity	OR	CLL
VMRT ST (ms)	1.00	≥ 805	100	100	∞	-
VMRT ST O/I Ratio	.760	≥ 1.21	80	80	16.0	1.2
WBRA Diag RT (ms)	.880	≥ 795	60	100	15.4*	1.0
WBRA Diag Spd (m/s)	.680	≤ 0.93	100	60	15.4*	1.0
WBRA Lat Acc (m/s^2)¥	.700	≤ 2.50	100	60	12.6*	0.8
WBRA Lat Dec (m/s^2)¥	.800	≤ 2.12	100	60	12.6*	0.8
WBRA Lat Spd (m/s)¥	.800	≤ 0.76	100	60	12.6*	0.8
WBRA Lat Acc Asym (%)¥	.800	≥ 40	100	60	12.6*	0.8
WBRA Lat RT Asym (%)†	.688	≥ 15	75	75	9.0	0.6
WBRA Lat RT (ms)†	.656	≥ 610	50	100	9.0*	0.5
WBRA Diag Acc (m/s^2)	.680	≤ 2.38	100	40	7.9*	0.5
WBRA Diag Dec (m/s^2)	.640	≤ 1.53	40	100	7.9*	0.5
WBRA Diag Time (s)	.640	≥ 62	40	100	7.9*	0.5
WBRA Diag Dist (m)	.600	≥ 24.90	100	40	7.9*	0.5
VMRT DT L-R Diff (ms)	.620	≥ 45	60	80	6.0	0.6

Table 4. High Linear Acc (25 g) Hits ≥ 9.25 per Session

Metric	AUC	Cut-Point	Sensitivity	Specificity	OR	CLL
VMRT ST (ms)	1.00	≥ 805	100	100	∞	-
VMRT ST O/I Ratio	.760	≥ 1.21	80	80	16.0	1.2
WBRA Diag RT (ms)	.880	≥ 795	60	100	15.4*	1.0
WBRA Diag Spd (m/s)	.680	≤ 0.93	100	60	15.4*	1.0
WBRA Lat Spd (m/s)¥	.800	≤ 0.76	100	60	12.6*	0.8
WBRA Lat Acc Asym (%)¥	.800	≥ 40	100	60	12.6*	0.8
WBRA Lat Acc (m/s^2)¥	.700	≤ 2.50	100	60	12.6*	0.8
WBRA Lat RT Asym (%)†	.688	≥ 15	75	75	9.0	0.6
WBRA Diag Acc (m/s^2)	.680	≤ 2.38	100	40	7.9*	0.5
WBRA Diag Dec (m/s^2)	.640	≤ 1.53	40	100	7.9*	0.5
WBRA Diag Time (s)	.640	≥ 62	40	100	7.9*	0.5
WBRA Diag Dist (m)	.600	≥ 24.9	100	40	7.9*	0.5
WBRA Lat Dec (m/s^2)¥	.800	≤ 2.18	100	40	6.4*	0.4
VMRT DT L-R Diff (ms)	.620	≥ 45	60	80	6.0	0.6
WBRA Lat RT (ms)†	.656	≥ 595	50	75	3.0	0.2

CLINICAL RELEVANCE

- Despite very small cohort size, numerous exceptionally strong associations found between RHI and visual-motor control metrics
  - 39 of 49 associations exhibited 100% sensitivity and/or 100% specificity; 19 of 49 associations exhibited an OR ≥ 15
- Our findings support emerging evidence that neurological impairments can result from RHI that do not present clinical symptoms
  - Helmet sensor measures suggest adverse neuromechanical effects of RHI, despite use of helmet pad during contact practices
- Slow reaction time and/or impairment of visual-spatial orientation may be critically important indicators of altered brain processes
  - RHI appeared to affect VMRT (ST & DT), VMRT DT L-R Diff, VMRT ST O/I Ratio, WBRA Diag RT, and WBRA Diag Spd values
- Collectively, the study findings are consistent with previously reported RHI effects on speed and efficiency of neural information processing between brain hemispheres,[1-3] which we found to be manifested as slowed RT and impaired visual-spatial awareness

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