Descriptive Analysis of Preseason Baseline Data Collected From University Varsity Student-Athletes Using a Comprehensive Concussion Assessment Battery

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BACKGROUND & OBJECTIVES

- Diagnosis and management of sport-related concussion (SRC) can be difficult due to the heterogenous presentation and resolution of symptoms and impairments. Therefore, a multifaceted, interdisciplinary and individualized assessment approach is essential for SRC.[1]
- This approach should include a variety of assessment tools and non-invasive procedures that evaluate symptoms[1,2] and various measures of neurocognitive functioning,[2,3] balance and postural sway,[2,4] cerebral blood flow,[5,6] cognitive-motor integration (CMI)[7,8] and oculomotor function.[9]
- The Varsity Athlete Data Analysis Research (VADAR) Consortium was established at York University as a long-term initiative to compare the heterogenous features of SRC in male and female varsity student-athletes using a comprehensive battery of assessment tools and emerging tests.
- First action item of the VADAR Consortium was to collect baseline data from a large cohort of university varsity student-athletes to optimize our assessment approach to SRC and to obtain a normative dataset.
- The objectives of this study were twofold:
  1. **To conduct a descriptive analysis of preseason baseline data collected from York University varsity student-athletes using a comprehensive battery of assessments.**
  2. **To examine the effects of sex, concussion history and interaction effects between sex and concussion history on assessment variables.**

METHODS

- Assessments were performed at York University's Goreman/Shore Sport Injury Clinic in August 2019.
- Athletes completed consent forms and a demographic/medical info sheet which screened them for the following:

Inclusion Criteria	Exclusion Criteria
• $\geq$ 18 years of age • No reported history of concussion **(No RHOC)** • Reported history of medically diagnosed concussion **(RHOC)**	• In concussion protocol at assessment date • Strabismus, colour blind or epilepsy diagnosis • History of neck pain within previous two years • Musculoskeletal injury to the knee, hip, ankle • Medications that may alter cerebral blood flow

Assessments

1. Sport Concussion Assessment Tool 5 (SCAT5)[10]

- Total number of baseline symptoms (out of 22) and total symptom severity score (out of 132).
- Standard Assessment of Concussion cognitive tests scores for five-word immediate memory (out of 15), five-word delayed recall (out of 5) and concentration (out of 5).
- Modified Balance Error Scoring System (mBESS) errors made in the double leg, single leg and tandem stance were summed to obtain the mBESS total error score (out of 30).

2. Force Plate Postural Sway Assessment

- Centre of pressure (COP) measures were quantified in **anteroposterior (AP)** and **mediolateral (ML) directions** during two 80 sec quiet standing tasks performed with **eyes open (EO)** and **eyes closed (EC)** on an AMTI AccuSway force plate.
- Formulas from Prieto et al[11] were used to calculate following: 95% confidence ellipse area (AREA-CE) (mm^2); root-mean-square COP displacement (RMSdisp) (mm); mean COP velocity (COPvel) (mm/sec); range of COP displacement (mm).

3. Brain Dynamic Indicator™ (BrDI™)

- Comprised of a **standard condition (Figure 1A)** and a **CMI condition (Figure 1B)**.
- Athletes completed five trials in four target directions (left, right, up, down) per condition.
- BrDI™ variables: ballistic movement time (MTb) (sec); full movement time (MTf) (sec); reaction time (RT) (sec); peak velocity (PV) (mm/sec); normalized path length (PLfN) (%); absolute error (AE) (mm^2); variable error (VE) (mm^2).

4. HurtSHynes™ Test (Sport-specific version of the BrDI™)

- Athletes executed movement responses to four visual directional cues (left, right, up, down) administered by an examiner while running a timed 26 m sprint **(see Figure 2 for description of the "Up" visual cue and athlete responses)**.
- Comprised of a **standard condition** (*responses matched visual cues*) and a **CMI condition** (*responses were opposite to visual cues*). Completion time (ms) and the number of errors were recorded per condition.

5. Ultrasound Cerebral Blood Flow Volume (BFV) Assessment

- Portable LOGIQ™ e ultrasound system was used to measure blood flow velocity, vessel diameter and cross-sectional area (CSA) of the **common carotid (CCA)**, **internal carotid (ICA)** and **vertebral artery (VA)** bilaterally **(Figure 3)**.
- Cerebral BFV volume (mL/min) was estimated for each cervical artery bilaterally using the formula from Schöning et al[12]:

time-averaged mean velocity (cm/sec) x vessel CSA (cm^2) x 60 sec to adjust for one cardiac cycle

6. Oculomotor Assessment

- Administered using NeuroFlex® Software Program and FOVE® Virtual Reality headset.
- **Saccade task:** rapid eye movements directed towards a series of targets; saccade latency (ms) recorded per eye movement.
- **Antisaccade task:** voluntary eye movements directed in an equidistant and opposite direction of a red target; antisaccade reaction time (ms) recorded per eye movement.

7. Computerized Stroop Colour and Word Test (SCWT)

- Comprised of a **word task** (*identify the colour word)*, a **colour task** (*identify the colour of the 'X' letter sequences*) and an **interference task** (*identify the ink colour of the colour word).* Athletes provided responses to as many items as possible within 45 secs per task. The number of errors per task were summed to obtain the total number of SCWT errors.

Statistical Analysis

- Descriptive statistics (mean $\pm$ SD or n (%)) were calculated for demographic characteristics. Data for each assessment was stratified by sex and concussion history for descriptive analyses (mean $\pm$ SD).
- Two-way ANOVA was used to examine the effects of sex, concussion history and interaction on each assessment variable. Statistical significance was accepted at $P < 0.05$ for all analyses.

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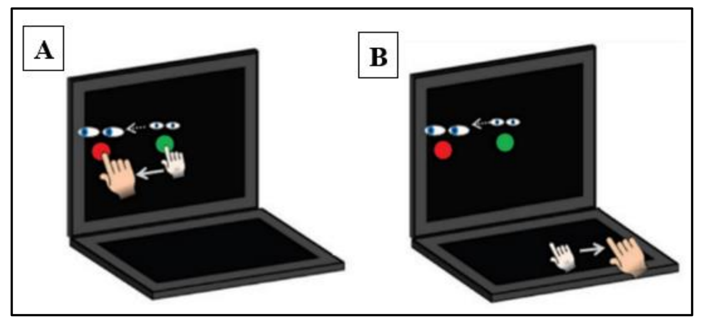

Figure 1. Illustration of the Brain Dynamic Indicator™. **(A)** Vision and hand movements were aligned in the standard condition. **(B)** Vision and hand movements in the cognitive-motor integration condition were decoupled to plane change (eyes gaze at red target on the vertical screen while gliding finger along horizontal screen) and cue reversal (cursor movement 180° rotated from hand motion). Illustration reprinted from Smeha et al[13] with permission under the terms of the Creative Commons CC BY license (link: https://creativecommons.org/licenses/by/4.0/).

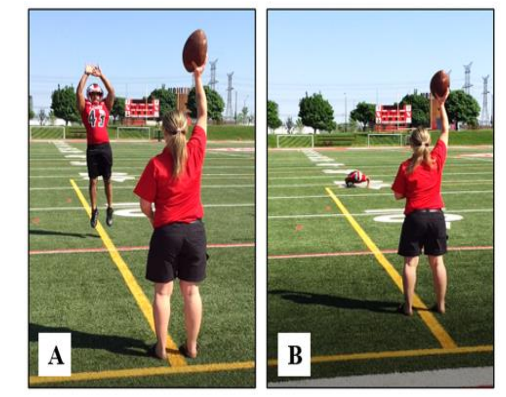

Figure 2. "Up" visual cue of the HurtSHynes™ Test and the corresponding athlete responses per condition. **(A)** Standard condition (*responses matched visual cues*): examiner raised the football over their head, the correct response from the running athlete was to jump up with both hands in the air. **(B)** Cognitive-motor integration condition (*responses were opposite to visual cues*): examiner raised the football over their head, the correct response from the running athlete was to drop down into a push-up stance. Images reprinted from master's thesis submitted by colleague Christina Amaral.[14]

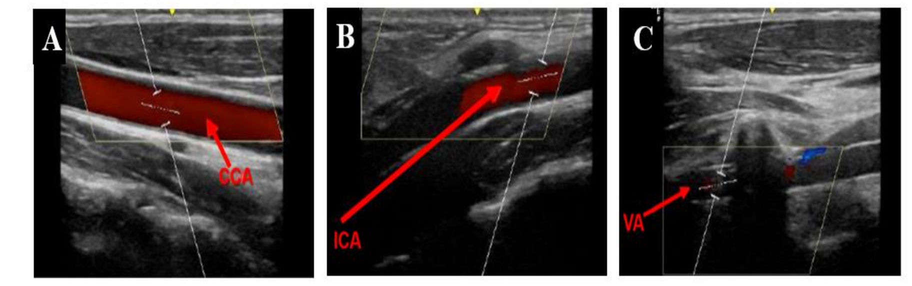

Figure 3. Doppler ultrasound imaging of the cervical arteries. **(A)** The common carotid artery (CCA) imaged in the longitudinal plane. **(B)** The internal carotid artery (ICA) imaged at the level of bifurcation of the CCA. **(C)** The vertebral artery (VA) imaged at the level of the intertransverse segments of the cervical vertebrae. Images reprinted from master's thesis submitted by colleague Ravneet Kalkat.[15]

RESULTS

Table 1. Descriptive statistics for demographic characteristics of male and female university varsity student-athletes.

Characteristic	Male (n = 165)	Female (n = 160)
Age, mean $\pm$ SD	20.18 $\pm$ 1.82	19.84 $\pm$ 1.78
Previously diagnosed concussions, n (%)		
0	103 (62.42)	82 (51.25)
1	39 (23.64)	43 (26.88)
2	13 (7.88)	23 (14.38)
$\geq$ 3	10 (6.06)	12 (7.5)
Years since last concussion, mean $\pm$ SD	3.19 $\pm$ 2.63	2.28 $\pm$ 2.52
Varsity sport, n (%)		
Basketball	18 (10.91)	13 (8.13)
Cross-country	3 (1.82)	6 (3.75)
Field hockey	-	18 (11.25)
Football	33 (20)	-
Ice hockey	34 (20.61)	24 (15)
Rugby	-	24 (15)
Soccer	24 (14.55)	25 (15.63)
Tennis	5 (3.03)	4 (2.5)
Track and field	22 (13.33)	27 (16.88)
Volleyball	14 (8.48)	14 (8.75)
Wrestling	12 (7.27)	5 (3.13)

RHOC, reported history of concussion.

Table 2. Student-athlete sample sizes for each assessment stratified by sex and concussion history.

	Sex		Concussion History	
Assessments	Male	Female	No RHOC	RHOC
SCAT5†	147	150	165	131
Force Plate Postural Sway Assessment	149	137	160	126
Ultrasound Cerebral BFV Assessment	38	41	38	41
BrDI™	70	58	89	39
HurtSHynes™ Test	114	113	114	113
Oculomotor Assessment	87	74	84	77
Computerized SCWT	87	73	83	77

RHOC, reported history of concussion; No RHOC, no reported history of concussion; SCAT5, Sport Concussion Assessment Tool 5; BFV, blood flow volume; BrDI, Brain Dynamic Indicator; SCWT, Stroop Colour and Word Test

† Mean sample sizes are listed for SCAT5 due to variation in the number of athletes that provided data for each component or test.

Table 3. Significant interaction effects on assessment variables in university varsity student-athletes.

Variable	Description of Interaction Effects
BrDI™	
VE (mm^2)	Female athletes with a RHOC exhibited significantly larger VE in standard condition compared to male athletes with a RHOC ($P = 0.022$).
HurtSHynes™ Test	
Completion time (sec)	Female athletes with No RHOC had significantly longer completion times in standard condition compared to male athletes with No RHOC ($P = 0.001$).
Total errors	Male athletes with No RHOC made significantly more errors in the CMI condition compared to female athletes with No RHOC ($P = 0.018$).

RHOC, reported history of concussion; No RHOC, no reported history of concussion; BrDI, Brain Dynamic Indicator; VE, variable error; mm^2, millimetres squared; sec, seconds; CMI, cognitive-motor integration.

Table 4. Significant effects of sex and concussion history observed on assessment variables in university varsity student-athletes.

	Sex		Concussion History	
Variable	Male	Female	RHOC	No RHOC
SCAT5				
Total number of baseline symptoms			↑ ($P = 0.007$)	
Total symptom severity score			↑ ($P = 0.015$)	
Five-word immediate memory score		↑ ($P = 0.008$)		
Five-word delayed recall score		↑ ($P = 0.006$)		
Concentration total score		↑ ($P = 0.02$)		
mBESS errors	↑ Single leg errors Tandem errors ($P < 0.001$) Total errors			
Force Plate Postural Sway Assessment				
AREA – CE (mm^2)	↑ EO ($P = 0.032$) EC ($P = 0.001$)			
RMSdisp AP (mm)	↑ EO ($P = 0.009$) EC ($P < 0.001$)			
COPvel AP (mm/sec)	↑ EO ($P = 0.013$) EC ($P < 0.001$)			
Range AP (mm)	↑ EO ($P = 0.026$) EC ($P = 0.002$)			
RMSdisp ML (mm)	↑ EC ($P = 0.006$)			
COPvel ML (mm/sec)	↑ EC ($P = 0.007$)			
Range ML (mm)	↑ EO ($P = 0.045$) EC ($P = 0.016$)			
Ultrasound Cerebral BFV Assessment				
CCA BFV (mL/min)	↑ Left CCA ($P < 0.001$) Right CCA ($P = 0.003$)		↓ Right CCA ($P = 0.032$)	
ICA BFV (mL/min)	↑ Left ICA ($P = 0.023$) Right ICA ($P = 0.001$)			
VA BFV (mL/min)		↑ Left VA ($P = 0.032$)		
BrDI™				
PV (mm/sec)	↑ Standard ($P = 0.002$) CMI ($P < 0.001$)			
VE (mm^2)		↑ Standard ($P = 0.049$)		
MTf (sec)	↑ CMI ($P = 0.002$)			
HurtSHynes™ Test				
Total errors	↑ CMI ($P = 0.031$)			

RHOC, reported history of concussion; No RHOC, no reported history of concussion; SCAT5, Sport Concussion Assessment Tool 5; mBESS, modified Balance Error Scoring System; AP, anteroposterior; ML, mediolateral; EO, eyes open; EC, eyes closed; AREA – CE, 95 % confidence ellipse area; mm^2, millimetres squared; RMSdisp, root-mean-square centre of pressure displacement; COPvel, mean centre of pressure velocity; mm/sec, millimetres per second; range, range of centre of pressure displacement; BFV, blood flow volume; CCA, common carotid artery; ICA, internal carotid artery; VA, vertebral artery; mL/min. millilitres per minute; BrDI, Brain Dynamic Indicator; PV, peak velocity; VE, variable error; MTf, full movement time; sec, seconds; CMI, cognitive-motor integration condition.

P values are based on a two-way ANOVA.

↑ Mean value significantly higher in athletes with a RHOC compared to athletes with No RHOC.

↓ Mean value significantly lower in athletes with a RHOC compared to athletes with No RHOC.

↑ Mean value significantly higher in male athletes compared to female athletes.

↑ Mean value significantly higher in female athletes compared to male athletes.

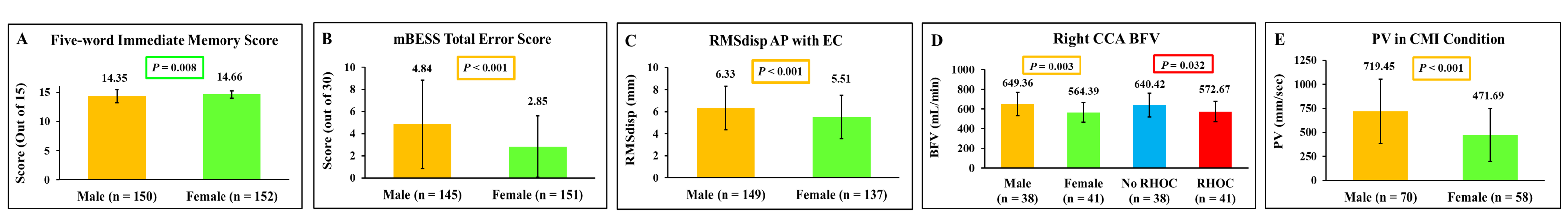

Figure 4. Bar charts displaying significant effects of sex and concussion history on assessment variables based on two-way ANOVA. Mean values for each group are provided per variable. **(A)** A significant effect of sex was observed for five-word immediate memory score within the Sport Concussion Assessment Tool 5 (SCAT5). Female athletes had a significantly higher mean five-word immediate memory score compared to male athletes. Note the ceiling effects in scoring in both male and female athletes. **(B)** A significant effect of sex was observed for modified Balance Error Scoring System (mBESS) total error score. Male athletes had a significantly higher mean mBESS total error score compared to female athletes. **(C)** A significant effect of sex was observed for root-mean-square centre of pressure displacement (RMSdisp) quantified in the anteroposterior direction (AP) during quiet standing on a force plate with eyes closed (EC). Male athletes had significantly larger mean RMSdisp in the AP direction with EC compared to female athletes. **(D)** Significant effects of sex and concussion history were observed for cerebral blood flow volume (BFV) within the right common carotid artery (CCA). For the significant effect of sex, male athletes exhibited significantly higher mean cerebral BFV in the right CCA compared to female athletes. For the significant effect of concussion history, athletes with a reported history of concussion (RHOC) exhibited significantly lower mean cerebral BFV in the right CCA compared to athletes with no reported history of concussion (No RHOC). **(E)** A significant effect of sex was observed for peak velocity (PV) in the cognitive-motor integration (CMI) condition of the Brain Dynamic Indicator™. Male athletes exhibited faster mean PV in the CMI condition compared to female athletes.

DISCUSSION

- Significantly greater number of baseline symptoms in athletes with a RHOC compared to athletes with No RHOC **(Table 4)** is consistent with findings observed in high school and collegiate/university varsity athletes.[16,17]
- The observed ceiling effect in scoring on the SCAT5 five-word immediate memory test **(Figure 4A)** has previously been demonstrated in high school and collegiate/university varsity athletes at baseline.[2,17]
- Male athletes made significantly more mBESS errors **(Table 4, Figure 4B)** and exhibited significantly faster COPvel and larger RMSdisp compared to female athletes **(Table 4, Figure 4C)**. These results align with studies that examined baseline mBESS scores[2,18] and COP measures of postural sway in various athlete cohorts.[19,20]
  - Anthropometric or anatomical differences and previous competitive experience in artistic sports are potential factors underlying the significant effects of sex on mBESS errors and COP measures of postural sway.[20]
- Male athletes had significantly higher bilateral BFV in the CCA and ICA compared to female athletes **(Table 4)**.
- Athletes with a RHOC had significantly lower BFV in the right CCA compared to athletes with No RHOC **(Table 4, Figure 4D)**.
  - While studies have found significantly reduced CBF in concussed athletes compared to matched healthy athletes,[5,6] long-term studies on sex differences in CBF in athletes with a history of SRC are scarce.[21]
- The current study is the first to report significant effects of sex on BrDI™ variables **(Table 4)**. Previous studies found no significant effects of sex on BrDI™ variables in university varsity[7] and youth athlete cohorts.[8]
  - Significantly higher PV in male athletes compared to female athletes **(Table 4, Figure 4E)** could be the result of male athletes possessing highly developed skills in executing eye-hand coordination tasks extremely fast.
- Athletes with a RHOC exhibited no deficits on the BrDI™ and HurtSHynes™ Test, which indicates that they had cognitively recovered from their previous concussions.
- No significant effects of sex, concussion history and interaction were observed on saccade latency, antisaccade reaction time and errors made in each of the three SCWT tasks.
- A healthy survivor effect may have occurred in the cohort of athletes with a RHOC. Former athletes that retired during adolescence due to a history of one or multiple SRCs and persisting concussion symptoms may exhibit impairments on some of the assessments administered in this study.
- Concussion history reporting may have been influenced by recall bias. Some athletes may have chosen not to disclose a recent history of SRC in order to start their season on time without delay.

FUTURE DIRECTIONS

- SCAT5 ten-word list for immediate memory and delayed recall tests should be administered at baseline and post-concussion time points to eliminate ceiling effects in scoring.
- Subjective assessments for a specific metric can be paired with an objective assessment for a similar metric when evaluating impairments following SRC and to longitudinally monitor recovery.
  - Ex. The BrDI™ can be administered during the acute stage of SRC to objectively assess CMI deficits. The HurtSHynes Test™ can be co-administered with the BrDI™ during the athlete's return to sport progressions when they have been medically cleared to engage in sport-specific activities.
- Develop sex-specific models for measures of balance, COP measures of postural sway and cerebral BFV to enhance our understanding of sex-related differences in athletes following SRC and during recovery.

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