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Does baseline concussion testing aid in identifying future concussion risk?

Jaclyn B. Caccese, PhD,

University of Delaware, Department of Kinesiology and Applied Physiology

Kassandra E. Johns, MS, ATC,

Georgia Southern University, School of Health and Kinesiology

Jody L. Langdon, PhD,

Georgia Southern University, School of Health and Kinesiology

George W. Shaver, PsyD,

Georgia Southern University, Regents Center for Learning Disorders

Thomas A. Buckley, EdD, ATC

University of Delaware, Department of Kinesiology and Applied Physiology and Interdisciplinary Biomechanics and Movement Science Program

Abstract

The purpose was to determine differences in pre-season baseline performance between student-athletes who suffered a future sport-related concussion (fSRC) and those who did not. Collegiate student-athletes (82 fSRC, 82 matched control, age=18.4±0.8years, height=172.7±10.3cm, mass=80.1±20.9kg) completed baseline Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), Balance Error Scoring System (BESS), and Standardized Assessment of Concussion (SAC). Results of the independent t-tests suggested there were no differences between the fSRC and the control groups for ImPACT composite scores (95% confidence intervals, Visual Memory: fSRC 70.4–75.9, Control 73.4–78.5, $p=0.134$; Verbal Memory: fSRC 83.8–87.7, Control 85.7–89.9, $p=0.155$; Reaction Time: fSRC 0.562–0.591, Control 0.580–0.614, $p=0.071$; Visual Motor Speed: fSRC 38.5–41.1, Control 38.2–40.9, $p=0.757$), BESS total errors (fSRC 11.3–13.7, Control 11.8–14.4, $p=0.483$), or SAC (fSRC 26.6–27.4, Control 26.9–27.6, $p=0.394$). Receiver operating characteristic (ROC) areas-under-the-curve were 0.417–0.515. Our findings suggest that baseline concussion assessments cannot be used to predict individuals who may sustain a fSRC.

Keywords

prevention; mild Traumatic Brain Injury (mTBI); ImPACT; neuromuscular control

Introduction

There are a growing number of sport-related concussions (SRCs) annually (Bakhos et al., 2010), so determining factors that elevate a student-athlete's risk of sustaining SRCs is of utmost importance. There are potential risk factors, such as a student-athlete's age, that are not modifiable (Emery et al., 2017). Other potential risk factors are modifiable, such as lower neck strength and practice/game contact time modifications (Emery et al., 2017; Wasserman et al., 2018). Understanding potentially modifiable risk factors can aid in developing SRC-prevention strategies, including equipment modifications, rule changes, and individual injury prevention strategies (Emery et al., 2017; Schneider et al., 2016).

One modifiable risk factor includes pre-existing deficits in neurocognitive function. For example, baseline neurocognitive performance has been used as a correlate of neuromuscular control and coordination to identify individuals at elevated risk of future non-contact anterior cruciate ligament (ACL) injuries (Swanik et al., 2007). These same deficits may also predispose individuals to SRC. If clinicians can identify individuals at elevated risk of future SRC (fSRC) from baseline performance on SRC assessments, then potential targeted interventions can be developed. The purpose of this study was to determine differences in pre-season (baseline) performance between student-athletes who later went on to suffer a fSRC and those who did not. We hypothesized the fSRC group would present with worse baseline testing performance in both neurocognitive assessments and balance testing.

Materials and Methods

Participants

There were 545 potential participants with baseline assessments performed pre-season over four years. From this, there were 82 concussions (of 107), which had complete baseline scores and had matched healthy participants. Therefore, 164 collegiate student-athletes (82 fSRC, 82 control) were used in analyses (Table 1). All SRCs were reported to an athletic trainer and then referred to and diagnosed by a team physician based on the 3rd Consensus Statement on Concussion in Sport definition, the guidelines at the time the study was conducted (McCrory et al., 2009). Control participants were matched based on self-reported previous concussion history, sex, sport, and position (Table 1). Exclusionary criteria were incomplete or invalid baseline tests. Participants provided written informed consent as approved by the university's institutional review board.

Procedures

Participants completed baseline measurements, including the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), Balance Error Scoring System (BESS), and Standardized Assessment of Concussion (SAC) on one occasion prior to participating in intercollegiate athletics. Each assessment has been described in detail elsewhere but is described briefly below (Broglia et al., 2018; Katz et al., 2018),

- The ImPACT is the most widely used computerized neuropsychological test for SRC baseline testing and evaluation (Kelly et al., 2014). There are six test

modules, which are used to evaluate attention span, working memory, sustained and selective attention time, response variability, non-verbal problem solving, and reaction time. From the six test modules, four composite scores are generated, including Verbal Memory (higher score is better), Visual Memory (higher score is better), Visual Motor Speed (higher score is better), and Reaction Time (lower score is better).

- The BESS is the most commonly used test for the evaluation of postural control following SRC (Buckley et al., 2016). The BESS involves three different stances (double limb stance, single limb stance and tandem stance) on two surfaces (firm and foam). Each position is held for 20 seconds with the participants' eyes closed and hands on their hips. Errors are recorded by the administering clinician, and total scores range 0–60, where a lower score reflects “better” balance. All BESS tests were video recorded and scored by the same examiner.
- The SAC is a mental status exam consisting of four sections: orientation, immediate memory, concentration, and delayed recall (McCrea, 2001a; McCrea, 2001b). It has a maximum total score of 30 points, and each incorrect answer results in a loss of one point, so a higher score reflects better cognitive performance.

Statistical Analysis

The outcome measures included ImpACT composite scores, total BESS score, and total SAC score. The independent variable was group (fSRC vs. control). The differences in baseline assessments between groups were determined through independent samples t-tests. Additionally, a receiver operator characteristic (ROC) curve determined the predictive ability of each outcome measure. Alpha was set a priori at 0.05 and a Bonferroni correction was used for multiple comparisons; significance was determined $p < 0.008$.

Results

There were no significant differences between the fSRC group and the control group for any of the outcome measures (Table 2). The ROC analyses indicated that all outcome measures had poor predictive ability (AUC 0.417–0.515) of fSRC (Figure 1).

Discussion

A clear understanding of potentially modifiable risk factors is required to identify individuals at elevated concussion risk and then develop prevention strategies. Herein, we explored the link between baseline concussion assessments and fSRC. We hypothesized that athletes with poorer performance on baseline testing would be more likely to sustain a fSRC due to the potential link between neurocognitive performance and neuromuscular control (Swanik et al., 2007). However, there were no differences between groups across any of the outcome measures tested. Moreover, baseline assessments had poor predictive ability of fSRC (ROC AUC 0.417–0.515), which can be interpreted like a coin flip or worse. Therefore, clinical baseline concussion assessments were unable to predict fSRC, suggesting that neurocognitive differences do not predispose certain individuals to SRC.

Conversely, athletes who suffered future non-contact ACL injuries had poorer neurocognitive performance on ImPACT during their pre-season tests (Swanik et al., 2007). We speculated that the same may be true for SRC because impairments in neuromuscular control and coordination may result in poorer reactive movement strategies. Our findings did not support this hypothesis. Non-contact ACL injuries are associated with deficits in neuromuscular control (Swanik et al., 2007). While it would seem possible that errors in neuromuscular control and coordination could put athletes at increased risk for SRC, it may be that concussions are more subject to chance (e.g. a hard hit by a defender) than non-contact injuries such as ACL injuries (Chandran et al., 2018). Alternately, recent findings suggest that SRC impacts are among the most severe for each individual player, suggesting tolerance to head acceleration might be individual-specific (Rowson et al., 2018). In addition, these clinical tests may lack discriminant ability because they were designed for acute concussion diagnosis. Finally, ACL injuries have definitive diagnoses that can be confirmed via physician physical examination and MRI with high sensitivity, whereas concussion requires clinical judgement supported by objective testing, and may leave some room for interpretation or go unreported. The potential for unreported SRC is a limitation; however, athletic trainers monitored all practices/games, which may have mitigated the potential for unreported/undiagnosed SRC (Craig et al., 2019).

In summary, our findings suggest that baseline concussion assessments are not different between individuals who sustain a fSRC and those who do not. Additionally, baseline concussion assessments have poor predictive ability for fSRC. Future studies should investigate other potentially more sensitive measures of neuromuscular control and coordination to aid in identifying individuals fSRC risk.

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Figure 1.

Overlay of ROC analyses for outcome measures, including 1a) ImPACT composite scores (area under the curve (AUC): Visual Memory=0.435, Verbal Memory=0.432, Reaction Time=0.417, Visual Motor Speed=0.515), 1b) SAC and BESS (AUC: BESS=0.476, SAC=0.456).

Table 1.

Demographic information. Mean $\pm$ Standard Deviation. There were no group differences in age ($p=0.185$), height ($p=0.113$), weight ($p=0.660$), or concussion history ($p=0.808$).

	SRC	Control	Total
N	82	82	164
Females (N)	37	37	74
Age (years)	18.5 $\pm$ 0.9	18.3 $\pm$ 0.8	18.4 $\pm$ 0.8
Height (cm)	173.9 $\pm$ 11.5	170.9 $\pm$ 7.8	172.7 $\pm$ 10.3
Mass (kg)	79.5 $\pm$ 22.1	81.2 $\pm$ 18.8	80.1 $\pm$ 20.9
Concussion History (N)	0.6 $\pm$ 0.9	0.6 $\pm$ 1.0	0.6 $\pm$ 1.0
Days from baseline to concussion or analysis	Median = 274 Range 3–1170	Median = 505 Range 1–1287	Median = 380 Range 1–1287
Sports (N)			
Football	36	20	56
Women's Soccer	10	5	15
Men's Soccer	3	12	15
Women's Basketball	5	2	7
Men's Basketball	2	2	4
Women's Tennis	1	2	3
Cheerleading	20	13	33
Swimming	1	7	8
Track	2	2	4
Volleyball	2	6	8
Baseball	0	8	8
Softball	0	3	3

Table 2.

Outcome measures and results of independent samples t-tests between groups (fSRC and Control).

		N	Mean	Std. Deviation	95% Confid. Interval		t	p	Cohen's d
					Lower Bound	Upper Bound			
Visual Memory	fSRC	82	73.12	12.45	70.39	75.86	-1.507	0.134	0.235
	Control	82	75.95	11.57	73.41	78.49			
	Total	164	74.54	12.07	72.68	76.40			
Verbal Memory	fSRC	82	85.74	8.90	83.79	87.70	-1.428	0.155	0.224
	Control	82	87.82	9.67	85.69	89.94			
	Total	164	86.78	9.32	85.34	88.22			
Reaction Time	fSRC	82	0.577	0.066	0.562	0.591	-1.818	0.071	0.266
	Control	82	0.597	0.076	0.580	0.614			
	Total	164	0.587	0.071	0.576	0.598			
Visual Motor Speed	fSRC	82	39.83	5.93	38.53	41.14	0.310	0.757	0.049
	Control	82	39.54	6.01	38.22	40.87			
	Total	164	39.69	5.96	38.77	40.61			
BESS	fSRC	82	12.46	5.37	11.27	13.66	-0.703	0.483	0.112
	Control	82	13.09	5.87	11.78	14.39			
	Total	164	12.78	5.62	11.90	13.65			
SAC	fSRC	82	27.01	1.73	26.63	27.39	-0.854	0.394	0.133
	Control	82	27.24	1.73	26.86	27.62			
	Total	164	27.13	1.73	26.86	27.40			