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Original Article

A SPORTS CONCUSSION BASELINE IMPLEMENTED AT THE CONCLUSION OF A COLLEGIATE ATHLETE'S CAREER

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ABSTRACT

As concussion diagnosis persists as a major clinical challenge for sports medicine practitioners, there has been a heightened emphasis on concussion baselines. This has led to an increase in computerized neuropsychological baselines that are initiated at the beginning of an athlete's career and administered again upon a suspected concussion. However, their utility and reliability have been called into scrutiny. As the brain health of athletes rightly remains a key priority, there have been no studies positing a concussion baseline as part of an athlete's exit health physical to document their brain health after their athletic career. The purpose of this report is to present a noncomputerized, objective, neurologically supported concussion baseline that can be used to document athletes' brain health at the end of their careers. A total of 31 division-1 male collegiate football players were assessed using this baseline, and their data was reported.

Keywords: Sports-Related Concussion, Baseline, Documentation, Brain Health, Traumatic Brain Injury

INTRODUCTION

Traumatic brain injury (TBI) is a major cause of morbidity and mortality throughout the world. In the United States alone, the Center for Disease Control and Prevention (CDC) reports that there were around 61,000 TBI-related deaths in 2019. A TBI is defined as a bump, blow, or jolt to the head or a hit to the body that results in the brain's rapid acceleration and deceleration.[1] They are characterized clinically by using the Glasgow Coma Scale (GCS) into a mild traumatic brain injury (mTBI), moderate TBI (MTBI), or severe TBI (STBI).[1,2] A mTBI is defined on the less severe side with a GCS score of greater than or equal to 13.[1,2] In the clinic and throughout the literature, the terms mTBI and concussion are used interchangeably.[3,4] A recent report using data from emergency department visits, office visits, and a high school injury surveillance system estimates

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that approximately 1.0 to 1.8 million sports-related concussions (SRC) occur annually with a subset of around 400,000 SRCs occurring amongst high school athletes.[5] This categorizes athletes of all ages as high-risk for sustaining an SRC.[6] As the notoriety of concussions increases amongst the public, there have been many attempts to help protect athletes, such as legislation, rule changes, and equipment alterations. Still, the success of these interventions appears limited.[7,8]

Although our understanding of concussions has grown substantially over the past decade, the diagnosis, management, and treatment of this injury remains a challenge for sports medicine practitioners. Concussion diagnosis is complicated due to a lack of validated, objective diagnostic tests, a reliance of self-reported symptoms, and confounding symptoms caused by other common conditions (i.e., attention deficit hyperactivity disorder).[9,10] Concussions may cause a variety of nonspecific symptoms such as headache, mood changes, lack of concentration, fogginess, visual changes, fatigue, and more that make distinguishing between concussion etiology and other pathology difficult.[11] Furthermore, if left untreated, there are numerous studies suggesting the development of post-concussion syndrome.[11] This has led to the widespread adoption of computerized neuropsychological baseline assessments.[12,13] These computerized baselines are usually administered to an athlete at the beginning of the season and once again upon the incurrence of a suspected SRC.[12–14] This method is used to detect changes in neuropsychological measures that may be helpful in SRC diagnosis. However, a growing body of literature calls into question the utility and reliability of these computerized baselines, further demonstrating the need for better objective diagnostic metrics.[15–17]

Despite their prevalent use at the beginning of the season and upon the suspected SRC, no known studies are using computerized neuropsychological baseline assessments after player's athletic career. This report presents the first known use of a noncomputerized, neuro-centric baseline at the end of an athlete's career. This study aims to provide a way to assess and document the athlete's brain health upon the end of their athletic career using neurologically supported, objective metrics.

METHODS

This study was reviewed and approved by the UC Institutional Review Board #2017-3008. Personal and medical information about an identifiable living person were not reported. The care or management was not changed for athletes assessed in this study. Included in this study were a total of 31 male division-1 collegiate football players between 21 and 23 years old. All athletes baselined did not return the following year for further sports participation due to exhausted eligibility. Each athlete was subjected to our neuro-centric sports concussion baseline as a part of their routine end-of-career health physical.

The proposed noncomputerized baseline is a battery of established neurological assessments grouped to provide a comprehensive view of brain function. Figure 1 and 2 represent the consent form administered before completing the baseline and a data collection tool for this proposed baseline. Most of these methods have been published elsewhere, but for completeness, we have included an overview of them directly in this report.[18–24] Our neurologic baseline includes measurements of eye-hand coordination,[18] a variety of reaction times[18,19] (motor, visual, central visual reaction time, and peripheral visual reaction time), stereopsis[20], neuro-reflexes, oculomotor function,[21–23] accommodation,[20–22] convergence,[21] proprioception, peripheral processing of movement and color perception,[18,23] as well as electroretinographical metrics, and structural images of the retinal cell layers within the back of the eye.[24] The totality of this neurologic baseline takes approximately 40 minutes per athlete and can accommodate up to 10 athletes per hour with a group of 3 to 5 testers proficient in the following methodologies.

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FIG. 1 Sports concussion exit baseline consent form.

Post-Season Sports Concussion Baseline Check-In Sheet

Name: ______________________ **Today's Date:** ______________

Signature: ______________________ **Date of Birth:** ______________

Parent/Guardian Signature (<18 years old): ______________________________

Sport-Related Information

Sport: ____________________ Position: ____________________

Height (*ft 'inch*): __________ Weight (*lbs*): __________ Handed (*left/right*): __________

Medically-Related & Relevant Information

____

____

____

____

____

____

History of Concussion(s)__________ (Y/N) Number and dates: ____________________

Eye Glasses: __________ (Y/N) Rx: ____________________

You must have corrected vision, wearing glasses or contacts, to do some of these tests.

Eye-Hand Coordination using the Dynavision D2™

The Dynavision D2™ by Dynavision Global Holdings LLC (DBA: Dynavision International) is a device that can record eye-hand coordination, motor, and visual reaction time data. The pre-programed *A exercise on the Dynavision D2 device was performed to assess eye-hand coordination. This program sequentially illuminates one button at a time for 60 seconds. Each time the athlete hits an illuminated button on the Dynavision, another light illuminates, and the athlete hits this newly lit button. This occurs for the entire 1-minute duration of the *A program. Essentially the instructions are to "hit as many buttons as possible within a 60-second run." The athlete was instructed to stand comfortably in an athletic stand, about eye level, and 18 to 22 inches from the center screen (T-Scope) on the

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FIG. 2 Sports concussion exit baseline data collection form.

NAME: ______________________________ DATE: ____________________

Tests:	Norms:	Results:		Initials:	Comments:
Dynavision					
Dynavision A* (hits per min)	> 70 bpm				
Reaction Test - Overall (sec)	< 0.40 sec				
Central Visual Rxn Time	-	L:	R:		
Peripheral Visual Rxn Time	-	L:	R:		
% Difference (Central/Peripheral)	< 20%	L:	R:		
Stereopsis					
Fly Wing (mm)	> 10 mm	L:	R:		
Randot ("X"/10)	≥ 4	________/10			
Phoropter		Only 1 eye required			
Horizontal Phoria	2-4 Eso	OD:	OS:		
Horizontal Phoria (Plus 1)		OD:	OS:		
Vertical Phoria	0	OD:	OS:		
ACA	4-6 Exo	OD:	OS:		
Ocular Motor Assessments					
Scanning Saccades - OU Dist.	≥ 30	________ in 1 min			
Reading Saccades - OU Close (sec)	< 60 sec(s)	________ sec(s)			
Near/Far - OU Dist.	≥ 25	________ in 1 min			
Brock String (inches)	< 3 inch(es)	________ inch(es)			
Electrophysiology					
RETeval - ERG	-	________ complete?			
OCT	-	________ complete?			
Other					
Confrontation of Visual Fields	> 75° / > 65°	R: __/__	L: __/__		
Closed Eye Turn	345-375°	R: ____°	L: ____°		
Eye Dominance	-	2H:	1H:		

Confrontation of Visual Fields				
	Red:	Blue:	Green:	Yellow:
Right (MVMT / Color):	___/___	___/___	___/___	___/___
Left (MVMT / Color):	___/___	___/___	___/___	___/___

Additional Tests (if needed):

Dynavision. After the 60-second assessment, the number of illuminated buttons pressed and the average reaction time (in seconds) were recorded.[18,21,23]

Reaction Tests using Dynavision D2™

Overall visual and motor reaction time assessments were measured using the off-the-shelf Mode C program on the Dynavision D2™ device. The athletes included in the study also performed the central visual reaction time (CVRT) and Peripheral Visual Reaction Time (PVRT) tests for the exit baseline. The specific methods for how we use the Dynavision D2™ device for concussion management, including both the CVRT and PVRT have been published in the Journal of Visualized Experiments.[18,19]

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Central Visual Reaction Time

To measure the CVRT, the subject was instructed to stand about 14 inches from and centered on an unlit button next to the center screen on the Dynavision. They were instructed to press and hold the lit button on the opposing side of the screen, engaging the button in front of them to light up randomly. Once lit up, the participant was instructed to hit it quickly. It is important to clarify that the participant can stare straight ahead at the button intended to light up for this assessment. The time between the button directly in front of the subject lighting up and then releasing the initial button was measured as their CVRT.[19]

Peripheral Visual Reaction Time

To measure the PVRT, the subject was instructed to stand about 14 inches from and center on the Dynavision's lit button. They were to press/hold the illuminated light until the button on the opposing side of the screen illuminated. This consisted of 3 tests for each side (one with a single row of possible buttons to light up, one with half of the board, and the last with a single button that would light up). An average of the time it took for the subject to release the button they were to hold after a new button illuminated for the three tests on each side (left and right) was recorded for this test.[19]

Calculated Difference between CVRT and PVRT

The difference between the CVRT and PCRT was calculated and recorded as part of this exit sports concussion baseline. The calculation for this measurement is (PVRT-CVRT)/CVRT.[19]

Stereopsis Assessment using a Stereo Fly and Randot

Stereopsis was measured with the Stereo Fly (Stereo Optical Company, Inc., Chicago, IL). This test is designed to evaluate both gross stereopsis and fine depth perception. The Stereo Fly test is used as a standard in stereo testing and only works with stereo glasses. Polarizing glasses were placed on the athlete, who was asked whether "the fly's wings appeared to be standing up at them and in three dimensions?" Subjects were instructed to observe the fly at 14 inches from their nose. If the response was positive, they were asked to "reach out and touch each of the fly's wing tips with the tip of a ballpoint pen and that position." The distance between the two-dimensional image and the ballpoint pen tip in space was recorded with a millimeter ruler. The higher number in millimeters indicates better stereopsis when measured on the Stereo Fly. Randot testing measures smaller increments of stereopsis by wearing polarized glasses and looking at a three-dimensional chart consisting of 10 diamonds, each made up of 4 circles. In each diamond, one circle had an added degree of difficulty and appeared to be three-dimensional. Subjects were instructed to identify the three-dimensional circle from each of the 10 diamonds. The correct amount was recorded.[20,21]

Neurologic Reflex Assessment with a Phoropter

A traditional phoropter was used to assess for each athlete's horizontal and vertical phorias and the Accommodative-Convergence-Accommodation (ACA) at 14 inches. The ACA was determined by assessing the horizontal phoria, re-assessing the horizontal phoria after adding 1 diopter, and finding the difference between the first and the second measured horizontal phorias. The horizontal phoria, horizontal phoria plus 1 diopter, vertical phoria, and ACA was recorded for each eye.

Near Oculomotor Measurement using Reading Saccades

One standard 10 × 10 alphanumeric Hart chart on a regular 8.5 × 11-inch sheet of paper was centered about 14 inches before the athlete. The athlete was instructed to read out loud the alphanumeric at the top of the left column and then the alphanumeric at the top of the right column and alternating down the two columns until the bottom is reached without moving their head, or in other words by only moving their eyes. Once the bottom of the first and tenth columns were reached, they would read the

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alphanumeric out loud at the top of the second column, alternating with the alphanumeric at the top of the ninth column, working down the columns. The athlete would continue this until the bottom alphanumeric of the fifth and sixth columns were read out loud. The time it took them to complete the entire sheet was recorded.[18,22,23]

Oculomotor and Accommodative Assessments using Near Far Sheets

Two standard 10 × 10 alphanumeric Hart charts were used, but one was printed at approximately half of the size dimensions as the normal one spanning the whole 8.5 × 11-inch piece of paper (10 × 10 alphanumeric on 4.25 × 6.5 paper or standard sheet folded in half). The athletes were instructed to stand about 10 feet from a wall where the normal 10 × 10 chart was hung and to hold the smaller chart about 14 inches from their face, aligning the bottom of the normal chart on the wall with the top of the handheld chart. The athletes were then instructed to read out loud each character starting with the character in the upper left corner of the smaller chart then the upper left character on the normal chart and alternating down the columns between the two charts for 1 minute without moving their heads, or in other words by only moving their eyes. Once the bottom of the first column was reached in both the near and far sheets, the athletes were instructed to continue the out loud reading but now with the top of the second column on both the near and far sheet. After the end of the 1 minute, the total number of alphanumerics read out loud was recorded.[22,23]

Convergence and Suppression Assessment using a Brock String

The athlete was instructed to hold the end of a string to the bridge of their nose. The instructor then oriented a bead about 14 inches from the bridge of the athlete's nose and pulled the string taut. The athlete was then told to stare at the bead for 10 seconds until convergence and accommodation occurred, and they perceived "two" strings. Once they reported they saw two strings, they were instructed to point to where the strings crossed. The distance between where the subject pointed and the spot of the bead was measured and recorded. It was also noted if the subject was under/over-converging based on whether the participant pointed beyond or before the bead. If the athlete was having difficulty perceiving two strings, this could indicate suppression, and the athlete should be referred to a health care provider for further testing.[18,20,23]

Peripheral Vision Motor & Color Processing using Confrontation of Visual Field

This test involved using a spotter (to monitor the athlete's eyes), a protractor, and four colored cards. The spotter stands approximately 5 feet from the athlete and eye level with them. The instructor stands behind the athlete, picks one of the colored cards, started shaking it up and down to create movement, held it about 18 inches from the athlete's head, and slowly moved forward from approximately 100 degrees, encroaching into the athlete's field of view. The athlete was instructed to call out which side the card was on when they first see the movement. Once the athlete calls out the movement, the instructor stops shaking the cards, but continues to advance the card slowly. The athlete is now instructed to call out what color the card is, continuing to use only their peripheral vision. The angles in degrees at which they reported seeing the card's movement and the card's color were both recorded (straight ahead from the subject being 0 degrees and horizontal from the athlete being 90 degrees).

Electroretinography using RETeval™ by LKC

The RETeval™ by LKC was used to stimulate the athlete's eyes with flashes of light, and data regarding electrical activity was recorded by the device. The amplitude, speed, and frequency of electrical responses to the stimulation were recorded. More information regarding the methods for this device can be found using the manufacturer recommendations at https://lkc.com/resources/research/lkc-videos/.

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Retinal Structural Imaging using Optical Coherence Tomography (OCT) by Optovue

Athletes underwent an Optical Coherence Tomography (OCT) exam to assess and document the structural components of the back of their eyes (fovea, optic nerve head, and retina) with an image. The methods for this exam can be found at https://www.optovue.com/oct.[24]

Proprioception using Closed-Eye Turns

Athletes were instructed to stand straight forward with their feet together and touching, their arms crossed so that their hands touched the opposite shoulder, and their eyes closed. They were told to turn to attempt one complete 360-degree turn to the right, while keeping their eyes closed and hands on their shoulders. Once they felt they reached a full 360-degree turn, they were to stop, and the degrees off their initial position (0 degrees) was recorded. They were to repeat this to the opposite side. The instructor used a protractor to measure the degrees the subject turned.[18]

Statistical Analysis

Results were evaluated through descriptive statistics and reported as means, standard deviations, and confidence intervals. Confidence intervals of 95% are presented here for comparison against the internally established normative values.[25]

RESULTS

A total of 31 male division-1 collegiate football players were assessed at the end of their collegiate athletic career using our neurologic sports concussion exit baseline. All 31 athletes were healthy at the time of assessment. Table 1 presents the summarized data for all the exit baseline parameters collected. The normative data presented in Table 1 was internally established from this university's athlete population using this same proposed exit baseline as part of their intake concussion baseline assessment over multiple years.[18]

T-tests were performed on the neuro-visual system data to assess for differences between the neurologic exit sports concussion baseline metrics gathered in this study and the internally generated normative values from this university's athlete population. These percent changes and p-value results are shown in Table 2. The only neuro-visual measurement that did not demonstrate a significant difference between the exit baseline and intake normative values was the Brock string assessment for convergence ability, despite a 53% improvement.

The overall percent changes from the internal intake normative values to the obtained neuro-visual related exit baseline data is demonstrated in Figure 3 where 90% of these measures demonstrated a significant change when compared to the internal norms. Of note, these significant changes were all improvements, where the athletes performed better than the normative values on neuro-visual metrics within the sports concussion exit baseline.

DISCUSSION

To our knowledge, this neurologic baseline is the first to be proposed as a sports concussion baseline implemented at the end of a college athlete's career. The battery of tests that make up this baseline are established but have not been proposed together as a comprehensive review of multiple neurological processes to document an athlete's brain health once their career has finished. This sports concussion exit baseline is intended to assess and document an athlete's overall brain health after their collegiate athletic career. The purpose of this report is to present the methods that make up this thorough neuro-baseline as well as an introduction to the concept of an exit sports concussion baseline. The emphasis is to provide sports medicine practitioners a neuro-centric modality to assess, document, and ensure their athletes' brain health throughout their careers, not solely for the beginning of their eligibility and upon a suspected SRC.

The utility of the data gathered from this proposed exit sports concussion baseline allows sports medicine practitioners to compare their athletes' brain health against their internally developed

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TABLE 1 Sports Concussion Exit Baseline Individual Assessment Descriptive Statistics

Baseline Assessment:	Norm:	N:	Mean:	STD:	95% CI:
Dynavision *A (hpm[a])	> 70	21	95.0	8.45	91.4–98.7
Dynavision Mode C Reaction Time (sec)	< 0.40	21	0.354	0.0541	0.331–0.377
L-CVRT[b] (sec)	-	21	0.310	0.0539	0.286–0.333
R-CVRT (sec)	-	21	0.294	0.0484	0.274–0.315
L-PVRT[c] (sec)	-	21	0.323	0.0336	0.308–0.337
R-PVRT (sec)	-	21	0.324	0.0499	0.302–0.345
Difference L-CVRT & L-PVRT (%)	< 20%	21	6.06%	14.0%	0.09%–12.0%
Difference R-CVRT & R-PVRT (%)	< 20%	21	10.7%	11.5%	5.80%–15.6%
Stereo Fly – Lt Wing (mm)	> 10 mm	28	14.3	7.35	11.6–17.0
Stereo Fly - Rt Wing (mm)	>10 mm	28	23.5	10.6	19.6–27.5
Randot ("X"/10)	>= 4	28	6.50	2.12	5.72–7.28
Phoropter - Horizontal Phoria	2-4 Eso[d]	15	–1.47	4.84	–3.92–0.982
Phoropter - Vertical Phoria	0	15	0	0	–
Phoropter – ACA[f]	4-6 Exo[e]	15	3.33	2.23	2.20–4.46
Reading Saccades (cpm[g])	< 60	29	48.3	8.03	45.4–51.2
Near/Far (cpm)	>= 25	14	34.4	5.42	31.5–37.2
Brock String (inches)	+/- 3	17	–1.40	3.62	–3.12–0.323
CoVF[h] - Rt MVMT[i] (°)	> 75	13	89.2	2.89	87.6–90.7
CoVF - Rt Color Processing (°)	> 65	13	75.5	11.0	69.5–81.4
CoVF - Lt MVMT (°)	> 75	13	89.2	3.23	87.4–90.4
CoVF - Lt Color Processing (°)	>65	13	75.9	11.8	69.5–82.3
RETeval OD[j] Pupil Area Ratio (4/16 Tds)	-	18	1.74	0.587	1.47–2.01
RETeval OS[k] Pupil Area Ratio (4/16 Tds)	-	18	1.84	0.498	1.61–2.07
OCT OD RNFL[l] Thickness (um)	-	17	99.7	8.33	95.6–103.8
OCT OS RNFL Thickness (um)	-	17	99.1	8.79	94.9–103.2
CET[m] – Left (°)	345-375	18	359.7	6.29	356.8–362.6
CET – Right (°)	345-375	18	353.9	13.3	347.7–360.1

[a]hpm=hits per minute. [b]cvrt=central visual reaction time. [c]pvrt=peripheral visual reaction time. [d]esophoric (–). [e]exophoric (+). [f]aca=accommodative-convergence accommodation ratio. [g]cpm=characters per minute. [h]covf=confrontation of visual fields. [i]mvmt=movement. [j]OD=right eye. [k]OS=left eye. [l]rnfl=retinal nerve fiber layer thickness. [m]cet=closed-eye turns.

normative values to assess for differences. If adopted as an entry sports concussion baseline this data can also be compared directly with the athlete's baseline measures. It is beyond the scope of this report to make diagnostic claims regarding an SRC because we do not present data from SRC patients. Although, sports medicine personnel with experience in SRC diagnosis and neurological assessments can chose to use these tests in whole or in part to aid their clinical decisions.

The University of Cincinnati (UC) has used a version of this sports concussion baseline over the past 10 to 12 years as part of their football players' routine intake health physical before beginning their college athletic careers. It is stated as "a version" because this sports concussion baseline has developed over

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FIG. 3 Percent change in neuro-visual functions compared to internally generated normative data.

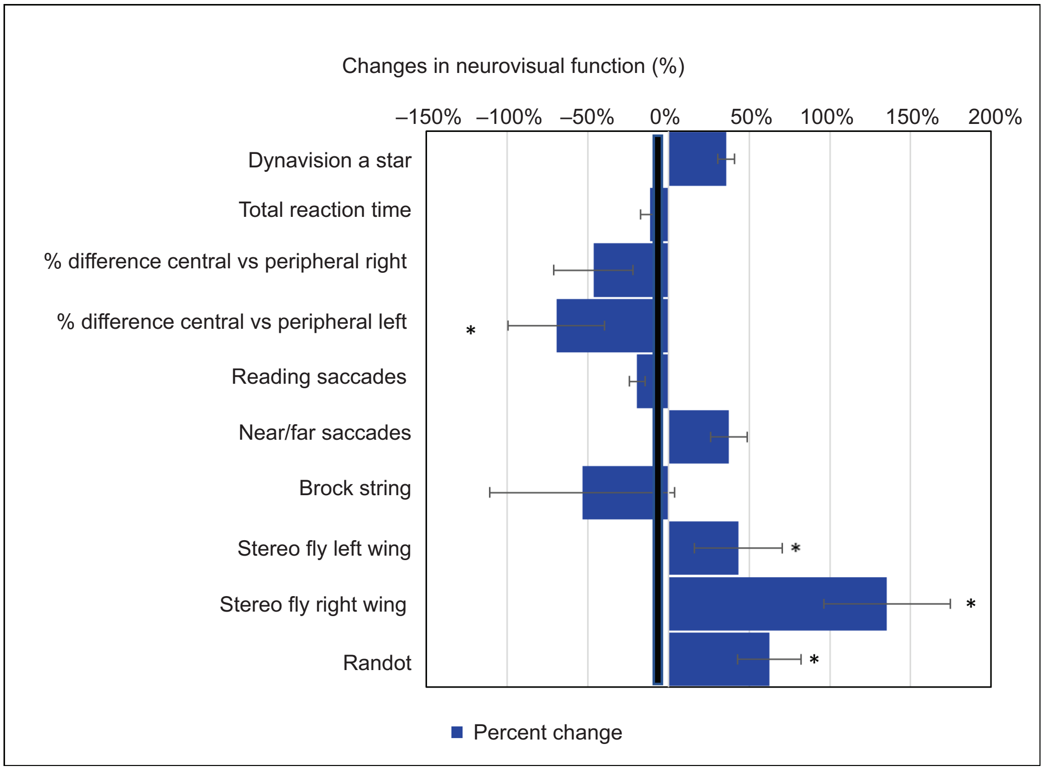

TABLE 2 Significance of Neuro-Visual Function Changes between Internal Generated Norms and Sports Concussion Exit Baseline

Neuro-Visual Assessment	Change From Norm (%)	P–Value
Dynavision *A Eye-Hand Coordination	36%	<0.001
Dynavision *A Overall Reaction Time	–12%	<0.001
% Difference (central vs peripheral) - Right	–50%	<0.001
% Difference (central vs peripheral) - Left	–78%	<0.001
Reading Saccades	–19%	<0.001
Near Far	37%	<0.001
Brock String	–53%	0.086406
Stereo Fly - Left Wing	43%	0.002194
Stereo Fly - Right Wing	135%	<0.001
Randot	63%	<0.001

the years and optimized to what is presented in this report. Numerous studies have reported the unique success of UC's neuro-visual training (NVT) program for SRC prevention, rehabilitation, and sports performance enhancement.[18,19,23,26,27] In addition to their baselining practices, UC also requires their athletes to participate in their neuro-visual training program designed to address the three pillars of NVT: eye discipline, oculomotor strength and endurance, and brain processing.[28] These NVT sessions occur 2-6 weeks before the start of organized team practices for the Fall season and before Spring ball training.[26,27] A total of approximately 240 minutes between the 2-6 weeks is performed, with a maintenance phase of 30 minutes per week once the Fall season and Spring ball practices begin.[26]

The UC football players begin their careers with a standard intake of health physicals and the sports concussion baseline proposed in this report. They are then subjected to UC's NVT program throughout

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their athletic careers to improve their eye discipline, oculomotor strength and endurance, peripheral visual processing and awareness, multitasking, and other cognitive skills. As UC has reported in the literature an 80% reduction in SRC sustained over the past 10 years, the risk can never be completely absolved.[18,26] Thus, upon a suspected SRC, this proposed baseline is performed again, and the data can be used as part of the clinical decisions. If an SRC diagnosis is made, this proposed sports concussion baseline determines the athlete's progress throughout their rehabilitation.[27] the football player is reenrolled into the team NVT program once cleared to return to play. As stewards of good brain health, adopting this sports concussion baseline as part of their routine "exit" health physical furthers UC's commitment to their athletes' brain health throughout their collegiate careers.

Figure 2 represents the data collection tool used for this proposed exit sports concussion baseline. Although, the scanning saccades assessment for far oculomotor performance was not evaluated during this study due to the athletes' time limitations. The complete exit baseline in Figure 2 takes approximately 40 minutes per athlete. Still, it can accommodate up to 10 athletes per hour with a staff of 3–5 practitioners familiar with the methods of these assessments. A benefit of these tests is that they are easily learned and can be carried out by college students or anyone with a baccalaureate degree or equivalent experience level. This may take the burden off already overworked sports medicine personnel.

Table 1 reports the descriptive statistics of the exit sports concussion baseline measurements. Of note, each of these metrics assessed after these football players collegiate careers either improved compared to the norms or became more representative of the center norm value. For example, the internally developed normative value for the eye-hand coordination measure using the Dynavision D2 device is 70 hits per minute. Yet, the exit sports concussion baseline demonstrates a 35.7% increase, averaging 95 hits per minute. The normative value for the Brock string convergence assessment is plus or minus 3 inches from the bead, making the goal value "0" representing optimal convergence. A positive Brock string value signifies an athlete under converging or the eyes not converging enough, where their eyes converge beyond the intended focus point of the bead. A negative Brock string value represents an athlete over-converging or the eyes converging too much, where their eyes converge in front of the focus point of the bead (between their face and the bead). An average convergence measure of −1.40 inches using the Brock string assessment as part of the proposed exit sports concussion baseline. Although the athletes evaluated during this study are over-converging, the 1.40 inches is within the norm of plus/minus 3 inches and is closer to the optimal value of "0" than it is outside the norm. These improvements could be attributed to UC's NVT program, conducted by football players.

In addition to these improvements, Figure 3 displays the percent changes of the neuro-visual-related metrics gathered by the proposed exit sports concussion baseline and compared to the normative values. The solid line at "0" represents the norm. The positive or negative percentage change does not correlate to improve or worsen, as it depends on the assessment modality. For example, the oculomotor data using the reading saccades assessment shows a −19% change compared to the norm value of 60 seconds. This corresponds to an average reading saccade score of 48.3 seconds which is 19% faster than the norm and can be interpreted as improving oculomotor function. 9 of the 10 neuro-visual metrics evaluated using the proposed exit sports concussion baseline demonstrated a significant improvement, except for convergence assessed by using the Brock string. In fact, of these 9 improved measures, 8 are significantly improved with a 99% confidence, and a 95% confidence for the stereopsis measure using the left wing of the Stereo Fly. The percent change and p-values for the neuro-visual data from the exit sports concussion baseline are reported in Table 2.

To improve the validity of this exit sports concussion baseline documentation of an athlete's brain health at the end of their college career, it is suggested that this neuro-baseline be considered as part of an athlete's routine health physical at the beginning of their college career. This will enhance the ability to interpret an individual player's brain health by comparing it directly against their initial neurological values.

LIMITATIONS

It should be noted that this proposed exit sports concussion baseline cannot be conducted in a classroom setting as is common with computerized neuropsychological baseline assessments. Although, the exit sports concussion baseline can be implemented in an athletic training room or clinical setting similarly to a routine health physical. Furthermore, it is noted that not all 31 athletes evaluated in this study completed the entire exit baseline panel. This can be partly attributed to players leaving the university before completing all the tests within the exit baseline. It may also contribute to the increase in "exit" responsibilities of the athletes that occur once their eligibility is over, such as final physicals, last academic support meetings, equipment distribution, etc. In addition to the obvious time limitations of the college athletes, we are aware of the time limitations of the sports medicine practitioners and the commitment of this proposed exit baselines due to the requirement of testers familiar with the relevant methods. Although it is emphasized that these responsibilities can be delegated to student volunteers interested in gaining hands-on experience to strengthen future academic or job applications potentially.

CONCLUSION

The data collected from this proposed exit sports concussion baseline represents objective cognitive functions for multiple neurological systems that are commonly affected by an SRC. The improvement in these functions for the University of Cincinnati athletes throughout their careers, demonstrated by a significant percent change compared to the internally developed norm values, may correlate to improved brain health concerning the neuro-processes measured by this battery of tests. This ability to assess and document objective brain health measures supports the utility of this proposed exit sports concussion baseline to be used after an athlete's college career.

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CONFLICT OF INTERESTS

Jonathan Vincent declares that he consults for his family's company, Dynavision Global Holdings LLC (DBA: Dynavision International), and is the founder of a Limited Liability Company, Inneuractive LLC, that trains and educates athletes, coaches, athletic trainers, and other interested healthcare practitioners in neuro-visual training methodologies for performance enhancement. The other authors declare that they do not have any conflicts of interest.

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