Quantitative Assessment of Balance for Accurate Prediction of Return to Sport From Sport-Related Concussion

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Background: Determining when athletes are able to return to sport after sports-related concussion (SRC) can be difficult.

Hypothesis: A multimodal algorithm using cognitive testing, postural stability, and clinical assessment can predict return to sports after SRC.

Study Design: Prospective cohort.

Level of Evidence: Level 2b.

Methods: Athletes were evaluated within 2 to 3 weeks of SRC. Clinical assessment, Immediate Post Concussion and Cognitive Testing (ImPACT), and postural stability (Equilibrate) were conducted. Resulting data and machine learning techniques were used to optimize an algorithm discriminating between patients ready to return to sports versus those who are not yet recovered. A Fisher discriminant analysis with leave-one-out cross-validation assessed every combination of 2 to 5 factors to optimize the algorithm with lowest combination of type I and type II errors.

Results: A total of 193 athletes returned to contact sports after SRC at a mean 84.6 days (±88.8). Twelve subjects (6.2%) sustained repeat SRC within 12 months after return to sport. The combination of (1) days since injury, (2) total symptom score, and (3) nondominant foot tandem eyes closed postural stability score created the best algorithm for discriminating those ready to return to sports after SRC with lowest type I error (13.85%) and type II error (11.25%). The model was able to discriminate between patients who were ready to successfully return to sports versus those who were not with area under the receiver operating characteristic (ROC) curve of 0.82.

Conclusion: The algorithm predicts successful return to sports with an acceptable sensitivity and specificity. Tandem balance with eyes closed measured with a video-force plate discriminated athletes ready to return to sports from SRC when combined in multivariate analysis with symptom score and time since injury. The combination of these factors may pose advantages over computerized neuropsychological testing when evaluating young athletes with SRC for return to contact sports.

Clinical Relevance: When assessing young athletes sustaining an SRC in a concussion clinic, measuring postural stability in tandem stance with eyes closed combined with clinical assessment and cognitive recovery is effective to determine who is ready to successfully return to sports.

Keywords: Sports-related concussion; multimodal assessment; tandem balance; return to sports

Sports-related concussion (SRC) is a leading cause of morbidity in youth.[19] SRC is being recognized more readily by the general public as health care providers' ability to diagnose SRC is improving.[39,40] Recognition of a head injury and prompt referral for evaluation by a physician experienced in concussion diagnosis is best practice.[21] Once identified, initial management for SRC can foster rehabilitation and recovery, which typically occurs in less than 1 month.[40] Before resuming contact sports, there is a consensus that athletes should be fully recovered from SRC and have

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The following author declared potential conflict of interest: H.A.K. obtained a paid research coordinator from a grant from AMSSM/ACSM Foundation.
DOI: 10.1177/19417381211068817

completed a graded return to play without symptom exacerbation.[40]

Determination of what constitutes a full recovery and readiness to return to sports continues to be debated.[2,9,23,29] Symptom resolution has long been a prerequisite of full recovery; however, reliance on reported symptoms alone may underestimate athletes with continued cognitive and/or postural stability deficits who remain at high risk for a reinjury on resuming sports.[29] Multimodal evaluation has supplanted reliance on symptoms only and represents a more vigorous assessment process often including performance of cognitive tasks, evaluation of balance, and testing of other neurological functions.[3,21,40] The psychometric properties of such multimodal testing have been described, but clinical judgment remains the gold standard for determining recovery from SRC.[21] No single test yet appears able to discriminate those physiologically recovered and ready to return to sports from those not.[29]

Symptom scores are the most sensitive parameter in determining recovery.[7,16,21] Immediate Post Concussion and Cognitive Testing (ImPACT) can determine which patients may have a protracted recovery.[34,35] These data alone have reasonable sensitivity but lack specificity and a have a substantial number of false-positive results (subjects determined still concussed when they were not).[48]

The modified balance error score system (m-BESS) is a component of the SCAT5 (Sport Concussion Assessment Tool, 5th edition) but has diminished ability to detect concussion if performed >48 hours postinjury, and performance subsequently may vary with a significant practice or learning effect.[13,42,50] There are questions of m-BESS validity,[4,36] reliability,[14] and influence of fatigue.[51]

Howell et al[24] compared m-BESS with the Equilibrate platform and found that video-force plate analysis was better able to detect subtle differences. Healthy athletes' m-BESS scores after SRC only increase by 2 to 3 errors[6,31] and the sensitivity of m-BESS in acute concussion may only be as high as 71.4%. Corwin et al[8] found that a device-based measure of balance (Biodex) did not discriminate healthy from concussed youth any better than clinical measures.

Up to 30% of youth athletes sustaining SRC may require longer than a month to recover,[2,9,10,23] and athletes within this subgroup often have comorbidities such as attention deficit and hyperactivity disorder (ADHD), depression, anxiety, learning disabilities, or have had multiple previous head injuries.[2] Many such athletes are not asymptomatic at their preinjury baseline and hence waiting for symptom resolution may not differentiate readiness to return to sports. Many athletes are eager to resume play but the risk of reinjury is significant if competition is resumed too early.[22]

The complexity of such decision-making is significant, and a better understanding of which variables differentiate the athlete ready to return to sports from an athlete still recovering is advantageous for all involved. Machine learning (ML) is a computational technique where data from multiple variables are analyzed in combinations and the optimal combination and weights of the variables is determined to maximize sensitivity and specificity of an outcome.

The purpose of this study was to use ML techniques to calculate which subject parameters measured during recovery from injury best differentiate between patients ready to successfully return to sports from those still recovering.

We hypothesized that there is an algorithm using the optimal combination of multiple variables for predicting when athletes (even those with a prolonged recovery) are ready to safely return to sports.

METHODS

Study Design and Participants

A single site, prospective, repeated-measures design was used in this longitudinal investigation. After obtaining institutional review board approval from Albany Medical College, 207 athletes (aged 10-26 years) who sought care for an SRC at a concussion specialty clinic between January 1, 2014, and December 31, 2018, were enrolled in the study. Inclusion criteria included (1) SRC diagnosis within 21 days of first clinical visit, (2) completion of subsequent clinical visits until recovered, and (3) 10 to 26 years old at time of injury.

Outcome Measures

Definition of SRC

SRC was diagnosed by an experienced sports medicine physician or neurologist using criteria consistent with the definition by McCrory et al[39,40] at the 2012 and 2016 international consensus on concussion in sport. Only nonmotor sports were considered, and equestrian and ski or snowboard injuries were included.

Demographic characteristics, medical history, and injury-related information were collected in office via clinical interview with athletes (and one of their parents if <18 years old). A clinical intake form was used to determine study eligibility.

Neurocognitive and Symptom Impairment

The ImPACT assessment was used to measure neurocognitive impairment as soon as athletes could tolerate taking the computerized test battery.[27]

Recovery From SRC

Medical clearance to return to sports was achieved when patients were symptom free at rest and after physical exertion, per international consensus.[21,40] Athletes were required to have a normal physical examination, including vestibulo-ocular characteristics and balance, and meet the cognitive metrics defined in Figure 1. Composite scores for verbal memory, visual memory, processing speed, reaction time, and a postconcussion symptom scale were reviewed with patients at the time of their visit and used to help determine whether a subject was recovered from their concussion based on psychometric data.[28,37,48] Preinjury academic performance was also considered as it can influence postinjury performance among athletes

A full recovery was defined as:

1. A return to symptom score <10, off medication AND
2. Non-focal neurological exam including clinical assessment of balance with modified balance error scoring system AND
3. ImPACT test showing one of the following:
   a. Return to baseline performance if available OR
   b. >80%ile performance on 3 out of 4 parameters in above average student OR
   c. >50%ile performance on 3 out of 4 parameters in average student OR
   d. >25%ile performance on 3 out of 4 parameters in below average student

Figure 1. Clinical criteria for clearance for full return to sports. Subjects were asked to categorize themselves as average, above average, or below average in school. School performance was discussed with subjects (and parents when available), and typical grades were compared with self-determination of performance category.

especially if baseline testing is not available.[49,53] It is noteworthy that the investigators were blinded as to quantitative assessment of postural stability at the time when clinical assessment of recovery and readiness to return to sports was made. Recovery time was defined as total number of days from the date of injury to the date of receiving medical clearance for full return to (contact) sports participation.

Procedure

Athletes were enrolled in our research registry once they had provided informed consent (and assent when <18 years old) to participate. Athletes were seen at 2- to 4-week intervals and at each visit they had a clinical interview and physical examination, which included an ImPACT test. Physical examination included all components which are found in the Sports Concussion Assessment Tool, 3rd edition (SCAT3)[7] or 5th edition (SCAT5)[13] and a complete neurological examination, which included cranial nerve assessment (external ocular muscles, visual fields, fundoscopy), upper and lower extremity assessment (power, sensation, deep tendon reflexes, dysdiadochokinesis, finger-nose testing, ulnar drift, Romberg), heel-toe gait, and balance in tandem stance with eyes closed with errors noted per m-BESS.[46]

Subjects also underwent a quantitative assessment of postural stability with the Equilibrate Balance Platform (Balance Engineering). The Equilibrate platform evaluates a combination of force plate–derived center of mass movement and motion analysis assessment of torso sway. These data have been used to describe postural stability as an indicator of athletic performance and neurologic function.[24,25] The Equilibrate system has been suggested as an accurate assessment of postural stability after SRC.[43] In this study, quantitative balance data from the Equilibrate system were not factored into the physician's decision-making regarding recovery.

Subjects were consistently tested by the same study personnel (research coordinator) and were asked to complete 3 trials each of 8 positions (feet together with eyes open then closed, single leg eyes open on right and left, tandem stance right foot forward eyes open and closed, tandem stance left foot forward eyes open and closed). During each trial, the subject wore a vest secured by Velcro with 7 reflective markers that were tracked by 2 mounted video cameras. The subject's movement in each position was also captured via their stance on a force plate, plus motion capture of markers sway by the cameras. Results were stored on a laptop connected to both devices and the Equilibrate software calculated a balance score based on the 3 trials for each position.

Athletes were instructed to return to school as soon as possible after their initial visit and allowed to resume light aerobic exercise once able to tolerate this without symptom exacerbation.[18,40,45] Their progression through the initial steps of a graded return to play protocol (noncontact) was guided by the physician and compliance was corroborated with patients and parents at follow-up visits. Once clinical assessment indicated that patients were asymptomatic with normal physical examination and reported tolerance of noncontact exertion with acceptable ImPACT scores, athletes were permitted to return to contact sport. The definition of "asymptomatic" was based on previous investigations, which have noted that adolescents typically do have some symptoms at baseline.[1] Lau et al[35] used a cutoff of a total symptom score of 7 in a cohort of male high school football players. In our practice, we choose to use a total symptom score <10 given the inclusion of male and female athletes, many with comorbidities (ADHD, mood disorder, learning disability) or a previous history of concussion, and the wide variety sports.

Athletes were contacted at 6 months and 12 months post–return to sports via telephone interview to assess their success in return to sports (Figure 2).

Data Analysis

Univariate Analysis

Based on clinical assessment at the time of examination, every patient at every visit was categorized as either ready to return to sports ("ready") or not ready to return to sports ("not ready").

A univariate analysis was performed (Matlab 2017, MathWorks) for each variable (symptom score, physical examination, ImPACT composite scores, Equilibrate balance data) to determine which variables correlated to the clinical assessment at each visit. Variables whose scores demonstrated significant differences between the 2 groups (ready vs not ready) indicate correlation to the clinical examination. For each of the continuous variables shown in Table 1, the data between the 2 groups were compared using either a Student *t* test (t^*), Welch *t* test, or Mann-Whitney *U* test depending on the distribution and variance of the data. Categorical data were analyzed using a chi-square test (χ^2) for independence. The false discovery rate (FDR) for each variable was also calculated to determine the robustness of the statistical conclusion. Differences were considered significant if $P \leq 0.05$ and the FDR ≤ 0.1.

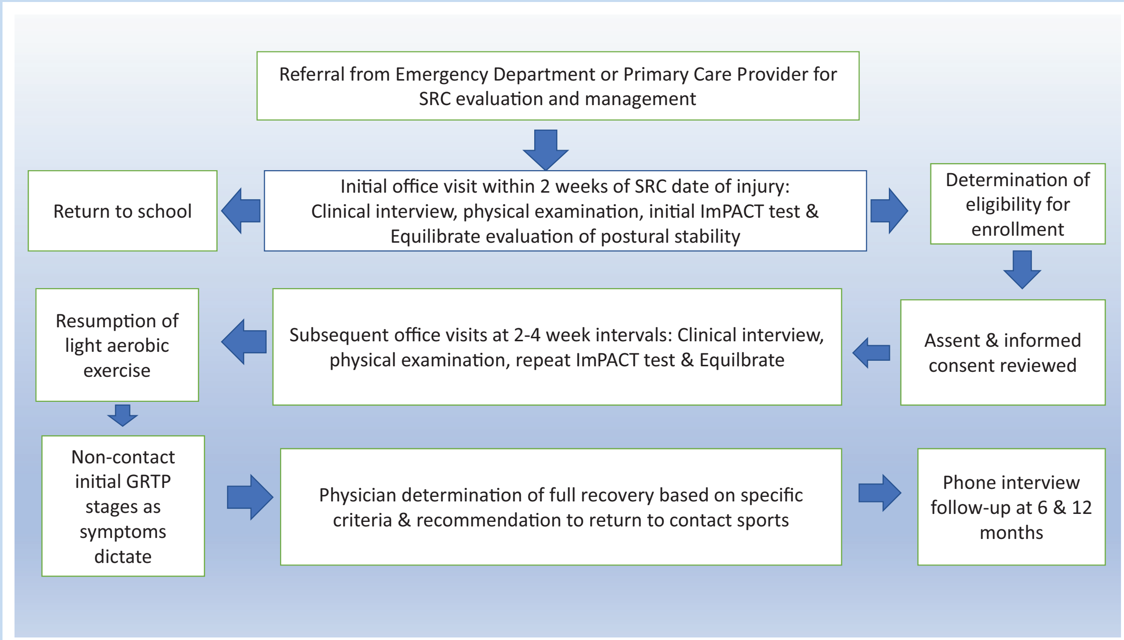

Figure 2. Illustration of protocol. GRTP, graded return to play.

A receiver operating characteristic (ROC) curve was generated for each variable and the area under the curve (AUC) calculated. The greater the AUC, the better the measurements are able to distinguish between the 2 groups.[20] ROC curves have previously been shown to illustrate sensitivity and specificity in determining recovery from concussion.[35]

Multivariate Analysis

A multivariate analysis was conducted to determine which variables and the minimum number of individual variables that, when used together and weighted, most effectively discriminate between patients who were ready to return to sports versus those not ready.

A Fisher discriminant analysis (FDA) was applied to every combination of the variables shown in Table 2 to determine the most accurate model that could be used to discriminate patients in the 2 groups (ready vs not ready). Essentially, FDA weighs each variable to maximize the separation in data between the 2 groups and minimize overlap in the data.[15]

To independently assess the strength of the models created using FDA, a leave-one-out cross-validation (LOOCV) technique was used.[33] This ML process systematically removes 1 patient's data and then retrains the model using the remaining data. The new model is then applied to the left-out patient to determine whether the patient is incorrectly or correctly classified as belonging to the ready or not ready group. Then the second patient's data are left out while the first patient is included for training a new model. The process is repeated until each of the observations have been left out and the model has been optimized.

For each combination of variables, the type I and type II statistical errors were calculated, a ROC curve was generated, and the area under the ROC curve was calculated. These metrics indicate how well a model (weighted combination of variables) classifies the 2 groups of assessments.

In this study, FDA was applied to the data from the first and last visits of each patient. To determine which variables are the strongest predictors of ready to return to sports, every combination of 2 variables, 3 variables, 4 variables, and 5 variables were used to generate models. The best models were chosen as the ones which had the lowest combination of type I and type II errors. ROC curves were generated using the entire data set for each of the best models to show the classification accuracy of the model.

RESULTS

In this study, 207 patients were enrolled, of which 193 (male 105, female 88) met criteria for analysis and 14 were excluded (either failed to adhere to protocol or were lost for follow-up). Mean age was 15 ± 2.4 years. Age ranges included 5.5% subjects <12 years, 17.0% 12 to 14 years, 65.5% 14 to 18 years, and 12.0% >18 years. There was a wide variety of sports played when injured, with soccer being the most common (Figure 3). As expected, there were a range of comorbidities (mood disorder, ADHD, learning disability, previous concussion) among male and female athletes (Table 2). Time to office presentation, return to school, and return to contact sports are also shown in Table 2.

Of 193 subjects, 30 (15.5%) were reinjured after their return to contact sports once cleared, and 12 (6.2%) within the first

Table 1. Univariate hypothesis testing results including the type of testing performed, the *P*-value, the false discovery rate (FDR), and the area under the curve (AUC) of the receiver operating characteristic (ROC) curve[a]

Measurements	Test	*P*	FDR	AUC
Demographics				
Sex	χ^2	0.9213	1	0.5236
Contact level of sport	χ^2	0.7302	1	0.5018
Mood disorder	χ^2	0.8793	1	0.5051
Attention deficit and hyperactivity disorder	χ^2	0.3221	1	0.5086
Learning disability	χ^2	0.8308	1	0.5021
Previous concussion	χ^2	0.6514	1	0.5178
Number of injuries	MW	0.8663	1	0.5019
Number of previous concussions	MW	0.4704	1	0.5213
Previous concussion date category	MW	0.5338	1	0.5187
Age	MW	0.8551	1	0.5062
Height	MW	0.9425	1	0.5025
Days since injury	*t**	<0.001	0	0.6832
Equilibrate balance				
Two feet eyes open	MW	0.1504	1	0.5487
Two feet eyes closed	*t**	0.0013	0	0.5891
Dominant foot eyes open	*t**	0.1840	0.9946	0.5719
Nondominant foot eyes open	MW	0.0158	0	0.5817
Dominant foot tandem eyes open	MW	0.0569	0.7714	0.5645
Dominant foot tandem eyes closed	MW	0.0583	0.8044	0.5641
Nondominant foot tandem eyes open	*t**	<0.001	0	0.5832
Nondominant foot tandem eyes closed	MW	0.0083	0	0.5893
ImPACT neurocognitive				
Total symptom score	*t**	<0.001	0	0.7974
Verbal memory raw	*t**	<0.001	0	0.6686
Verbal memory percentile	*t**	<0.001	0	0.6575
Visual memory raw	MW	<0.001	0	0.6210
Visual memory percentile	MW	0.0012	0	0.6098
Processing speed raw	MW	<0.001	0	0.6369
Processing speed percentile	*t**	0.0063	0	0.6493
Reaction time raw	*t**	0.3679	0.9933	0.6112
Reaction time percentile	MW	<0.001	0	0.6365

(continued)

Table 1. (continued)

Measurements	Test	*P*	FDR	AUC
Symptom checklist				
Headache	*t**	<0.001	0	0.7606
Nausea	MW	0.0024	0	0.5475
Vomiting	MW	0.2208	1	0.5059
Balance problems	*t**	<0.001	0	0.6124
Dizziness	*t**	<0.001	0	0.6317
Fatigue	*t**	<0.001	0	0.6333
Trouble falling asleep	MW	0.0015	0	0.5690
Sleeping more than usual	MW	<0.001	0	0.5668
Sleeping less than usual	MW	0.0163	0	0.5492
Drowsiness	*t**	<0.001	0	0.6304
Sensitivity to light	*t**	<0.001	0	0.6928
Sensitivity to noise	*t**	<0.001	0	0.6532
Irritability	*t**	<0.001	0	0.6175
Sadness	MW	0.0727	0.9625	0.5281
Nervousness	MW	0.0305	0.0079	0.5420
Feeling more emotional	MW	<0.001	0	0.5637
Numbness or tingling	MW	0.4451	1	0.5068
Feeling slowed down	*t**	<0.001	0	0.5846
Feeling mentally foggy	*t**	<0.001	0	0.5889
Difficulty concentrating	*t**	<0.001	0	0.6907
Difficulty remembering	MW	0.0204	0	0.5470
Visual problems	MW	0.0036	0	0.5447

[a]Measurements with $P \leq 0.05$ and FDR ≤ 0.1 were considered significant and are shaded in gray. Student *t* test (*t**), Mann-Whitney *U* test (MW), chi-squared test (χ^2) were used to compare data from subjects ready to return to sports versus those not ready.

12 months of resumption of sports. These reinjuries occurred on average 404.7 ± 236.7 days after their return to sport. Number of days until initial return to sport did not predict reinjury.

Univariate Analysis

The univariate analysis was performed on all variables listed in Table 1.

The univariate hypothesis testing revealed that differences in many of symptom scores, ImPACT test composite scores, and some of the balance scores are significant between groups (ready to return vs not ready).

Multivariate Analysis

The multivariate FDA with LOOCV analysis showed that a combination of 3 variables resulted in the lowest type I/type II errors. The optimal combination of variables were (1) days since injury, (2) total symptom score, and (3) balance in tandem stance with nondominant foot forward and eyes closed. The minimum type I error was 13.85% (sensitivity of 86.15%) and

Table 2. Comorbidities of injured athletes, plus description of presenting time frame and clinical decisions

	Mood disorder	Attention Deficit and Hyperactivity Disorder, n/Total (%)	Learning Disability	Previous Concussion
All	18/193 (9)	14/193 (7)	9/193 (5)	85/193 (44)
Female	7/193 (4)	4/193 (2)	4/193 (2)	34/193 (18)
Male	11/193 (6)	10/193 (5)	5/193 (3)	51/193 (26)
	Time to presentation (days)	**Return to school (days post injury)**	**Return to contact sports (days post injury)**	
Median	14	0.5	53	
Mean	21.9	2.2	84.6	
SD	26.9	4.7	88.8	

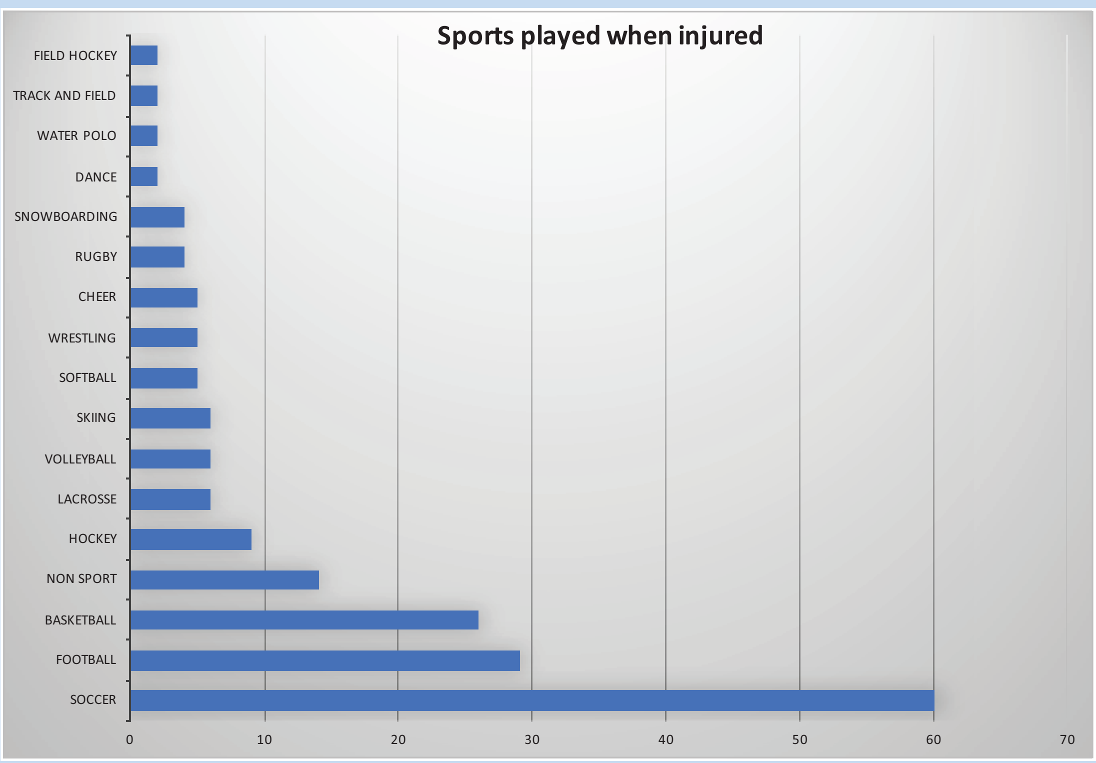

Figure 3. Sports played when injured.

type II error was 11.25% (specificity of 88.75%) when these variables were weighted and used together. The optimal weights assigned to each assessment are

$$t = 0.4791x_1 + 0.2923x_2 - 0.8277x_3$$

where x_1 is the amount of days since injury, x_2 is the nondominant foot tandem eyes closed score, and x_3 is the total symptom score. The calculated t value will determine whether the measurements classify an athlete as ready to resume sports or not. If the t value is greater than 0.29, the patient is classified

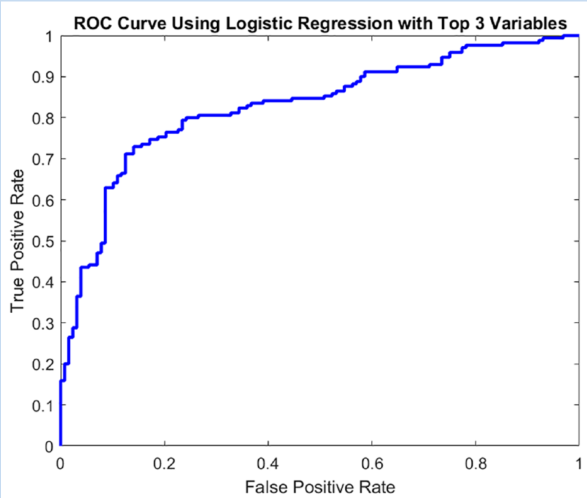

Figure 4. The receiver operating characteristic (ROC) curve calculated using Fisher discriminant analysis (FDA), all assessments, and the best combination of variables: days since injury, total symptom score, and nondominant foot tandem eyes closed.

as ready to return to sports. If the value is less than 0.29, the athlete is classified as still injured.

Type I error in this analysis is defined as a patient who was classified as not ready to return to sports when in fact they were ready to return. Type II error is defined as a patient who was classified at ready to return to sports when in fact they were not ready. These low errors show that it is possible to classify between the 2 groups of assessments (ready to return vs not ready) using as few as these 3 measurements. Using these same measurements, the AUC of the ROC curve for all assessments was 0.8177 (Figure 4).

AUC values that lie between 0.5 and 1.0 are clinically useful.[8,32,35] The AUC value shows that the combination of variables weighted using our optimal algorithm can discern between patients who should be cleared to return to sports after a concussion versus those who should not.

DISCUSSION

Current best practices dictate a multimodal analysis to determine when an athlete should be cleared to return to sports after SRC.[21] When clinical examination is ambiguous or when a multimodal assessment demonstrates contradictory outcomes, determination of which patients are ready to return to sports can be challenging. We have used the ML technique to demonstrate that a small number of key variables, when combined and weighted appropriately, can be used to discriminate between patients who are ready to return to sports versus those who are not. Using these techniques, we have defined the minimum variables as (1) symptom score, (2) balance in tandem stance with nondominant foot forward, and (3) days since injury. The optimal algorithm using these 3 variables has sufficient sensitivity and specificity for clinical use.

Based on univariate analysis, computerized neuropsychological testing with ImPACT was able to discriminate between the population of patients who were ready to return to sports versus the population who were not, but when ImPACT scores alone were applied to individual patients, there was greater error than when these scores were combined with time from injury and tandem balance with eyes closed. One of the key criticisms of the ImPACT program has been that the cognitive test scores do not add much to the symptom score inherent to the program.[11,34,48]

The increased sensitivity and specificity of the weighted multivariate analysis may be particularly important in patient populations with comorbidities (ADHD, learning disability, mood disorder) such as the high school athletes in this study who had comorbidities (>20%) and a previous concussion (>40%). This higher complexity of athletes with SRC is not uncommon in a referral center. Rosenbaum et al[47] describe 600 consecutive mild traumatic brain injuries to a multicenter subspecialty clinic and noted 15.3% had ADHD, 34% had a mood disorder, 9.3% had a learning disability, and 49.6% had had a prior concussion. If baseline cognitive testing is not available when assessing such a clinic population, it may necessitate more focus on a small combination of other objective parameters. Baseline testing has been acknowledged to improve neurocognitive test's ability to identify SRC but is not considered mandatory.[11,12,40]

The clinical assessment of readiness for return to play took academic performance into account.[11] However, despite considerations for academic performance, ImPACT composite scores were less able to differentiate those ready for return to play than the combined, weighted scoring system optimized through the ML algorithm.

It took on average 2 to 3 months from time of injury for subjects to return to contact sport in this investigation. This prolonged recovery trajectory is not unexpected based on the mean age of this cohort,[26,47,52] the variety of sports played when injured, athletes with comorbidities, and inclusion of male and female athletes.[30]

Recovery trajectory differences between male and female athletes differ, with female athletes taking longer to recover.[26] Even when taking into account comorbidities such as anxiety and depression, female athletes take longer to recover from head trauma.[47] This investigation included slightly more male athletes (105) than female (88), but there were more male athletes with ADHD and a greater proportion who had had a previous concussion. In the analysis, sex was not a significant factor in readiness to return to sport.

Our patients were permitted to return to exercise once symptoms diminished, and the majority resumed the noncontact steps (stages 1-4) of graded return to play[21] during their recovery. The vast majority returned to school within 1 week, though many required academic accommodations during their recovery.[18] Allowing athletes to return to some physical activities may have prolonged their return to sports, as athletes and their families were more likely satisfied that they were making progress and less impatient with the protocol we followed.

Our athlete population was heterogenous with many sports represented; hence, the injury risk on resuming sport varied widely. High school football concussion rates of 4% to 5% are described[17,41] when athletes report to athletic trainers, but 15% to 45% by other more direct methods[38] that diminish underreporting.

An overall high school SRC injury rate of 3.7% was observed[44] but Harris et al[22] describe 2.6 times greater reinjury risk after 1 concussion and 5.9 times reinjury risk after 2 concussions. In our study, 12 of the 193 (6.2 %) subjects determined to be ready to return to sports were reinjured within 12 months on resumption of contact sports. Our reinjury rate is lower than previous estimations after 1 or 2 concussions (49.6% of our cohort had a history of a previous concussion).

As a referral concussion clinic, there is undoubtedly a referral bias in the patients we evaluated. One significant limitation of this study is that high school athletes who recovered quickly probably were not represented as they would more likely be managed by their primary care provider and not referred to the concussion clinic. Our study cohort is more representative of a specialty concussion clinic and a far higher proportion of athletes with protracted recoveries, similar to other investigations.[47] Future investigation ideally would ascertain baseline data from healthy subjects, follow them prospectively, and collect further data from those experiencing SRC as has been recently conducted in collegiate athletics.[5]

This study indicates that clinicians who conduct multimodal analysis for assessment of readiness to return to sports after SRC should focus on serial assessment of tandem balance with eyes closed, symptom score, and days since injury to determine when patients are ready to return to sports. Tandem balance with eyes closed measured with a video-force plate was the variable best able to discriminate athletes recovered from SRC when combined with symptom score and time since injury. Optimized, weighted, combination of these variables may pose advantages over m-BESS and computerized neuropsychological testing data alone when evaluating high school athletes with SRC, particularly for athletes who have comorbidities or a history of previous concussion.

ACKNOWLEDGMENT

The authors wish to thank Michelle Bowen and Alexandra (Cronin) White for their substantial efforts with data collection; Dr Deborah Light and Dr John Pugh for assistance with subjects recruitment; Craig Nelson DC for assistance in conception and methodology and the Albany Medical Center Department of Medicine Chairs Dr Rick Blinkhorn and Dr Ed Philbin for their support and encouragement. Balance Engineering LLC provided the Equilibrate platform through a research agreement.

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