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Risk Factors for Initial and Subsequent Core or Lower Extremity Sprain or Strain Among Collegiate Football Players

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Context: Exposure to game conditions and previous injury are known to increase the risk of injury, but little available evidence pertains to modifiable factors that may mediate dynamic control of body segments, such as core muscle endurance and neurocognitive capabilities.

Objective: To identify potentially modifiable factors associated with the occurrence of a core or lower extremity sprain or strain during participation in football.

Design: Prospective cohort study.

Setting: National Collegiate Athletic Association Division I Football Bowl Subdivision football program.

Patients or Other Participants: All team members who participated for the duration of 1 season or both of 2 consecutive seasons (n = 142).

Main Outcome Measure(s): Predictors of injury occurrence were derived from analysis of preparticipation data that included the results of front plank hold (FPH) and neurocognitive tests. Receiver operating characteristic analysis was used to establish binary classifications of injury risk. Logistic regression analyses were conducted to build multivariable injury-prediction models for optimal discriminatory power.

Results: Exceptionally good discrimination between injured and noninjured participants was provided by models that included the results of the FPH and ImPACT neurocognitive tests. A high level of exposure to game conditions and injury during the preceding year magnified the effects of other risk factors. A model for identifying players with an elevated risk for injury occurrence during both of 2 consecutive seasons included FPH $\leq$120 seconds, verbal memory score $\leq$87, composite reaction time $\geq$560 milliseconds, and starter status. Having $\geq$2 of the 4 risk factors demonstrated 44% sensitivity and 91% specificity, with an odds ratio = 8.40.

Conclusions: Core muscle endurance and neurocognitive processes may both play important roles in generating anticipatory muscle stiffness during participation in collegiate football. These factors may be particularly important for players who sustained an injury during the previous year and those who have a high level of game exposure.

Key Words: musculoskeletal injury prevention, neurocognition, clinical decision making

Key Points

- The efficiency of neural processes linking sensory perceptions to muscle responses may be altered by either mild traumatic brain injury or musculoskeletal injury.
- The volume of exposure to game conditions and injury history are important factors to consider when assessing musculoskeletal injury risk among collegiate football players.
- Neurocognitive efficiency and resistance to core muscle fatigue are potentially modifiable factors that may mediate susceptibility to core and lower extremity sprains and strains.

Emerging evidence strongly suggests that the dynamic stability of the lower extremity kinetic chain depends heavily on neurocognitive processes.[1–6] Head blows sustained during football participation can have long-lasting adverse effects on neurocognitive function,[7–10] and recent authors[11–13] have documented an increase in the rate of musculoskeletal injuries after a concussion diagnosis. The majority of injuries sustained by collegiate football players are lower extremity sprains and strains, most of which are knee and ankle injuries, resulting from contact.[14] Incidence rates for both lower extremity injuries and concussions sustained during collegiate football games appear to have increased in recent years, whereas the incidence rate for noncontact lower extremity injuries has not increased.[14] Because each successive injury sustained by a collegiate football player appears to increase the risk for subsequent injuries, any potentially modifiable factors that elevate such a risk need to be identified and addressed to prevent progressively worsening dysfunction and future disability.[15]

The risk for subsequent injury was 1.5 to 2 times greater for high school and collegiate football players who had previously been injured.[16–18] Although previous injury is widely recognized as a primary injury risk factor, a deficiency in some protective mechanism that existed before an athlete's initial injury may be responsible for a predisposition to both the initial and recurrent injuries.[19] Among young adult recreational athletes who had never sustained a concussion, those who demonstrated low neurocognitive test scores exhibited different kinematic and kinetic patterns during drop-jump landings and immediate rebound jumping in an unanticipated direction than those observed in participants who had high neurocognitive test scores.[1] Alternatively, failing to completely restore preinjury functional capabilities may exacerbate an athlete's predisposition to subsequent injuries.[2,20] Alterations in brain processing of neural input are also apparent after musculoskeletal injury, and these almost certainly have an adverse effect on the ability to respond rapidly to unanticipated events.[3,4,20] Musculoskeletal injury had an adverse effect on neurocognitive test performance within 72 hours of a traumatic event that restricted sport participation for at least 48 hours.[21] Thus, either mild traumatic brain injury or musculoskeletal injury may have persistent negative effects on neuromechanical responsiveness to a rapidly changing sport environment.

A generally nonmodifiable primary injury risk factor for football players is a high level of exposure to game conditions, but its potential interaction with other risk factors may magnify the effect on a given player's susceptibility to injury. Rapid fatigue of the core musculature and low back dysfunction have been associated with elevated risks for core and lower extremity injuries among collegiate football players.[22,23] Because the core muscles and the capsulo-ligamentous structures of the lumbopelvic complex mechanically link the core to the lower extremities, rapid fatigue of the core muscles and multisegmental movement asymmetries may indicate suboptimal neuromuscular control. The purpose of this exploratory cohort study was to assess possible associations of routinely administered preparticipation tests of physical performance and neurocognitive status with subsequent occurrences of core or lower extremity sprain or strain during either of 2 consecutive football seasons. Our primary interest was in identifying any factors associated with such injury occurrences during both seasons.

METHODS

A prospective cohort study design was used to analyze associations between potential risk factors and subsequent injury occurrence among National Collegiate Athletic Association Division I Football Bowl Subdivision football players over 2 consecutive seasons (2014 and 2015). All study procedures were approved by the Institutional Review Board at the University of Arkansas. Of 142 individual players, 83 participated during both seasons and 59 participated during 1 season. Season 1 players totaled 113 (age = 19.7 ± 1.4 years, height = 188.0 ± 6.8 cm, mass = 106.9 ± 22.7 kg), and season 2 players totaled 112 (age = 19.7 ± 1.4 years, height = 187.2 ± 6.8 cm, mass = 108.3 ± 22.3 kg). The only exclusion criterion was a lack of complete preparticipation data, which was not the case for any player on the roster for either of the 2 years.

All preparticipation screening data were acquired by strength coaches and athletic trainers affiliated with the program, and injuries sustained between the beginning of preseason practice sessions and the end of the season were documented by the athletic training staff. An *injury* was operationally defined as an acute core or lower extremity sprain or strain that occurred during sport-related activities (ie, documented in the athlete's electronic medical record) and that resulted in any limitation of normal participation (ie, included on a coach's injured player status report). Fractures, dislocations, contusions, lacerations, abrasions, and overuse syndromes were excluded. Thus, the analysis was limited to musculoskeletal injuries that were most likely to result from an insufficient neuromuscular response to dynamic loading of the core and lower extremity muscles and joints rather than resulting from the sudden imposition of an uncontrollable external load of great magnitude on a single anatomic structure.

Figure 1. Height-adjustable apparatus used to maintain proper position for front plank posture-hold test.

Preparticipation Screening

Core muscle endurance was assessed by a front plank hold (FPH) test, which assessed the number of seconds an athlete was able to maintain posterior body surface contact with a height-adjustable apparatus that provided an external reference for maintaining the proper position (Figure 1). Lower extremity power output was assessed by a single-legged broad jump for distance, and movement quality was quantified by the standardized Functional Movement Screen (Functional Movement Systems, Inc, Chatham, VA) rating scale and summary score for 7 movement patterns. Body mass index and estimated mass moment of inertia (MMOI) were calculated from measurements of height and body mass obtained during the preparticipation examination. Neurocognitive testing (version 3.0; ImPACT Applications, Inc, Pittsburgh, PA) was conducted before each athlete's first season of participation in the football program and was repeated when a concussion had been sustained during the preceding season. Neurocognitive performance values for the most recent test consisted of composite reaction time (RT), processing speed, visual memory, and verbal memory. Injuries sustained before initiation of the 2-year study were documented by self-report. The number of years of prior participation in the program was documented, and each player's position was classified as belonging to either a back (quarterbacks, running backs, receivers, tight ends, defensive backs, and kickers) or line (centers, guards, tackles, defensive ends, and linebackers) category. Each player's level of exposure to game conditions was dichotomously estimated on the basis of whether he had achieved starter status for at least 1 game during the season(s) of interest, which previous researchers[23] found provided predictive value equivalent to the total number of games in which a football player participated during the season.

Table 1. Receiver Operating Characteristic, Univariable, and Multivariable Analysis Results for Season 1 (N = 113)

Variable	Area Under the Curve	Cut-Point	P Value[a]	Odds Ratio (90% Confidence Interval)		
				Univariable	3 Factor Adjusted	4 Factor Adjusted
Composite reaction time, ms	0.595	≥685	.003	4.42 (1.04, 12.99)	4.75 (1.92, 11.78)	4.78 (1.91, 11.96)
Mass moment of inertia[b]	0.604	≥310	.002	3.71 (1.81, 7.62)	3.54 (1.66, 7.55)	3.23 (1.49, 6.99)
Body mass index[c]	0.571	≥29.8	.006	2.84 (1.49, 5.40)	NA	NA
Processing speed	0.507	≤28	.042	2.80 (1.16, 6.76)	NA	NA
Front plank hold, s	0.568	≤119	.058	2.18 (1.06, 4.51)	NA	1.68 (0.76, 3.75)
Starter status	NA	≥1 game	.063	1.98 (1.03, 3.80)	2.07 (1.01, 4.22)	2.14 (1.04, 4.43)
Visual memory	0.496	≤64	.123	1.89 (0.88, 4.02)	NA	NA
Verbal memory	0.496	≤84	.266	1.36 (0.73, 2.54)	NA	NA
Position category	NA	Back/line	.427	1.16 (0.62, 2.17)	NA	NA

Abbreviation: NA, not available.

[a] Fisher exact test 1-sided *P* value.

[b] Calculated as kg × m^2.

[c] Calculated as kg/m^2.

Data Analysis

Receiver operating characteristic analysis of injured versus uninjured status was used to classify individual players as having high-risk or low-risk status for each potential injury predictor that demonstrated >.50 of the area under the curve or a clearly discernable cut-point, thereby permitting 2 × 2 cross-tabulation analysis and calculation of the odds ratio (OR). The strength of a univariable association between a predictor and outcome was considered significant if the 90% confidence interval (CI) lower limit for the OR was >1.0. The Breslow-Day χ^2 test for homogeneity of ORs across the strata was calculated to identify any statistically significant interaction effects, with $P < .10$ as the criterion. Backward stepwise logistic regression analysis was conducted to assess the relative contribution of a given binary predictor variable to the discriminatory power of a multivariable model on the basis of its adjusted OR magnitude. The combination of binary predictor variables that provided the strongest discrimination between injured and uninjured players was selected as the final multivariable prediction model, without regard for the 90% lower limit of a variable's adjusted OR.

A binary multivariable classification of injury risk was derived from the results of the logistic regression analysis, which categorized each player as having high-risk or low-risk status on the basis of the number of injury risk factors. The resulting categorization was considered significant if the 90% CI lower limit for its OR was >1.0. Each analysis was performed using SPSS (version 24.0; IBM Corp, Armonk, NY). Three complete analyses were performed: (1) data obtained from the cohort of 113 players who participated during season 1, (2) data obtained from the cohort of 112 players who participated during season 2, and (3) data obtained from the cohort of players who had sustained a core or lower extremity injury (ie, had an injury history) during season 1 and who participated again during season 2.

RESULTS

Over the course of 2 football seasons, at least 1 core or lower extremity injury was sustained by 44% of players (99/225). The 2 × 2 cross-tabulation and logistic regression analyses of variables demonstrated an association with injury occurrence during season 1 (Table 1). A 3-factor model that consisted of RT (≥685 milliseconds), MMOI (≥310), and starter status was derived (model χ^2 [3] = 21.12, $P < .001$), which demonstrated good fit to the data (Hosmer and Lemeshow test $P = .856$). A binary prediction model specifying ≥2 of the 3 factors demonstrated 54% sensitivity and 78% specificity, with OR = 4.11 (90% CI = 2.07, 8.14). A 4-factor model that included the FPH (≤119 seconds) slightly increased the predictive power (model χ^2 [4] = 22.27; $P < .001$; Hosmer and Lemeshow test $P = .458$). A binary prediction model specifying ≥2 of the 4 factors demonstrated 70% sensitivity and 64% specificity, with OR = 4.30 (90% CI = 2.21, 8.35). The influence of game exposure on injury incidence is depicted by comparing starter status to nonstarter status for those with no other risk factor versus those who were positive for at least 1 of the other 3 risk factors (RT ≥685 milliseconds, MMOI ≥310, or FPH ≤119 seconds; Figure 2).

During season 2, 40% of the players (45/112) sustained at least 1 core or lower extremity injury. The 2 × 2 cross-tabulation and logistic regression analyses of variables demonstrated an association with injury occurrence (Table 2). A 3-factor model that consisted of FPH (≤99 seconds), RT (≥800 milliseconds), and processing speed (≤28) was derived (model χ^2 [3] = 9.19, $P = .027$), which demonstrated good fit to the data (Hosmer and Lemeshow test $P = .792$). A binary prediction model specifying ≥1 versus 0 of the 3 factors demonstrated 49% sensitivity and 73% specificity, with OR = 2.60 (90% CI = 1.34, 5.08). The inclusion of injury history created a 4-factor model that increased predictive power (model χ^2 [4] = 10.27, $P = .031$) and demonstrated acceptable fit to the data (Hosmer and Lemeshow test $P = .502$). A binary prediction model specifying ≥2 of the 4 factors demonstrated 46% sensitivity and 93% specificity, with OR = 6.84 (90% CI = 2.73, 17.17). Although the Breslow-Day χ^2 test for homogeneity of ORs failed to demonstrate a significant interaction effect ($P = .152$), players with a season 1 injury and at least 1 additional positive factor demonstrated a substantially greater injury incidence than those without a season 1 injury (Figure 3). A stratified analysis on the basis of a season 1 injury yielded an uninjured OR = 1.80 (90% CI = 0.79, 4.08) compared with an injured OR = 6.67 (90% CI = 1.85, 23.98). Because neither of the stratified OR estimates was within the 90% CI for the other, a meaningful interaction may exist.

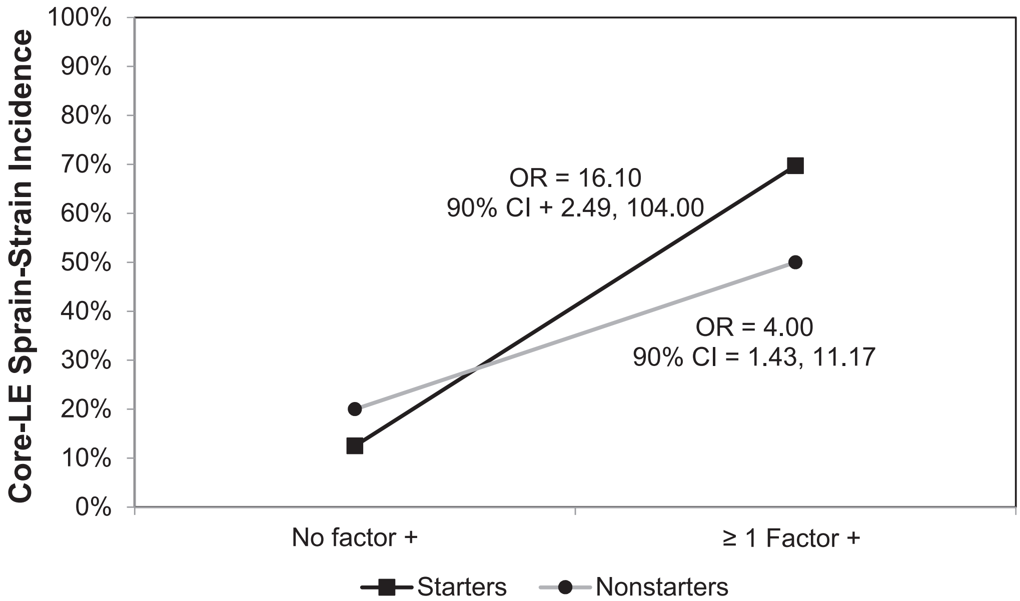

Figure 2. Effect of predicted risk status (3-factor model: no factor + versus ≥ 1 factor +) on season 1 injury incidence, stratified on the basis of having started in at least 1 game (starters [n = 41] versus nonstarters [n = 72]). Abbreviations: CI, confidence interval; OR, odds ratio.

Among players who had sustained at least 1 injury during season 1, 44% (18/41) sustained at least 1 injury during season 2. The 2×2 cross-tabulation and logistic regression analyses of variables demonstrated an association with season 2 injury occurrence (Table 3). A 3-factor model that consisted of FPH (≤120 seconds), verbal memory (≤87), and RT (≥560 milliseconds) was derived (model χ^2 [3] = 8.57, P = .036), which demonstrated good fit to the data (Hosmer and Lemeshow test P = .854). A binary prediction model specifying ≥2 versus 0 or 1 of the 3 factors displayed 61% sensitivity and 74% specificity, with OR = 4.45 (90% CI = 1.46, 13.57). Inclusion of starter status created a 4-factor model that increased predictive power (model χ^2 [4] = 10.67, P = .031) and showed exceptionally good fit to the data (Hosmer and Lemeshow test P = .918). A binary prediction model specifying ≥2 versus 0 or 1 of the 4 factors demonstrated 44% sensitivity and 91% specificity, with OR = 8.40 (90% CI = 1.98, 35.66). Although the Breslow-Day χ^2 test for homogeneity of ORs failed to demonstrate a significant interaction effect for starter status (P = .286), 86% (6/7) of starters with ≥2 of the other 3 factors being positive sustained an injury compared with 50% (5/10) of nonstarters having sustained an injury (Figure 4). A stratified analysis on the basis of starter status yielded a nonstarter OR = 2.67 (90% CI = 0.58, 12.24) compared with a starter OR = 13.50 (90% CI = 1.79, 103.11). Although the magnitude of difference between the stratified OR estimates suggests the existence of a meaningful interaction, the nonstarter estimate fell within the 90% CI for the starter estimate. A loss of statistical power from the reduction in the number of cases included in the stratified analyses explains the width of the 90% CI for the starter OR estimate, but this lack of precision creates uncertainty that must be acknowledged.

DISCUSSION

All 3 of our 4-factor prediction models included the FPH core fatigue resistance test result and the RT derived from the ImPACT neurocognitive test. Tsushima et al[10] found

Table 2. Receiver Operating Characteristic, Univariable, and Multivariable Analysis Results for Season 2 (N = 112)

Variable	Area Under the Curve	Cut-Point	P Value[a]	Odds Ratio (90% Confidence Interval)		
				Univariable	3 Factor Adjusted	4 Factor Adjusted
Front plank hold, s	0.532	≤99	.025	3.29 (1.33, 8.14)	2.74 (1.07, 7.01)	3.08 (1.18, 8.06)
Composite reaction time, ms	0.502	≥800	.048	3.93 (1.20, 12.84)	2.51 (0.71, 8.80)	2.57 (0.73, 9.08)
Visual memory	0.501	≤52	.086	2.68 (0.99, 7.27)	NA	NA
Body mass index[b]	0.508	≥24.8	.150	2.46 (0.79, 7.63)	NA	NA
Processing speed	0.593	≤28	.051	2.29 (1.10, 4.80)	1.87 (0.85, 4.08)	1.86 (0.85, 4.09)
Verbal memory	0.519	≤85	.198	1.51 (0.79, 2.87)	NA	NA
Mass moment of inertia[c]	0.479	≥473	.209	1.65 (0.75, 3.62)	NA	NA
Season 1 injury	NA	Yes/no	.340	1.28 (0.66, 2.46)	NA	1.55 (0.77, 3.13)
Starter status	NA	≥1 game	.401	1.19 (0.62, 2.29)	NA	NA
Position category	NA	Back/line	.504	1.08 (0.57, 2.05)	NA	NA

Abbreviation: NA, not available.

[a] Fisher exact test 1-sided P value.

[b] Calculated as kg/m^2.

[c] Calculated as kg $\times$ m^2.

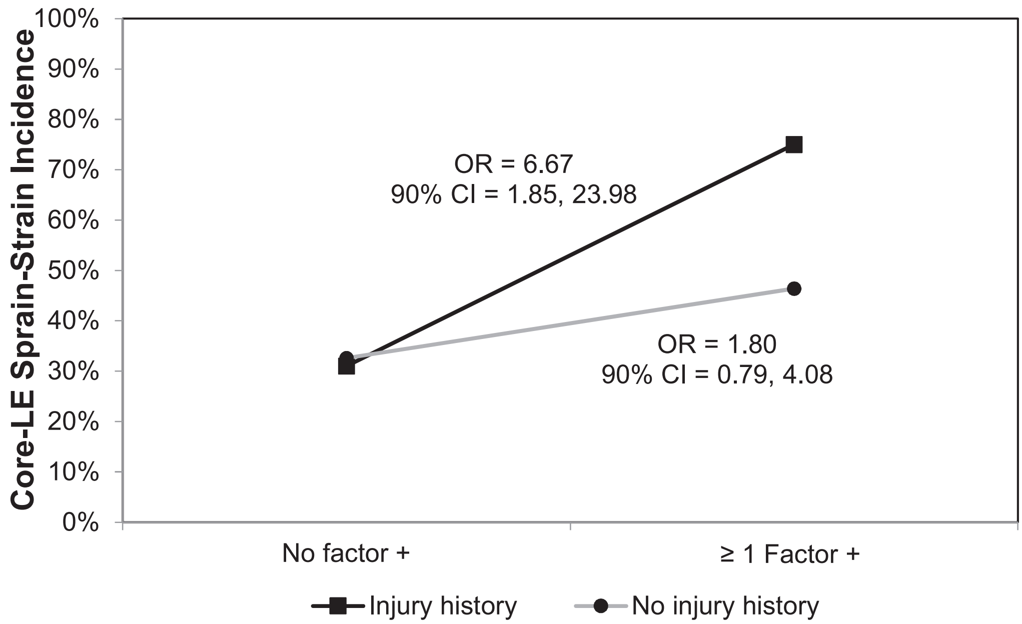

Figure 3. Effect of predicted risk status (3-factor model: no factor + versus ≥ 1 factor +) on season 2 injury incidence, stratified on the basis of season 1 injury history (injury history [n = 41] versus no injury history [n = 71]). Abbreviations: CI, confidence interval; OR, odds ratio.

that high school football players who had never sustained a concussion had poorer ImPACT RTs and processing speed scores than athletes who participated in low-contact sports, which they suggested may have been due to repetitive subconcussive head trauma. Swanik et al[5] observed that athletes who had sustained a noncontact anterior cruciate ligament injury had poorer baseline (ie, preinjury) ImPACT RT and processing speed scores than matched control athletes. The ImPACT RT ≥560 milliseconds cut-point for players injured during season 1 (Table 3) is relatively close to the cut-point of ≥545 milliseconds previously reported for lower extremity sprains and strains among collegiate football players,[6] as well as the mean value of 570 milliseconds identified for athletes who subsequently experienced noncontact anterior cruciate ligament injuries.[5]

A football player's capacity to tolerate the external loads imposed by collisions with opposing players requires rapid generation of muscle stiffness in the core and extremities, which may be achieved in a more effective manner by those who have a greater capacity for fatigue resistance. The strong association between FPH test performance and injury occurrence supports the findings of earlier researchers[22,23] who cited core muscle endurance as an important factor to include when assessing the injury risk among football players, despite a major difference in the postural positions maintained during the tests. Rapid generation of muscle stiffness in the core and lower extremities is also facilitated by early visual perception of impending events. A diminished capacity for generating lower extremity muscle stiffness has been documented[24] among collegiate football players who had sustained a concussion up to 90 days before testing. Furthermore, concussion slowed both central- and peripheral-vision RTs, with peripheral-vision RT being more adversely affected.[25] Reaction time during neurocognitive test performance was slower among athletes who had sustained multiple concussions,[26] and abnormalities in neurophysiological processes related to vision resulted from repetitive blows to the head that did not produce clinical symptoms.[7,9]

Table 3. Receiver Operating Characteristic, Univariable, and Multivariable Analysis Results for Season 1 Injured Players in Season 2 (N = 41)

Variable	Area Under the Curve	Cut-point	*P* Value[a]	Odds Ratio (90% Confidence Interval): Univariable	3 Factor Adjusted	4 Factor Adjusted
Front plank hold, s	0.536	≤120	.048	8.46 (1.28, 56.09)	3.55 (0.46, 27.349)	3.31 (1.06, 3.46)
Processing speed	0.570	≤28	.061	4.24 (1.17, 15.45)	NA	NA
Mass moment of inertia[b]	0.553	≥473	.061	4.24 (1.17, 15.45)	NA	NA
Verbal memory	0.556	≤87	.063	3.38 (1.12, 10.24)	2.91 (0.83, 10.20)	3.06 (0.83, 11.24)
Composite reaction time, ms	0.618	≥560	.081	4.27 (1.02, 17.80)	3.99 (0.86, 18.47)	7.03 (1.24, 39.76)
Body mass index[c]	0.559	≥35	.120	3.33 (0.90, 12.34)	NA	NA
Starter status	NA	≥1 game	.326	1.63 (0.57, 4.61)	NA	3.09 (0.82, 11.59)
Position category	NA	Line/back	.369	1.54 (0.53, 4.51)	NA	NA

Abbreviation: NA, not available.

[a] Fisher exact test 1-sided *P* value.

[b] Calculated as kg × m^2.

[c] Calculated as kg/m^2.

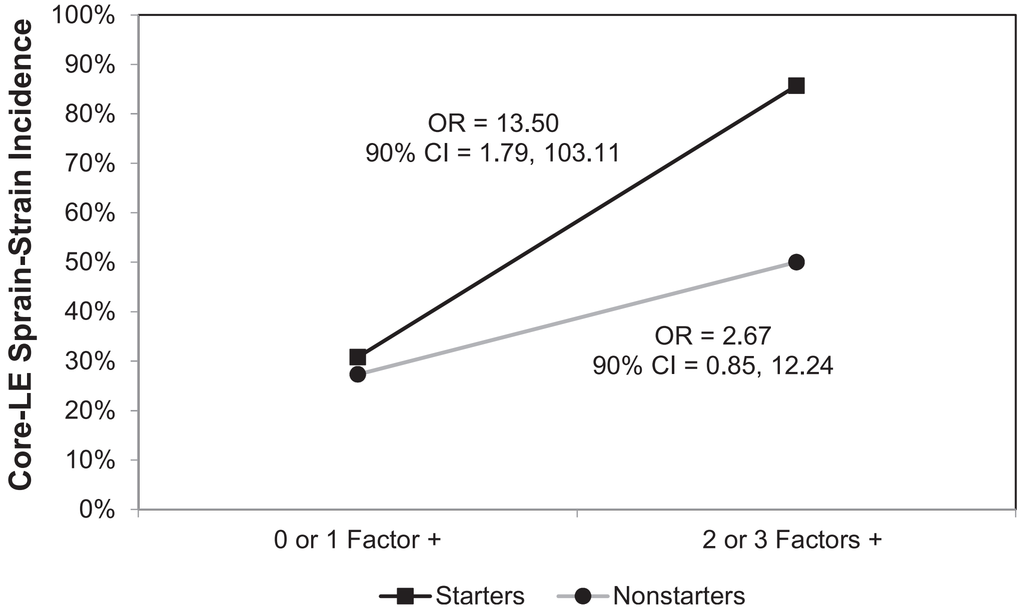

Figure 4. Effect of predicted risk status (3-factor model: 0 or 1 factor + versus 2 or 3 factors +) on season 2 injury incidence among players injured during season 1, stratified on the basis of having started in at least 1 game (starters [n = 20] versus nonstarters [n = 21]). Abbreviations: CI, confidence interval; OR, odds ratio.

Inconsistent findings pertaining to the identification of injury risk factors can result from different operational definitions of injury, cohort characteristics, baseline assessment tests for a given attribute, or statistical analyses. Considering confounding or interaction effects among variables is particularly important for the proper interpretation of statistical results. For example, injury history is widely recognized as a primary injury risk factor.[15] Because 82% of the cases included in the injury analysis over 2 consecutive seasons reflected participants who had previously sustained an injury (184/225), there were relatively few participants without a previous injury for a valid comparison. When we defined injury history as a core or lower extremity sprain or strain during season 1, 37% of season 2 players (41/112) were classified as having sustained a recent injury. A simple univariable cross-tabulation analysis of the association of season 1 injury history with season 2 injury occurrence yielded an OR = 1.28, but the stratified analysis for players who had sustained a season 1 injury with ≥1 risk factors among FPH, RT, and processing speed versus no risk factors demonstrated an OR = 6.67. An alternative assessment method includes interaction terms in a multivariable logistic regression analysis, but any combination of factors that exhibits either 100% sensitivity or 100% specificity renders the statistical output uninterpretable.[27] All 3 of the players who had both a season 1 injury and FPH ≤99 seconds were injured during season 2, whereas none of the 63 uninjured players exhibited both factors (ie, 100% specificity).

A high level of exposure to game conditions is an injury risk factor that often exerts a confounding effect, but it can also interact with other risk factors to magnify effects. Because the injury rate is as much as 10 times greater during football games compared with practice sessions,[16–18] an estimate of a player's volume of exposure to game conditions is important to include in a multivariable analysis. Total minutes of game participation or total number of game plays over the season would provide the most precise means of quantifying this exposure, but such detailed data are often unavailable. Although the univariable cross-tabulation results for starter status failed to demonstrate a strong association with injury occurrence in any of the 3 analyses, its relative predictive value increased when combined with other variables (Tables 1 and 3). The data analysis for the subset of players who had sustained an injury during season 1 showed that starter status had a strong modifying effect on other season 2 injury predictors (Table 3, Figure 3), but data partitioning reduced the number of cases to the extent that the interaction effect was not statistically significant. Furthermore, the combination of starter status with either a low FPH result (≤120 seconds) or a low ImPACT processing speed score (≤28) demonstrated 100% sensitivity, and the combination of nonstarter status with a fast ImPACT composite RT (<560 milliseconds) demonstrated 100% specificity. The perfect discriminatory power of these combinations precluded estimation of the strength of starter-status interaction effects using logistic regression multivariable analysis.

Limitations of this study included a reliance on self-report to document injuries sustained before the first year of participation in the football program and the lack of researcher involvement in data acquisition. We chose to delimit the definition of injury to exclude fractures and dislocations. However, such injuries could result from the same mechanisms as the knee and ankle sprains included in the indexed injuries. All preparticipation testing procedures were selected and administered by athletic program personnel. Each of the 4 scores derived from neurocognitive testing appeared to be clearly relevant to the risk for core or lower extremity injury, but the passage of as much as 4 years between baseline testing and the start of injury surveillance for a given football season represents a major limitation. Ideally, neurocognitive test results for injury risk assessment should be acquired from all players immediately before the start of each season. Neither the Functional

Movement Screen composite score nor single-legged broad-jump distance yielded a discernible receiver operating characteristic cut-point for binary injury risk categorization, and thus, these measures failed to provide any injury prediction value for this cohort. Relatively low OR values were observed for position category and body mass index, and neither of these variables were retained by any of the multivariable logistic regression analyses. Although the test-retest reliability of the FPH test result is unknown, our results suggest that the predictive validity of the postural position-hold duration for this test is very good.

Because activation of the core musculature precedes activation of muscles in the lower extremities and either previous injury or fatigue can adversely affect trunk control, a screening test that identifies suboptimal core stability may be an important indicator of a predisposition for core or lower extremity injury.[28] *Cognitive control* refers to the subset of brain processes underlying perception, memory, and action,[8] and *neuromechanical coupling* refers to modulations in muscle tone that can optimize joint stiffness.[4] A subtle cognitive-control deficit could adversely affect the ability to rapidly generate muscle stiffness, which may be due to either a previous concussion[11,24] or musculoskeletal injury.[20,29] Even football players exposed to repetitive head blows that did not result in a concussion diagnosis exhibited significant reductions in ImPACT verbal memory or visual memory scores.[9] Thus, the combination of low neurocognitive test scores with poor resistance to fatigue by the core musculature may identify collegiate football players who possess the highest level of risk for core and lower extremity injury, and the effect of these risk factors may be magnified by more exposure to game conditions. Currently, little evidence is available to guide training for improving cognitive control and neuromechanical coupling. Recently reported research findings[30] suggested that poor visuomotor responsiveness in collegiate football players can be dramatically improved through training, but further study is needed to assess the retention of improved capabilities and reduced injury incidence after such training.

CONCLUSIONS

Although our data were derived from a single collegiate football program over 2 seasons, credible lower limit estimates of effect magnitudes provide strong support for classifying the core or lower extremity injury risk on the basis of resistance to fatigue of the core musculature and neurocognitive test results. A high level of exposure to game conditions and having sustained an injury during the preceding year appeared to magnify the effects of other risk factors that may be modifiable through training. Further research is needed to confirm these findings, better understand the role of cognitive control processes in injury avoidance, and document the benefits that may be realized from a neuromechanical approach to reduction of injury risk.

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