

# Neurocognitive Reaction Time Predicts Lower Extremity Sprains and Strains

Gary B. Wilkerson, EdD, ATC • University of Tennessee at Chattanooga

**Context:** Prevention of a lower extremity sprain or strain requires some basis for predicting that an individual athlete will sustain such an injury unless a modifiable risk factor is addressed. **Objective:** To assess the possible existence of an association between reaction time measured during completion of a computerized neurocognitive test battery and subsequent occurrence of a lower extremity sprain or strain. **Design:** Prospective cohort study. **Setting:** Preparticipation screening conducted in a computer laboratory on the day prior to initiation of preseason practice sessions. **Participants:** 76 NCAA Division I-FCS football players. **Main Outcome Measures:** Lower extremity sprains and strains sustained between initiation of preseason practice sessions and the end of an 11-game season. Receiver operating characteristic analysis identified the optimal reaction time cut-point for discrimination between injured versus noninjured status. Stratified analyses were performed to evaluate any differential influence of reaction time on injury incidence between starters and nonstarters. **Results:** A total of 29 lower extremity sprains and strains were sustained by 23 of the 76 players. A reaction time cut-point of  $\geq .545$  s provided good discrimination between injured and noninjured cases: 74 % sensitivity, 51 % specificity, relative risk = 2.17 (90 % CI: 1.10, 4.30), and odds ratio = 2.94 (90 % CI: 1.19, 7.25). **Conclusions:** Neurocognitive reaction time appears to be an indicator of elevated risk for lower extremity sprains and strains among college football players, which may be modifiable through performance of exercises designed to accelerate neurocognitive processing of visual input. **Key Words:** clinical prediction guide, injury prevention, injury risk

Relatively little evidence is available in the research literature pertaining to

## KEY POINTS

Preparticipation neurocognitive testing documents baseline status for assessment of concussion recovery and also appears to identify elevated risk for sprains and strains.

Improvement in neurocognitive reaction time might reduce risk for injury occurrence, but no evidence currently exists to provide implementation guidelines for such training.

specific preparticipation screening procedures that can identify individual athletes who possess elevated injury risk. Lower extremity sprains and strains are the most common injuries sustained during participation in competitive sports,<sup>1</sup> which have been associated with previous injury, body mass, antagonist

strength ratios, neuromuscular coordination, muscle endurance, postural balance,

agility, core stability, low back dysfunction, joint alignment, gender, joint mobility, psychosocial stress, and many other factors.<sup>2-6</sup> Although evidence exists to support the association of various factors with lower extremity musculoskeletal injury, the relative contributions of individual factors to the multifactorial etiologies of different injury types have not been clearly elucidated.<sup>6</sup> The knowledge that various factors are related to injury risk in a general manner has little value without clear guidelines that can be used to distinguish individuals who possess modifiable high-risk status from those with low-risk status.<sup>7-9</sup> Athletic trainers and therapists need clinical prediction guides that provide quantifiable likelihoods for the occurrence of specific types of injuries when an athlete

exhibits a given risk profile. Such information would permit targeted interventions for high-risk athletes who would derive greatest benefit from the time and resources devoted to injury prevention efforts.<sup>10</sup>

Prolonged neurocognitive reaction time is now widely recognized as an important indicator of impaired brain function following a concussion, which can be quantified by computerized testing procedures that have been shown to provide highly reliable measurements.<sup>11</sup> Because preseason neurocognitive testing can enhance detection of postconcussion impairments, the practice has been recommended for all athletes who participate in contact and collision sports.<sup>12</sup> Swanik et al.<sup>13</sup> reported the first evidence of a possible link between brain function quantified by a computerized neurocognitive test and knee injury risk. The amount of time required for visual perception of a stimulus, information processing, and response to the stimulus may have some relationship to an athlete's situational awareness and capability for rapid generation of an appropriate motor response to external forces. The purpose of this study was to assess the magnitude and precision of a point estimate of the possible association between prolonged neurocognitive reaction time and the subsequent occurrence of a lower extremity sprain or strain within a cohort of college football players.

## Procedures and Findings

Valid neurocognitive test scores were obtained for 76 NCAA-FCS college football players ( $1.84 \pm 0.08$  m;  $100.97 \pm 19.25$  kg,  $19.8 \pm 1.5$  years of age) on the day prior to initiation of 2011 preseason practice sessions through administration of the complete ImPACT™ test battery (ImPACT Applications, Inc., Pittsburgh, PA). Invalid test results excluded six cases from the analysis and three team members failed to report for the testing session. An injury was operational defined as a lower extremity sprain or strain that required the attention of an athletic trainer, and that limited football participation to any extent for at least one day after its occurrence, during the period from the beginning of preseason practice sessions to the end of an 11-game season. Fractures, dislocations, contusions, lacerations, abrasions, and overuse syndromes were excluded from the analysis. All study procedures were approved by the Institutional Review Board of the University of Tennessee at Chattanooga.

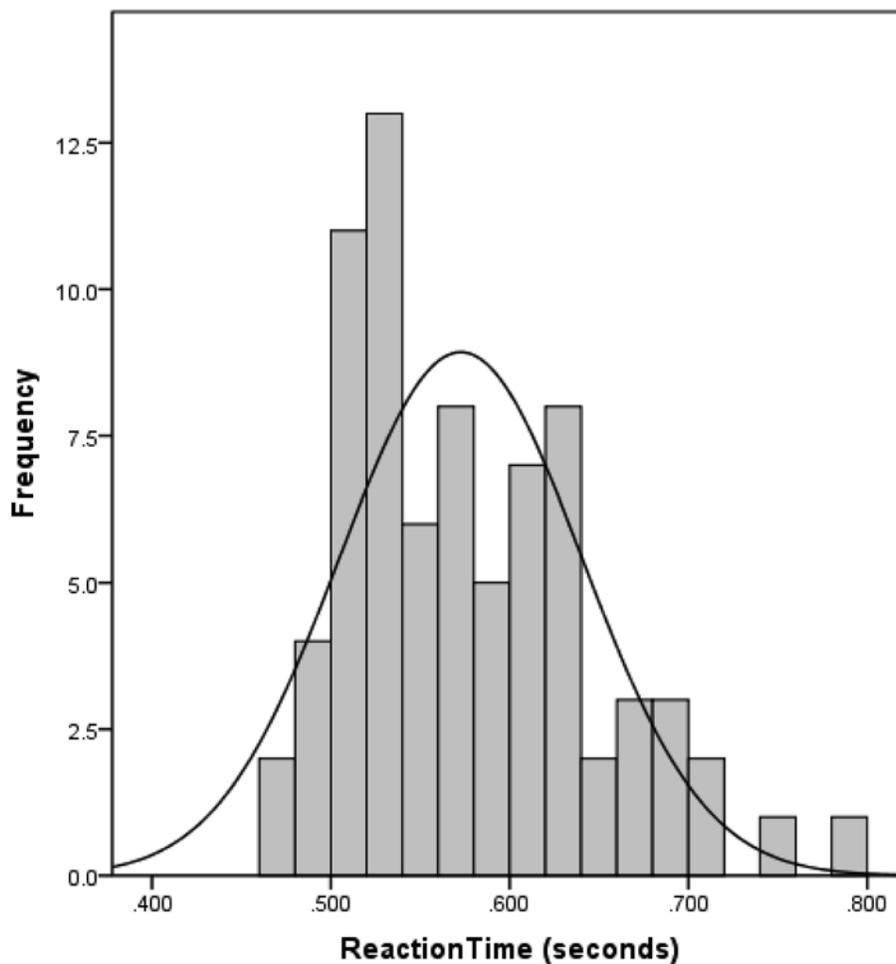
At least one lower extremity sprain or strain was sustained by 30% of the players (23/76). A total of 29

sprains and strains were sustained by the 23 injured players (5 hip/groin strains, 5 hamstring strains, 1 quadriceps strain, 6 knee sprains, 1 calf strain, 9 ankle sprains, and 2 mid-foot sprains). ImPACT™ composite reaction time values ranged from .470 s to .790 s, and the distribution of values demonstrated a positive skew (Figure 1; Mean =  $.573 \pm .068$  s; Median = .560 s). Receiver operating characteristic (ROC) analysis was used to identify the optimal cut-point for discrimination between injured versus noninjured status on the basis of reaction time, which was  $\geq .545$  s (Figure 2). The results of a  $2 \times 2$  cross-tabulation analysis of exposure status by outcome classification are presented in Figure 3 (44 high-risk cases  $\geq .545$  s and 32 low-risk cases  $< .545$  s). A confidence interval function for the relative risk of injury between players with slow versus fast reaction times is presented in Figure 4, which provides a visual representation of both the magnitude of the observed association and the precision of the relative risk point estimate.

Because starter status exposes football players to substantial elevation of injury risk,<sup>4,9</sup> the possibility for a differential influence of reaction time on injury incidence between starters ( $n = 32$ ) and nonstarters ( $n = 44$ ) was assessed with stratified analyses. Although the study power was not sufficient to demonstrate a statistically significant interaction effect, the relationships depicted in Figures 5 and 6 suggest that injury occurrence could be associated with an interaction of reaction time and starter status. Nonstarters demonstrated a greater amount of risk elevation than starters when the preseason reaction time was  $\geq .545$  s (i.e.,  $3.8 \times$  greater injury risk for nonstarters versus  $1.4 \times$  greater injury risk for starters), whereas the difference in mean reaction times of injured and noninjured starters (i.e.,  $.591 \pm .089$  s versus  $.570 \pm .069$  s) was greater than the difference between injured and noninjured nonstarters (i.e.,  $.575 \pm .049$  s versus  $.567 \pm .067$  s). Regardless of starter versus nonstarter status, a relatively slow neurocognitive reaction time clearly appears to increase risk for a lower extremity sprain or strain during participation in college football.

## Discussion

Slowing of reaction time and narrowing of peripheral vision were documented by Williams and Andersen<sup>14</sup> when college athletes were subjected to stress during testing of responses to visual cues, and the deteriora-



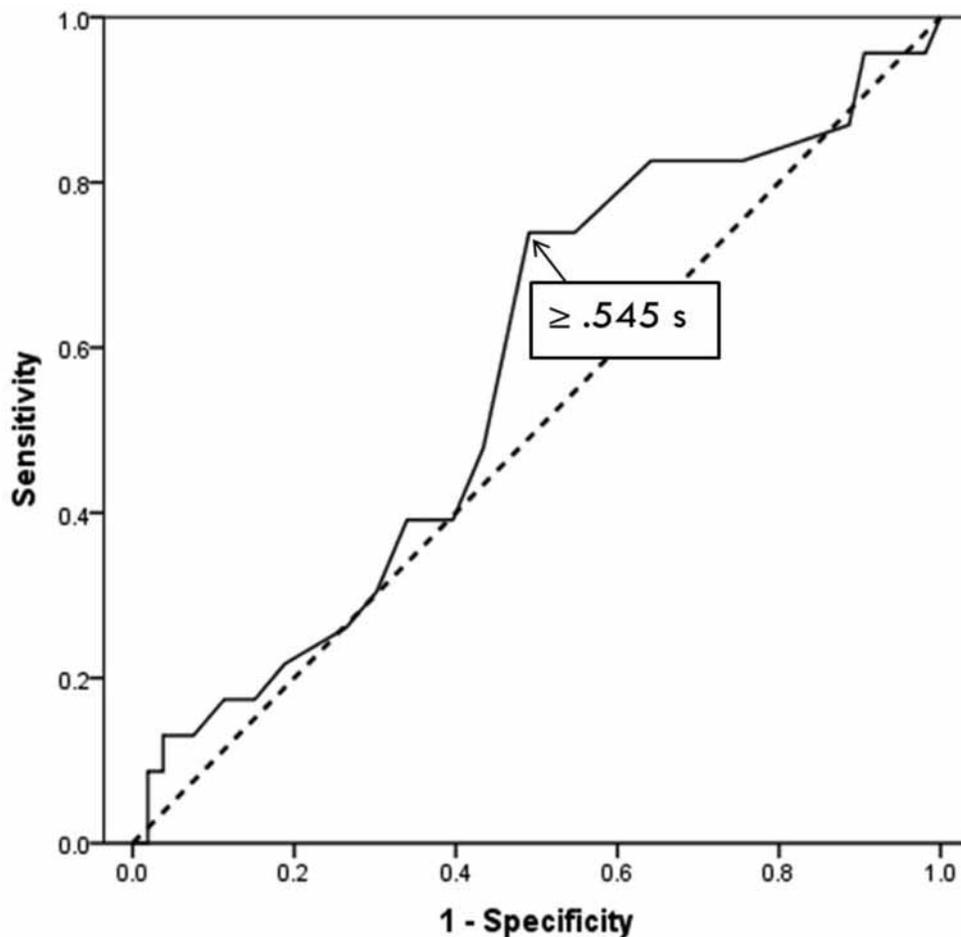
**Figure 1** Distribution of preparticipation ImpACT™ composite reaction time values for the cohort of 76 college football players.

tion in test performance was greatest for those who had experienced a greater number of negative life events during the previous year. The same researchers subsequently reported that the number of injuries sustained by the athletes was significantly related to narrowing of peripheral vision under stress and negative life events.<sup>15</sup> The finding that administration of an antidepressant medication (fluvoxamine) improved the reaction time of healthy subjects provides further evidence of an association between psychosocial stress and reaction time.<sup>16</sup>

The extreme demand for simultaneous situational awareness and rapid execution of complex motor patterns that is imposed by college football provides a plausible explanation for the findings of this study. Dynamic stability of the lower extremity requires rapid generation of internal moments to counteract external moments that are continuously changing and which may be difficult or impossible to anticipate. Vigilant visual monitoring of changing environment circumstances is almost certainly a critical factor for injury

avoidance. A relatively small delay in neural processing of visual input, or a relatively small narrowing of the peripheral field of vision, could have a major impact on the ability to anticipate external loads and to effectively generate muscle tension that will provide an adequate level of dynamic joint stability.<sup>13,15</sup>

The ROC cut-point for optimal discrimination between injured and noninjured college football players identified by this study (.545 s) also separates the mean ImpACT™ neurocognitive reaction time values reported by Swanik et al.<sup>13</sup> for 80 athletes who sustained noncontact ACL tears (.570 s) and 80 matched control athletes (.530 s). Although mean values provide a basis for comparison of the results of the two studies, the highly asymmetric distribution of reaction time values observed in this study (i.e., positive skewness value of .852 that was more than twice its standard error of .276) emphasizes the importance of using the median rather than the mean as an indicator of the central tendency of the cohort's performance values. The critical cut-point of  $\geq .545$  s for identification of



**Figure 2** Receiver operating characteristic curve for discrimination of injured college football players (i.e., lower extremity sprain or strain) from noninjured players on the basis of ImPACT™ composite reaction time.

	Injury	No Injury
≥ .545 s	17	26
< .545 s	6	27
Total	23	53

Fisher's Exact One-Sided  $P = .038$   
 Sensitivity = .74 Specificity = .51  
 +LR = 1.51 -LR = .51  
 Odds Ratio = 1.507/.512 = 2.94  
 90% CI: 1.19 – 7.25  
 Relative Risk = .395/.182 = 2.17  
 90% CI: 1.10 – 4.30

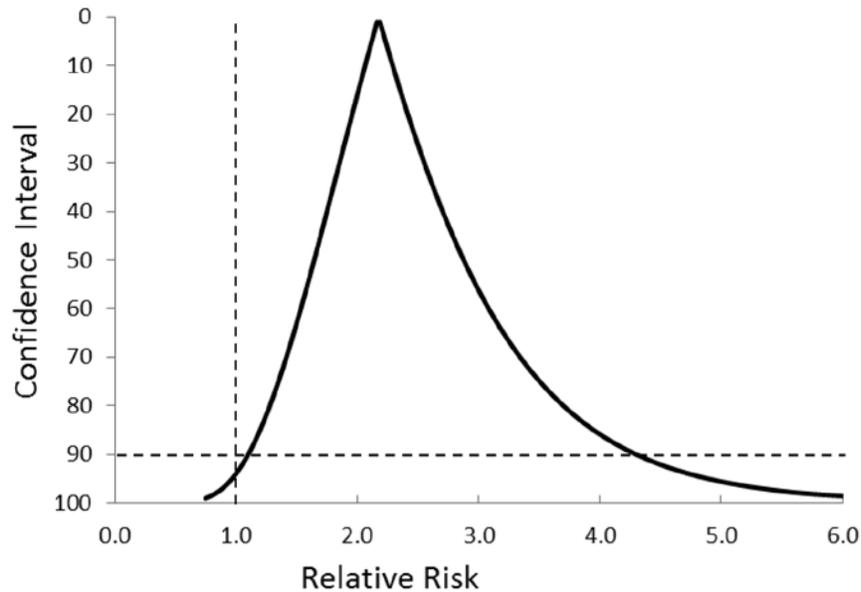
**Figure 3** Results of cross-tabulation analysis for discrimination of injured college football players (i.e., lower extremity sprain or strain) from noninjured players on the basis of ImPACT™ composite reaction time .545 s cut-point.

elevated injury risk was closer to the median value (.560 s) than the mean value (.573) of the dataset.

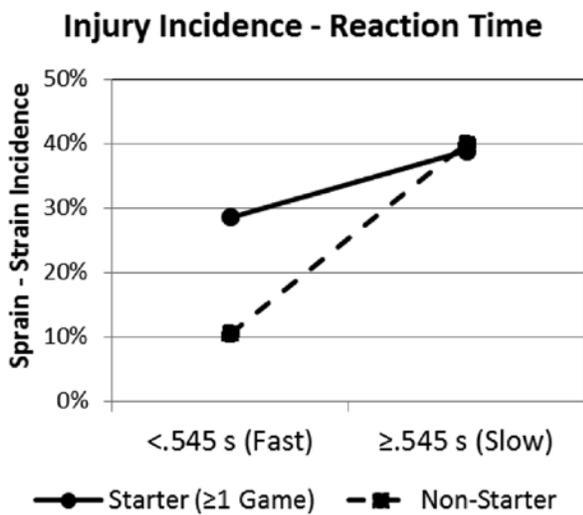
In addition to training activities that are believed to promote core and extremity adaptations relating to reflexive multisegmental muscle activation patterns

(e.g., plyometric jump training, postural balancing, and perturbation exercises), improvement in oculomotor skills, and neural processing of visual input to the central nervous system may also accelerate initiation of protective responses. Eckner et al.<sup>17</sup> demonstrated that performance on a visually-cued clinical test of reaction time was associated with the speed of a protective head maneuver in simulated sport environment. An extensive search of the literature failed to identify any evidence to support the effectiveness of any specific training method for improvement of visual function and information processing speed in competitive athletes,<sup>18</sup> but speed of processing training has been shown to improve the abilities of older adults who demonstrated relatively poor pre-training performance.<sup>19</sup> Thus, athletes who exhibit slow neurocognitive reaction time may derive the greatest benefit from activities designed to enhance responsiveness to visual stimuli.

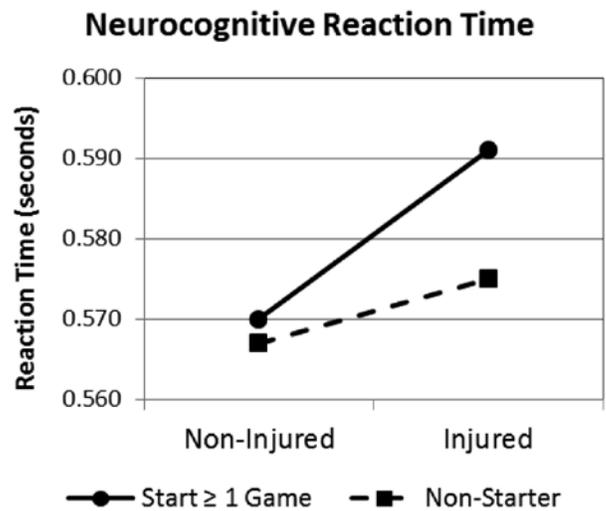
Future research should assess the extent to which any activities that improve neurocognitive reaction



**Figure 4** Confidence interval function for point estimate of relative risk for lower extremity sprain or strain with ImPACT™ composite reaction time  $\geq .545$  s versus  $< .545$  s (Relative Risk = 2.17; 90% CI: 1.10, 4.30). Horizontal dashed line corresponds to 90% confidence interval and vertical dashed line identifies the critical value that the lower limit must exceed for a positive association to exist between exposure and outcome.



**Figure 5** Lower extremity sprain and strain incidence for players dichotomously classified as low-risk (fast reaction time) versus high-risk (slow reaction time) and status as a nonstarter versus starter.



**Figure 6** Mean ImPACT™ composite reaction time for noninjured versus injured players and status as a nonstarter versus starter.

time can reduce injury incidence among athletes whose prior values were associated with elevated injury risk. Reaction time measurements acquired through a rapid and inexpensive procedure have been shown to correlate highly with those acquired from computerized neurocognitive testing,<sup>20</sup> which may make assessment of reaction time feasible as a component of the preparticipation examination. The specific cut-point for dichotomization of injury risk status derived from ROC analysis of ImPACT™ composite reaction time values is unlikely to correspond to the optimal cut-point value for a different measurement method, however.

Prolonged neurocognitive reaction time may be a risk factor for a variety of injury types, but injury-specific and sport-specific combinations of multiple risk factors can make the relative predictive value of a given factor highly variable,<sup>3</sup> and the optimal cut-point for dichotomous classification of injury risk may differ according to injury type, sport, gender, age group, etc. Thus, the results of this study may only apply to the prediction of lower extremity sprains and strains among college football players. Furthermore, the findings of this study need to be validated by replication of the procedures with other cohorts.

## Summary

Reaction time measured by a computerized test of neurocognitive function appears to be a good indicator of elevated risk for lower extremity sprains and strains among college football players. The results of this study demonstrated that an ImPACT™ composite reaction time value  $\geq .545$  s was associated with twice as much risk for injury relative to a faster value. Risk reduction might be possible through performance of exercises designed to accelerate neural processing of visual input, but no evidence is currently available to support a specific method of training for improvement of neurocognitive reaction time in athletes.

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**Gary Wilkerson** is a tenured professor in the Graduate Athletic Training Education Program at the University of Tennessee at Chattanooga.

**Monique Mokha, PhD, ATC**, Nova Southeastern University, is the Report Editor for this article.