

ORIGINAL RESEARCH

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# TRAINING STATUS INDICATORS PREDICT NEUROMUSCULAR CONTROL ALTERATIONS OVER THE COLLEGE MEN'S SOCCER SEASON

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## ABSTRACT

There is growing evidence supporting the link between overtraining and increased injury risk. The Landing Error Scoring System (LESS) is a neuromuscular control assessment of 17 lower extremity biomechanical risk factors. However, there is paucity in the literature focusing on the LESS across the competitive Division-1 men's college soccer season. This investigation sought to determine if significant changes in LESS scores occur over a competitive men's soccer season and whether these changes coincide with common training status indicators. Twenty-six healthy Division-1 college men's soccer players (age:  $20 \pm 1$  yr, height:  $181.5 \pm 6.4$  cm) were assessed for body mass (BM), resting heart rate (RHR), body fat (BF%), countermovement jump height (CMJ), and LESS at five experiment visits (V0-V4). A mixed effects model was analyzed to detect significant interactions between the LESS and each of the dependent variables. LESS scores were significantly elevated at V1 ( $p < 0.001$ ), which was conducted at the end of preseason training. Additionally, RHR and CMJ were shown to be significant predictors of LESS performance ( $p = 0.003$  and  $0.040$  respectively). Elevation in LESS scores following preseason training combined with the identification of RHR and CMJ further support the link between training status and injury risk. Periodic neuromuscular control assessments are essential for the optimization of performance and minimization of injury risk in college soccer athletes.

**Keywords:** Neuromuscular Control, Soccer, Training Status, Sport Science

The views expressed are those of the authors and do not reflect the official policy of the Department of Army, Department of Defense, or the U.S. Government.

## INTRODUCTION

As debilitating soccer injuries continue to mount despite additional preventative measures, many soccer organizations have increased their emphasis upon the monitoring of training status indicators [1, 2]. Much of the shift in recent focus is based on findings linking intensified physical demands with greater risk of injury [3-6]. Overtraining is characterized by impairments in physical performance and elevations in fatigue stemming from training loads which exceed an athlete's level of tolerance [7]. However, detecting overtraining remains a complicated process due to the variety of mechanisms and their complex interactions that determine both performance and fatigue outcomes. Consequently, periodic assessments of measures indicative of training status may be a viable proactive strategy for ensuring the physical wellbeing of soccer athletes.

The countermovement jump (CMJ) test is a common measure of lower body power which strongly correlates with lower body strength [8] and sprinting ability [9, 10]. CMJ performance is dependent on a number of factors, including: maximal force, rate of force development, and neuromuscular coordination of the upper and lower body [11]. The CMJ has recently been shown to be a superior indicator of neuromuscular fatigue compared to other performance measures, such as the squat jump, drop jump, and 20-m sprint test [12]. Furthermore, the CMJ is more conducive to in-season practical implementation than repeated anaerobic and/or prolonged aerobic performance tests, which require substantial time commitment and induce considerable physiological stress.

The energy required for maximal endurance tests are particularly problematic given the high demands already placed upon

the glycolytic and oxidative energy systems during soccer competition and training [13]. Overtraining effects are often related to severe depletion of energy stores as expenditure continuously surpasses dietary intake [14]. As such, frequent assessments anthropometric measures such as body mass (BM) and body fat percentage (BF%) are critical for preserving the physical wellbeing of the soccer athlete throughout the competitive season.

Overtrained athletes may also be distinguished by alterations to autonomic nervous system functioning [14]. Undesirable changes to the normal balance of sympathetic and parasympathetic activity can express in the form of increases in resting heart rate (RHR). Accordingly, previous investigations have shown fluctuations in RHR corresponding with the variations in training loads over the competitive season [15-17].

Another major concern with overtraining is the perturbation of normal movement patterns and neuromuscular control [18]. Prior research has indicated these fatigue-related motor system alterations may increase injury susceptibility [18-20]. The Landing Error Scoring System (LESS) provides an evaluation of 17 biomechanical injury risk factors during a standardized jump landing maneuver [21]. The detection of five or more injury risk factors ( $LESS \geq 5$ ) has been associated with greater risk of anterior cruciate ligament (ACL) injury [22]. While acute bouts of fatiguing exercise have been shown to negatively affect LESS scores [23, 24], no investigation to date has related longitudinal changes in LESS scores with common training status indicators in college men's soccer players.

Identifying significant relationships between LESS and common training status indicators would provide critical insight into

the growing paradigm linking training tolerance with injury risk. Consequently, this investigation aimed to determine if significant changes in LESS performance, as a measure of neuromuscular control and injury risk, occur over the competitive men's soccer season and whether these changes coincide with common training status indicators. Accordingly, we hypothesized that BM and CMJ would have significant negative relationships with LESS performance. In addition, BF% and RHR were hypothesized to be significant positive predictors of LESS performance.

## MATERIALS AND METHODS

### *PARTICIPANTS*

Twenty-six NCAA Division-1 Men's Soccer field position players (age:  $20 \pm 1$  years, height:  $181.1 \pm 6.5$  cm) = participated in this investigation. All participants were medically cleared for physical activity by the university's sports medicine department and free of any debilitating musculoskeletal injuries or contraindicated medical conditions disqualifying the participant from physical activity on each experimental visit. The study was approved by the University of Connecticut's institutional review board and all participants provided informed consent prior to completing any testing procedures.

### *MEASURES*

#### *Experimental Design*

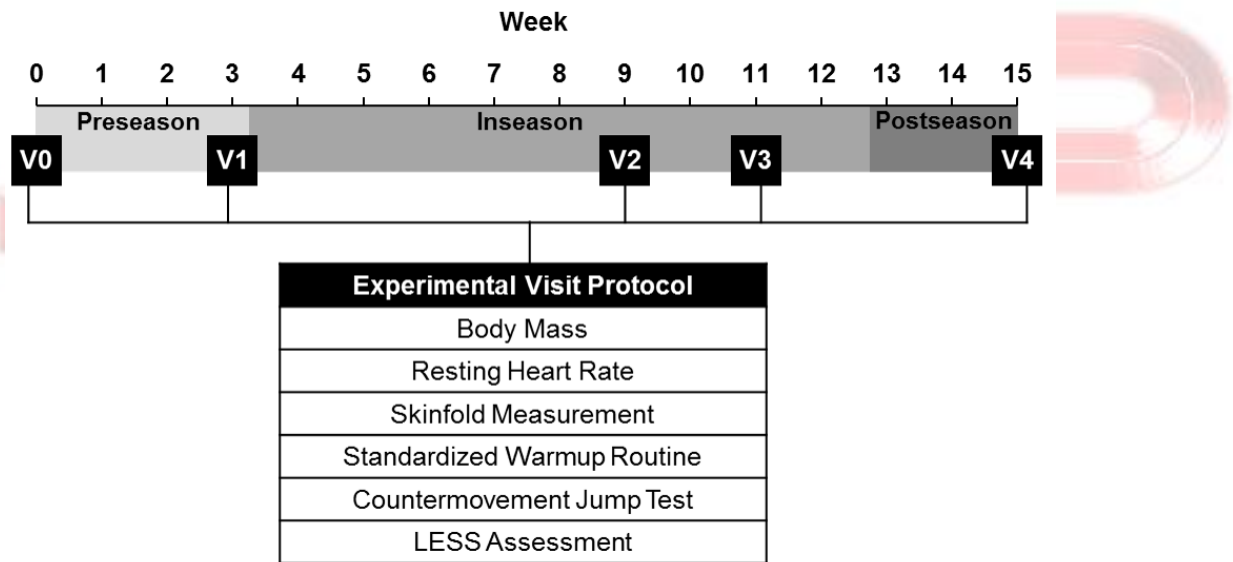
Five experimental visits (V0-V4) were conducted across the competitive fall season (Figure 1). V0 and V1 corresponded with when the team reported for preseason and the end of the preseason, respectively. Although the remaining visits were originally scheduled at four-week intervals, V2 was rescheduled

from week 7 to week 9 due to a building-wide power outage. The final visit (V4) was conducted after the conference tournament and two days prior to the first round of the NCAA tournament.

#### *Experimental Visit Protocol*

For each of the five visits, participants reported to the laboratory between 06:00-07:30 after a minimum eight hour fast. Upon arrival, participants were immediately assessed for body mass (BM) using a calibrated mass scale (Ohaus Defender 5000, model T51P; Ohaus Corporation, Pine Brook, NJ). Each participant was then provided a heart rate monitor (Polar Team 2 System, Polar Electro®, Kempele, Finland) and instructed to lie supine in a quiet, dimly lit room for a period of 7 minutes for assessment of resting heart rate (RHR). In accordance with the recommendations of prior literature [25-29], the minimum heart rate value recorded was considered to be the RHR.

Following the RHR procedures, skinfold measurements of the biceps brachii, triceps brachii, supriliac crest, and subscapula were taken from each participant by the strength and conditioning coach of the soccer team with over ten years of experience with these procedures. Body fat percentage (BF%) was subsequently calculated using the Durnin and Womersley formula [30]. Participants were then provided a supplemental beverage (Rockin' Refuel, Shamrock Farms Dairy, Shamrock Foods Company, Phoenix, AZ) by the strength and conditioning coach before completing a standardized warm-up. The order of exercises of the warm-up sequence was as follows: hamstring stretch, knee hugs, quad stretch, figure four stretch, side lunges, front lunges, cross-behind lunges, skipping, and squats.

**Figure 1.** Overview of the experimental design.

V#, Visit number; LESS, Landing Error Scoring System.

#### *Countermovement Jump (CMJ) Test*

After completion of the warm-up sequence, participants performed three attempts of the CMJ test separated by one-minute rest intervals. For all attempts, each participant began by standing motionless for a two-second period. When instructed, the participant performed a countermovement by bending their knees to a position that they felt comfortable with before jumping as high as possible and landing on the force plate [31-33]. All CMJ testing was performed on a Bertec FP4060-NC Force Plate (Bertec Corporation, Columbus, OH). Data from the force plate were sampled at a rate of 1,500 Hz with the analogue signal converted to a digital signal via Motion Monitor data acquisition software (version 7; Innovative Sports Training, Inc, Chicago, IL). For each jump, flight time ( $t$ ) was calculated between the instant of takeoff (force < 10N) and instant of landing (force > 10N). Subsequently, flight height was calculated using the flight-time formula [34, 35]:

$$\text{Flight height} = t^2 \cdot g \cdot 0.125$$

where  $g$  is the acceleration due to gravity ( $9.81 \text{ m}\cdot\text{s}^{-2}$ ). The highest CMJ recorded over the three attempts was used for analysis.

#### *Landing Error Scoring System (LESS) Test*

Lastly, participants were required to perform three successful attempts of a standardized jump-landing task to be assessed by the LESS [21, 36]. At the start of each attempt, participants stood on a 30-cm tall box with feet shoulder-width apart facing forward. When prompted, the participant first jumped down with both feet simultaneously on a target landing area positioned 50% of his height from the box before immediately jumping upwards as high as possible. An attempt was disqualified if the participant jumped upwards from the box, left with one foot first, or paused after making initial contact with the ground. Other than the task instructions, participants did not receive any feedback or corrective coaching on their landing technique. Jump-landing trials were recorded by a depth camera (frontal view only; Microsoft Kinect sensor version 1; Microsoft Corporation; Redmond, WA) controlled by a standard laptop computer.

Following data collection, depth camera data were evaluated and LESS scored with PhysiMax™ Athletic Movement Assessment software (PhysiMax Technologies Ltd.; Tel Aviv, Israel). This software has previously been shown to possess the same level of reliability as expert LESS raters [37].

### STATISTICAL ANALYSES

Data were analyzed using generalized linear mixed effects models (GLMEMs). In brief, GLMEMs function similar to simple linear regression models in that they explain changes in the dependent variable using population-mean or fixed effects. However, GLMEMs also incorporate participant-specific or random effects on the dependent variable, thereby accounting for participant-specific differences in initial outcome scores and progressions over time [38]. Furthermore, GLMEMs allow for analysis of participants with missing data points and datasets which are not normally distributed.

To address the research questions of the investigation, two GLMEMS were constructed; an empty model and a full model. The empty model was specified as:

$$LESS \sim 1 + (1 | ID)$$

where  $\sim$  denotes regressed upon, 1 denotes the intercept, and  $(1 | ID)$  denotes random effects of participant on intercepts. The full model included all of the predictors and was specified as the following:

$$LESS \sim 1 + VISIT + BM + RHR + BF + CMJ + (1 + VISIT | ID)$$

where VISIT denotes the experimental visit and  $(1 + VISIT | ID)$  denotes random effects of participant on intercepts and VISIT. To determine the presence of significant interactions at each experimental visit, VISIT

was included as a categorical variable. All other predictors (BM, RHR, BF, CMJ) were mean-centered prior to inclusion in the GLMEM.

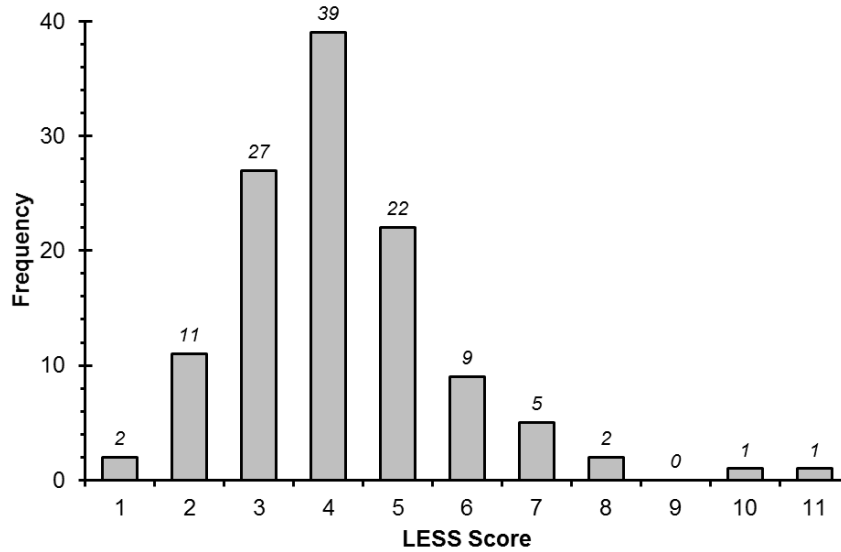
Goodness of fit was compared between the empty and full model using the Akaike information criteria (AIC) [39] and a chi-square ( $\chi^2$ ) difference test. All statistical analyses were performed using RStudio Version 0.98.1056 (© 2009-2013 RStudio, Inc). GLMEMs were conducted using the “lme4” package via the “glmer” and “glm” functions respectively [40]. P-values were determined using the lmerTest function [41] with the level of statistical significance set at  $p \leq 0.05$ .

### RESULTS

Mean and standard deviations (SDs) for each variable analyzed can be seen in Table 1. The frequency distribution of LESS scores across the season can be seen in Figure 2. Based on the positive skew and asymmetry of the distribution, it was determined that gamma regression with a log-link function was most suitable for interpreting the data.

Fixed effect mean estimates and standard errors (SE), SDs of random effects, as well as model fit indices can be seen in Table 2. The AIC, deviance, and log-likelihood all indicated that the full model better fit the data than the empty model. In addition, the  $\chi^2$  difference test determined that the reduction in residual variance was significant (degrees of freedom, 10; sum of squares, 43.0,  $p < 0.0001$ ). Significant interactions were detected between LESS scores and V1 ( $p < 0.001$ ), RHR ( $p = 0.003$ ), as well as CMJ ( $p = 0.040$ ). Figure 3 displays the Mean LESS scores for each experimental visit across the season.

**Figure 2.** Distribution of Landing Error Scoring System (LESS) scores across all participants and experimental visits during the college soccer season.

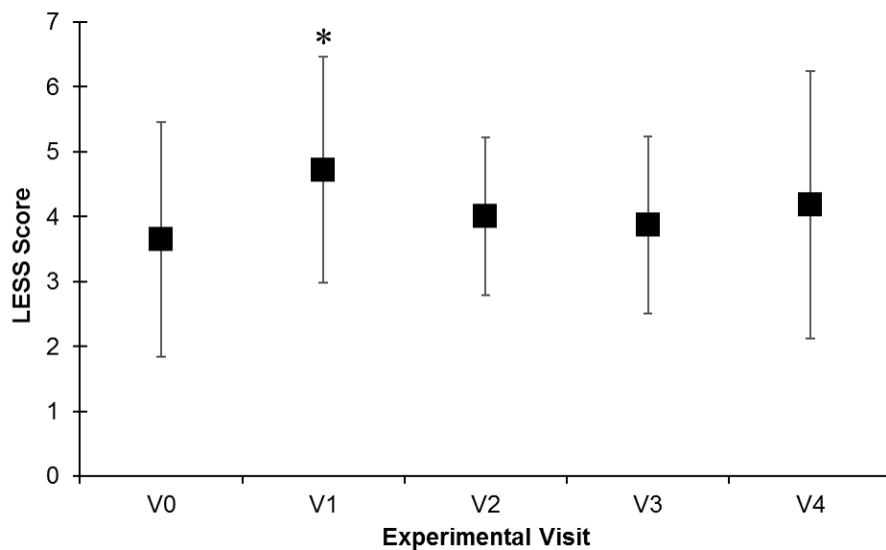


**Table 2.** Fixed Effects, Random Effects, and Model Fit Indices for Empty and Full Models

	<i>Empty Model</i>			<i>Full Model</i>	
<b>Fixed Effects</b> (Mean ± SE)	Intercept	1.410	± 0.049*	1.279	± 0.097*
	V1	—		0.294	± 0.084*
	V2	—		0.044	± 0.102
	V3	—		0.055	± 0.119
	V4	—		0.085	± 0.145
	BM	—		-0.009	± 0.010
	RHR	—		0.021	± 0.007*
	BF	—		-0.026	± 0.025
	CMJ	—		-0.026	± 0.013*
<b>Random Effects</b> (SD)	Intercept	0.129		0.252	
	VISIT	—		0.094	
	Residual	0.357		0.287	
<b>Model Fit</b>	AIC	434.0		411.1	

\* p < 0.05;  
 — Not applicable.

**Figure 3.** Mean LESS scores at each experiment visit. Error bars indicate standard deviations. \*, Significant interaction detected at V1 ( $p < 0.05$ ).



## DISCUSSION

The results of this investigation demonstrate significant impairments in neuromuscular control occur over the college men's soccer season. In addition, changes in LESS scores corresponded with two of the four training status indicators analyzed (RHR and CMJ). Altogether, these findings further emphasize that neuromuscular control

fluctuates with exposure to training and competition.

The observed variability in LESS scores supports recent criticism of the use of baseline screening for forecasting injury risk over extended periods of time [42]. This limitation was evident in a recent study by Krosshaug et al.[43] who found that only one of five kinematic and kinetic variables of the drop jump landing test was associated with future ACL incidence in elite female soccer and handball players over a seven-year period. Although it was concluded that the drop jump landing test was a poor screening

assessment for ACL injuries, the authors noted that the mean time between the drop jump landing test and injury incidence was 1.5 years. Our current investigation observed significant changes in LESS scores during a period of less than 4 months. Consequently, greater testing frequency may be necessary to capture the changes in neuromuscular control that occur across the competitive season to accurately evaluate injury risk.

The significant elevation in LESS scores at V1 is notable in that this visit was scheduled at the end of preseason training. This finding is in accordance with the results of a descriptive epidemiology study by Agel and Schisel [44] which identified higher injury rates in Division-1 College Men's Soccer during pre-season (8.1 injuries per 1,000 athlete exposures) than in-season and postseason training (2.8 and 1.9 injuries per 1,000 athlete exposures). Several factors have been theorized to increase injury risk during preseason training including the intensified physical demands as well as hot and humid environmental conditions [45]. Accordingly, a

previous investigation by DiStefano et al. [24] found that LESS scores following fatiguing treadmill tests were significantly higher with exposure to hypothermic and hypohydrated conditions. Subsequently, the results of this investigation suggest that motor control perturbations may serve as a mediator of the heightened injury susceptibility documented during preseason.

As evident by the significance and directionality of the effects of RHR and CMJ on LESS, neuromuscular control impairments were most pronounced when participants expressed signs of both autonomic stress and neuromuscular fatigue. Notably, the current study is the first to identify a relationship between RHR and LESS. Although no single test has been shown to provide a reliable and valid diagnosis of overtraining [7], the findings of the current study indicate that the overtrained athlete may be better identified by impairments across a diverse selection of training status assessments.

It is apparent in these data that the observed impairments in LESS were not contingent on adverse anthropometric changes. However, there was very little within-participant variability in either BM and BF% across experimental visits. As the appearance of motor control dysfunction far precedes that of deleterious anthropometric changes, these non-findings should not be interpreted as evidence against associating an athlete's LESS score with their current training status. Therefore, it is important for future research to examine changes in LESS in circumstances with more pronounced long-term anthropometric fluctuations before making any definitive conclusions on their relationships.

## CONCLUSIONS

The elevation in LESS scores following the heaviest period of training is further evidence for the growing paradigm linking training demands with injury risk as well as the mediating role of neuromuscular control impairments. In addition, the findings of this investigation support the use of the LESS as a valuable training status indicator that corresponds with other common tests. Ultimately, the findings of this investigation emphasize the importance of periodic neuromuscular control assessments to ensure the optimization of performance and minimization of injury risk in college men's soccer athletes.

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