PRINCIPLE COMPONENTS ANALYSIS TO CHARACTERIZE STRESS, PERFORMANCE, AND INJURY IN FEMALE COLLEGIATE SOCCER PLAYERS

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Stress created by training is needed to elicit physiological adaptations to increase performance, however, a stress threshold exists. We assessed 19 female collegiate soccer players during an eleven-week preparatory phase and measured stress, performance, and injury variables. We used a principal component analysis to explore relationships among stress, performance, and injury and identified five significant, oblique components. We found a weak, negative relationship between practice stress and anaerobic stress (r = -0.107, p = 0.05), a positive relationship between anaerobic stress and movement risk of injury (r = 0.459, p <.001), and a positive relationship between performance and general risk of injury (r = 0.309, p = 0.003). Sprint distance loaded on four components, and may be an important variable to monitor because it is related to stress, performance, and injury.

KEYWORDS: Athlete-monitoring, Physiological Stress, Periodization, Training, Practice, Gameplay

INTRODUCTION: The primary purpose of an athlete's strength and conditioning program is to increase performance and decrease risk of injury. A program achieves these goals by imposing a physical demand that exceeds the athlete's current physiological capacity, which initiates a state of physiological stress. In response to this stress, the body adapts to be able to overcome the previously excessive physiological demands. The body's adaptations are specific to factors underlying performance and injury: muscular power, strength, mobility, and tissue integrity. As a result of these adaptations, athletic performance improves and risk of injury decreases (Haff & Triplett, 2016).

A stress threshold exists. This is because the body's primary response to stress is the secretion of cortisol, which initiates the tissue remodeling process. As tissues remodel their size, integrity, and ability to absorb and produce force are increased (Haff & Triplett, 2016). Muscle force production underlies athletic performance, so muscle tissue remodeling improves performance through greater strength and power (Florini, 1987; MacDougall, 1986). If cortisol levels are too high, tissue degradation will exceed the capacity of tissue repair. Tissue degradation reduces a tissue's integrity and its ability to absorb and produce force. Excessive muscle tissue degradation results in net muscle loss, which causes a decrease in strength, power, and ultimately performance. Injury risk will also increase with tissue degradation, both inherently through lower ability to absorb force, and through poor movement patterns.

Stress must be optimized for performance benefits. Coaches use periodization when designing training programs to optimize physiological stress. Periodization varies volume and intensity over time, which allows for near maximal stress threshold to be met but not exceeded (Bompa & Buzzichelli, 2019). However, periodization and program design are often exclusive to training and do not account for additional stressors. Practice, game play, and travel also place significant physical stress on athletes. While academics, personal relationships, career decisions, and finances place mental stress on the collegiate athlete. This creates a problem, because stress, regardless of the source stimulates the secretion of cortisol, and cortisol has a systemic effect where the human body acts as one biological system. When multiple sources of stress exist there is a greater chance for chronically high concentrations of cortisol and tissue degradation. To optimize stress for athletic performance and injury, all sources of stress must be considered.

Recent advances in sport science wearable technology, such as Catapult Sports Systems, allows for quick and easy measurement of variables that can be used to monitor load. The ability to monitor practice and game load allows coaches and researchers to better quantify cumulative stress. The use of GPS data, in addition to strength and conditioning data, can be used to periodize training stressors effectively.

The purpose of this study was to investigate the relationship among all-source stress, performance, and incidence of injury in female collegiate soccer athletes. The research quantified physical stress using: GPS data, strength and conditioning load, mental stress using: sleep reports and stress questionnaires, and performance using: vertical jump data and game statistics. We hypothesized that there would be positive associations among stress, performance, and injury components.

METHODS: This study was conducted for the 11 week-long preparatory phase of a collegiate women's soccer team's annual training plan. Nineteen athletes (height: 1.65 ± 0.05 m, weight: 70.1 ± 4.52 kg) participated in the study voluntarily, following informed consent by the University's IRB.

Physical stress: Strength and conditioning session, practice session, and game play session data were collected to quantify physical stress. Athletes participated in regular strength and conditioning training sessions, unaltered by the research. Directly after the completion of each session, athletes were asked to individually rank the difficulty of the session, using Borg's (1982) 1-10 Rate of Perceived Exertion (RPE) scale. RPE and session duration were multiplied to find individual strength and conditioning session loads. The loads were grouped by week and summed to find weekly strength and conditioning loads for each athlete.

Athletes participated in regular soccer team practice, unaltered by the research, and match play while wearing an athlete tracking device (Playertek, Catapult Sports System, Melbourne, Australia), equipped with a global positioning system (GPS), accelerometer, and gyroscope. The device was used to collect data for all practice and game play sessions. The following GPS variables were extracted: player load, total distance (y-axis), work rate, high-speed running distance, sprint distance, acceleration bouts, and deceleration bouts. Individual athlete values were extracted for all GPS Variables; each variable was summed weekly.

Mental stress: Stress questionnaires and perceived rest scores were used to quantify mental stress. Athletes completed weekly college-stress questionnaires. The questionnaires were scored using a modified version of the ASU Wellness Stressful Event Checklist scoring system. Events with high stress were assigned a greater value than events associated with low stress. Individual athlete mental stress scores were recorded weekly.

Athletes provided rate of perceived rest (RPR) using a modified version of Borg's (1982) 1-10 perceived exertion scale and sleep duration prior to each strength and conditioning session. Individual RPR and sleep duration were multiplied to find individual level of rest. The scores were reversed so that a higher score corresponded with less sleep: insomnia. Individual athlete insomnia scores were summed weekly.

Performance: Counter-movement vertical jump and individual athlete game statistics data were collected to quantify performance. Athletes performed one maximal effort counter-movement vertical jump every Friday morning, prior to strength and conditioning and practice sessions. The vertical jumps were performed on top of two force plates (AMTI FP6060) and recorded using two cameras (SonyRX10ii, Tokyo, Japan) capturing frontal and sagittal planes. A custom-written MatLab script was used to process the force plate output and calculate peak power output. Individual athlete jump power values were recorded weekly. The vertical jump videos and Landing Error Scoring System (LESS) were used to asses jump landing mechanics. The scores were then modified so that a higher score corresponded with good landing quality. Individual landing error scores were recorded weekly. Resting heart rate was recorded before the vertical jump using a pulse oximeter (Zacurate, Stafford, TX).

Game statistics were collected for competitive match play, including: shots, shots on goal, goals scored, touches, dribbles, complete and incomplete passes, interceptions, dispossessions, turnovers, and shots blocked. Individual game statistics were multiplied by standardized coefficients designed for rating individual soccer performance (Lago et al, 2010). Game performance scores for each athlete were recorded in the database for the week the game occurred.

Injury: Athletes completed a weekly injury incidence report to quantify incidence of injury. Injury was defined by musculoskeletal pain that prevented, or regressed, participation in competitive or practice play. Only new injuries were counted; new injury was defined by absence of the specific injury in the previous week. Binary scoring was used to quantify presence (score of 1) and absence (score of 0) of self-reported injury.

Analysis: An exploratory factor analysis was conducted to determine a stress-injury-performance model. The effect of time was assessed, and the latent factor did not change over the season, thus, all data were collapsed into one model. Principal components analysis was selected as the factor extraction technique with Varimax and Direct Oblimin rotations. To select the best solution, factor matrices were examined for clearest interpretation.

RESULTS: Five significant components were identified with Kaiser's Eigenvalue and Catell's elbow criteria with a cumulative variance explained of 77.6%. The factor loadings were different between rotation methods, and the oblique rotation was interpreted because of a strong inter-relationship among Components 4 and 5 ($\sigma = 4.027$).

Component 1 was interpreted as a Practice Stress factor ($\lambda = 5.621$, $\sigma^2 = 40.1\%$), and the loading variables are presented in Table 1. Component 2 was interpreted as the Performance factor ($\lambda = 1.775$, $\sigma^2 = 12.7\%$) and the loading variables are presented in Table 1. Component 3 was interpreted as the Anaerobic Stress factor ($\lambda = 1.392$, $\sigma^2 = 9.9\%$), and the loading variables are presented in Table 1. Component 4 was interpreted as the General Injury Risk Factor ($\lambda = 1.071$, $\sigma^2 = 7.7\%$), and the loading variables are presented in Table 1. Component 5 was interpreted as the Movement Injury Risk Factor ($\lambda = 1.011$, $\sigma^2 = 7.2\%$), and the loading variables are presented in Table 1. Practice Stress and Anaerobic Stress components were weakly, negatively correlated ($r = -0.107$, $p = 0.05$). Performance and General Incidence of Injury components were positively correlated ($r = 0.309$, $p = 0.003$). Anaerobic Stress and Movement Injury Risk components were positively correlated ($r = 0.459$, $p <.001$). The correlations amongst the other components were not statistically significant.

Table 1. Principal components and their associated variables and factor loadings

	Compnt 1: Practice Stress	Compnt 2: Performance	Compnt 3: Anaerobic Stress	Compnt 4: General Injury Risk	Compnt 5: Movement Injury Risk
Total Distance	0.981				
Acceleration Bouts	0.974				
Deceleration Bouts	0.970				
Player Load	0.970				
High Speed Run Dist	0.857				
Work Rate	0.752				
Sprint Distance	0.539	0.316	0.485		-0.428
S&C Load			0.869		
Insomnia				0.445	-0.483
Mental Stress		0.587			
Jump Power		0.780			
Landing Error Score					-0.831
Injury Incidence				0.875	0.395
Resting Heart Rate		-0.752			

DISCUSSION: We hypothesized that there would be a positive association between stress and performance. Our hypothesis was rejected, stress and performance factors were not associated. A practice stress factor was identified that loaded with total distance, total acceleration efforts, total decelerations efforts, player load, high-speed running distance, work rate, and sprint distance (Table 1). This makes sense because all loading variables were data recorded by the athlete tracker which monitors player movement during practice, thus are indicative of the physiological stress placed on the athlete by practice. A factor was identified that loaded sprint distance and strength and conditioning load. This makes sense as an anerobic stress factor, because both variables primarily utilize anaerobic metabolism. A performance factor was found that loaded with sprint distance, mental stress, power, and low resting heart rate (Table 1). This was interpretated as performance, because athletes that sprinted more, displayed greater power output, and a lower resting heart rate are more likely to meet the physical demands of soccer. The loading of mental stress was interpretated to be an ability to cope with variant-source stress. Neither practice stress factor nor anaerobic stress factor correlated with performance.

We also hypothesized that injuries would increase with increasing stress. Our hypothesis was partially supported. A general injury risk factor was found and loaded positive insomnia scores with positive incidence of injury. Athletes who slept less also experienced more injuries. This makes sense as a general risk of injury factor. A movement injury risk factor was found that loaded negative sprint distance, negative insomnia scores, negative landing quality scores, and positive incidence of injury. Athletes that sprinted less, slept more, and displayed poor movement mechanics experienced more injury. This makes sense because poor movement mechanics increase extrinsic forces and decrease intrinsic forces which contribute to injury. Also athletes that spend less time sprinting experience less exposure to high extrinsic and intrinsic forces which increases their risk of injury when they are exposed, because they lack the physiological adaptations specific to optimal high force absorption and production.

Anaerobic stress and movement injury risk were associated, but anaerobic stress and general incidence of injury were not related. A statistically significant correlation was not identified between practice stress and either injury loading factors. This suggests that movement mechanics plays a role in risk of injury, especially when physiological stress is increased.

The research did not hypothesize the positive relationship between performance and incidence of injury. The performance factor (Component 2) and general injury risk factor (Component 4) positively correlated. High performance demands high force production. Thus an increase in risk of injury is inevitable with increasing performance. Coaches should direct focus to controllable factors that help reduce risk of injury when athletes are performing at high levels, such as optimizing movement mechanics, managing fatigue, and strengthening tissues that absorb and produce forces.

The sprint distance variable loads in Components 1, 2, 3, and 5 (Table 1), and therefore is an important variable to monitor because it can be used to assess practice stress, anaerobic stress, performance, and injury risk.

CONCLUSION: Physical and mental stress can be monitored with current technology, such as athlete trackers, and RPE scores. Monitoring stress from physical and mental sources may help with periodization where stress levels need to be optimized. We identified relationships between anaerobic stress and incidence of injury, and between performance and incidence of injury. Athletes need to focus on injury prevention factors particularly when performing speed and power skills. Sprint distance is an important variable to monitor.

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