8-2021

Athlete Monitoring Program in Division I Collegiate Female Soccer

Ai Ishida
East Tennessee State University

Athlete Monitoring Program in Division I Collegiate Female Soccer

---

A dissertation

presented to

the faculty of the Department of Sport, Exercise, Recreation, and Kinesiology

East Tennessee State University

In partial fulfillment

of the requirements for the degree

Doctor of Philosophy in Sport Physiology and Sport Performance

---

by

Ai Ishida

August 2021

Jeremy A. Gentles, Ph.D., Chair

Caleb D. Bazyler, PhD.

Satoshi Mizuguchi, Ph.D.

Adam L. Sayers, Ph.D.

Keywords: female soccer, athlete monitoring, individualized data analysis

ABSTRACT

Athlete Monitoring Program in Division I Collegiate Female Soccer

by

Ai Ishida

The objectives of this dissertation include 1) to review athlete monitoring strategies and the physical performance demands of female soccer match-play and to provide practical application of athlete monitoring programs, 2) to examine individual and group relationship between training load (TL) and subjective recovery and stress state and neuromuscular performance, and 3) to investigate acute effects of match-play on neuromuscular and subjective recovery and stress state in National Collegiate Association Athlete (NCAA) division I collegiate female soccer. TL was assessed using 10Hz Global Navigation Satellite System units. Subjective recovery and stress state was measured using the Short Recovery and Stress Scale (SRSS) consisting of 8 subscales including Physical Performance Capability (PPC) Mental Performance Capability (MPC), Emotional Balance (EB), Overall Recovery (OR), Muscular Stress (MS), Lack of Activation (LA), Negative Emotional State (NES), and Overall Stress (OS). Neuromuscular performance was assessed using countermovement jump (CMJ) with a polyvinyl chloride pipe (CMJ0) and 20kgs bar (CMJ20). CMJ variables included body mass (BdM), jump height (JH), modified reactive strength index (RSI), peak force (PF), relative peak force (RPP), eccentric impulse (EI), concentric impulse (CI), peak power (PP), relative peak power (RPP), eccentric average peak power (EAP), and concentric average power (CAP). Results of this dissertation showed that 12 individual players demonstrated negative correlations between total distance and MPC ($p \leq 0.05$, $r=-0.78$ to -0.34, number of significant individual correlations [N]=3) and OR ($p \leq 0.05$, $r=-0.91$ to -0.08, N=3). Positive correlations were observed between MS and total distance among all

individual players ($p \leq 0.05$, $r=0.21$ to 0.82, $N=3$) while the group correlations were moderate to large ($p \leq 0.001$, $r=0.55$). Results of this dissertation also demonstrated that significant moderate to large decreases were observed at 12 hours post-match in JH, RSI, CI, PP, RPP, and CPA in CMJ0 and CMJ20 ($p<0.05$, ES=0.63 to 1.35). Significant correlations were observed between CMJ20 PP from pre-match to 12 hours post-match and TLs ($p<0.05$, $r=-0.58$ to -0.68). When combined, results suggest that athlete monitoring programs may be effective when monitoring neuromuscular and subjective recovery and stress state changes at individual level in conjunction with group analysis in NCAA division I collegiate female soccer.

ACKNOWLEDGEMENTS

I could acknowledge my committee chair, Dr. Jeremy A. Gentles, for his commitment to my dissertation projects. I truly appreciate his constructive advice, critique, and commitment throughout this dissertation. I also would like to express sincere appreciation to my committee member, Dr. Caleb D. Bazyler, for his writing and data analysis engagement. His edits made this dissertation readable and useful in the sports science field. I am very grateful to my committee member, Satoshi Mizuguchi, for the engagement in a part of data and statistical analysis. He challenged me and kindly took care of the process of the dissertation. I also appreciate my committee member, Adam L Sayers, for assistance in data collection with the East Tennessee State University women's soccer team. He assisted greatly to improve this dissertation from the viewpoint of soccer.

Additionally, I appreciate my coworker, S. Kyle Travis, for helping my writing and understanding of sports science. I also would like to show my gratitude to Dr. Michael H. Stone, Meg Stone, and Brad H DeWeese for having me in this Ph.D. program and trusting me to conduct this research. I could not have finished this dissertation without their support. Furthermore, I thank coaches Jeremy Yelton, Matthew Yelton, Fiona Dodge, and women's soccer team members for their willingness to collaborate with our program. Finally, I appreciate my family for continuous support to study in the United States since 2016.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1. Introduction

Soccer is one of the most popular sports and is played by men and women at different competitive levels. Soccer is categorized as an intermittent physical activity due to the combination of repeated and prolonged sprints and walking, jogging, jumping, kicking, heading, and changing directions. As a result of the match-physical demands, soccer match-play induced fatigue impacts the recovery process in soccer-related physical performance and neuromuscular, physiological, and biochemical markers (Andersson et al., 2008; Claudino et al., 2017; de Hoyo et al., 2016; Nedelec et al., 2014; Romagnoli et al., 2016; Sams et al., 2018; Shearer et al., 2017; Varley et al., 2017). For example, Andersson et al. (2008) reported that statistically significant reduced countermovement jump (CMJ) height, increased creatine kinase (CK), and increased uric acid were found from pre-match to 21 hours after a match play in elite female soccer players. Based on the evidence from previous literature (Andersson et al., 2008; Claudino et al., 2017; de Hoyo et al., 2016; Nedelec et al., 2014; Romagnoli et al., 2016; Sams et al., 2018; Shearer et al., 2017; Varley et al., 2017), it would be beneficial for sports scientists and coaches to assess a current player's neuromuscular, physiological, and biochemical status using athlete monitoring measures.

Currently, there are more than 300 female soccer programs at the National Collegiate Athletic Association (NCAA) Division I. The NCAA Division I competitive season consists of 2 weeks of pre-season and 12-16 weeks of in-season with 20 to 25 matches. According to literature (Andersson et al., 2008; Djaoui et al., 2016; Dupont et al., 2010; Nedelec et al., 2014; Walker et al., 2019), the short and intense season schedule would not provide sufficient training and recovery times to maximize sports performance while reducing the risk of injuries. Specifically, the female soccer players are required to play 2 matches within 48 to 72 hours interval at the end of seasons. However, current evidence (Andersson et al., 2008; Djaoui et al., 2016; Dupont et al., 2010; Nedelec et al., 2014; Walker et al., 2019) supports that 2 matches within 48-72 hours interval do not allow for full recovery in biochemical and neuromuscular markers. Walker et al. (2019) showed that significantly increased cortisol and CK levels were observed at 16th week after the baseline when players completed 11 practices and 7 matches for the 4 weeks (from 12th to 16th week) (both, p<0.05). Rollo and colleagues (2014) also found that playing two soccer matches per week (72 hours interval between matches) significantly decreased sprint, jump, intermittent endurance performances at 6 weeks post-baseline compared to playing one match per week (all, p<0.05). Due to the NCAA female schedule, it would be quite challenging for sports scientists and coaches to physically and psychologically prepare the players to the next match.

To date, sports scientists and strength and conditioning coaches in the NCAA female soccer have involved athlete monitoring programs to minimize sports performance decrements to a match. Athlete monitoring tools are typically categorized into two different types for different purposes: load monitoring and response monitoring (Gabbett et al., 2017; Halson, 2014; Impellizzeri et al., 2019; Soligard et al., 2016). Load monitoring is used to quantify how much TL a player completed in a training session or match-play. An example of load monitoring is the total distances covered in a match-play by GPS units. Response monitoring, on the other hand, refers to the assessment of the degree of a player's recovery or response to TL accomplished. As individual players respond differently to a given TL, response monitoring can evaluate the current player's physical readiness. Countermovement jump is a common response monitoring tool to evaluate neuromuscular performance and fatigue in lower limbs (Andersson et al., 2008; de Hoyo et al., 2016; Oliver et al., 2008; Walker et al., 2019). Response monitoring also plays a role in evaluating physical performance changes in relation to training. For example, a sprinting test is a universal test to assess maximum running velocity in soccer (Andersson et al., 2008; Nedelec et al., 2014; Robineau et al., 2012; Rollo et al., 2014). Therefore, athlete monitoring programs play a vital role in physical performance in the NCAA Division I soccer.

Countermovement jump (CMJ) testing and subjective recovery and stress questionnaire are common monitoring tools to quantify a player's neuromuscular status and subjective recovery, and stress state in competitive soccer (Taylor et al., 2012). Compared to physiological and biochemical measures such as blood and saliva measures, CMJ and subjective recovery and stress measures have been used in competitive sports due to the feasibility and the non-invasive nature of these measures (Carling et al., 2018; Claudino et al., 2017; Halson, 2014). According to previous literature (Nedelec et al., 2014; Romagnoli et al., 2016; Varley et al., 2017), these measures are reflective of acute and chronic TLs in competitive soccer.

Another important factor is an analysis method in the athlete monitoring program. Previously, the monitoring data has been analyzed at group-level changes and relationships (McLellan et al., 2011; Oliver et al., 2008). Based on current reviews (Bailey, 2019; Kinugasa et al., 2004; Sands et al., 2019), individual data analysis could be more appropriate to optimize sports performance in competitive sports than group data analysis due to team success and heterogeneity. In competitive sports, team success (i.e., winning a match or a medal) can be determined by the performance of the team's or individual best players. Therefore, sports scientists and strength and conditioning coaches should assess the best player's physical and psychological status across a competitive season. Current evidence also supports that there are heterogeneous responses in relation to acute TLs in physical activity (Bagger et al., 2003; Bartlett et al., 2017; Bouchard & Rankinen, 2001; Katch et al., 1982). For example, changes in maximum oxygen consumption, HR, and systolic blood pressure differently respond to standardized and controlled exercise-training between individual subjects (Bouchard & Rankinen, 2001). Katch and colleagues (1982) also showed that biopsychological heterogeneity affected maximum aerobic power during treadmill running. Based on the evidence from previous literature (Bagger et al., 2003; Bartlett et al., 2017; Bouchard & Rankinen, 2001; Katch et al., 1982), it is possible that NCAA Division I female players may respond to a given TL at the different rate although the players are relatively homogenous samples. Therefore, individual data analysis could be potentially more suitable in competitive sports than group data analysis.

Although it is quite vital to consider the use of individual data analysis in competitive sports, limited data are available regarding the efficacy of individual data analysis, particularly in competitive sports players. Additionally, there is quite limited evidence regarding the acute neuromuscular status and subjective recovery and stress state in the NCAA Division I female soccer. The information is quite important to be considered to maximize the efficacy of an athlete monitoring program, which, in turn, maximize sports performance while reducing the risk of injuries. Therefore, the purposes of this dissertation were 1) to examine the relationships between match-derived TL, recovery and stress state, and neuromuscular performance at individual and group levels in Division I collegiate female soccer player, 2) to investigate the acute effects of a soccer match on neuromuscular performance and player's subjective recovery and stress state in Division I collegiate female soccer players, and 3) to identify the relationship between TLs of a match-play and the acute changes in neuromuscular performance. Specifically, the research questions of the study are as follows:

1) What is the relationship between a player's subjective recovery and stress state and neuromuscular performance at pre-match?

2) Is there a relationship between the change in a player's subjective recovery and stress state and training loads measures of a match-play?
3) Are these relationships stronger at individual analysis than the grouped analysis?
4) How do CMJ kinetic variables change after a match-play in female soccer players?
5) Is there a relationship between CMJ kinetic changes and TL after soccer match play?

Hypothesis:

1) Significant relationships will be observed between a subjective recovery and stress state and neuromuscular performance at pre-match.
2) Significant relationships will be found between the change in a player's subjective recovery and stress and volume-related match-derived TL (i.e., total distance, high speed running distance, and total PlayerLoad).
3) These relationships will be stronger at the individual level than at the grouped level.
4) Jump height, peak power, and concentric impulse at 1-day after a match will significantly decrease than the pre-match values.
5) There is a significant negative relationship between match-derived TL and (sRPE, total distance, HSR) and percentage changes in CMJ kinetic variables (i.e., jump height, peak power, and concentric impulse.

Chapter 2. Review of Literature

Introduction

Training is a process that prepares athletes for the physical, mental, and tactical demands of their sport (DeWeese et al., 2015a; Gabbett et al., 2017; Impellizzeri et al., 2019). To optimize adaptations for a specific sport, properly structured training programs should use overload and variation of stimuli, such as training volume and intensity. However, it may be difficult to overload and vary training stimuli during a competitive season. Because of match and travel schedules, players may spend the bulk of their time traveling and competing, leaving little time for training. If and when training is possible during a competitive season, athletes may become overreached if care is not taken when prescribing overload and variation (DeWeese et al., 2015a, 2015b). Practitioners such as sports scientists and strength and conditioning coaches should assess a player's physical and psychological state and plan proper training programs for performance enhancement.

Due to dense match and travel schedules in competitive soccer, current evidence illustrates that a player's physical and psychological state are negatively affected in response to soccer match-play (Andersson et al., 2008; de Hoyo et al., 2016; Gallo et al., 2016; Gravina et al., 2011; Malone et al., 2018; Nedelec et al., 2014; Thorpe, Strudwick, et al., 2017). Athlete monitoring aims to combat the negative effects of repeated match-play. Athlete monitoring has been shown to play an essential role to maximize sports performance during a competitive season while minimizing fatigue (Bourdon et al., 2017; Gabbett et al., 2017; Halson, 2014; Impellizzeri et al., 2019). The primary objectives of athlete monitoring programs in soccer are to assess training load (TL) completed by a player, the response to TL, a player's physical and psychological readiness to train or play, and the adaptations to improve sports performance

(Bourdon et al., 2017; Gabbett et al., 2017; Halson, 2014; Impellizzeri et al., 2019). The monitoring data inform practitioners of a player's current physical and psychological state and assist their training prescription (i.e., strength training, conditioning training, and recovery) for the next match (Bourdon et al., 2017; Gabbett et al., 2017; Halson, 2014; Impellizzeri et al., 2019). Therefore, incorporating athlete monitoring programs in competitive soccer should improve sports performance.

In the context of the National Collegiate Athlete Association's (NCAA) female soccer season, athlete monitoring programs are vital to guide player preparation. The NCAA female soccer players spent 2 to 3 weeks of pre-season, followed by 12 to 14 weeks of a competitive season. In the competitive season, players are required to play approximately 20 matches for the weeks concurrent with academic work. In addition to the long competitive season with the short pre-season, NCAA restricts sports coaches from providing mandatory session training sessions (May to August). The NCAA match schedule and restrictions produce high physical, physiological, and psychological loads, causing the increased risk of injuries (Agel & Schisel, 2013) and neuromuscular performance decrements (Sams et al., 2018), psychological and physiological alternations (Sekiguchi et al., 2018; Walker et al., 2019) in the early competitive season. However, the literature has not adequately addressed athlete monitoring in NCAA female soccer. Therefore, the objectives of this dissertation include, 1) to review athlete monitoring strategies and the physical performance demands of female soccer match-play and to provide practical application of athlete monitoring programs, 2) to investigate acute effects of match-play on neuromuscular and subjective recovery and stress state in NCAA Division I collegiate female soccer players, and 3) to examine individual and group relationship between TL and athlete monitoring measures.

Athlete Monitoring Measures in Soccer

It is essential to understand the roles, strengths, and limitations of athlete monitoring measures and appropriately select the measures based on sports-specific demands (Bourdon et al., 2017; Gabbett et al., 2017; Halson, 2014; Thorpe et al., 2017). When monitoring measures are improperly chosen, practitioners cannot evaluate physical and psychological states associated with sports performance (Bourdon et al., 2017; Gabbett et al., 2017; Halson, 2014; Impellizzeri et al., 2019). In soccer, measures should be related to match-play, such as running distance covered, sprinting velocity, jumping, and changing directions (Stølen et al., 2005). Based on previous literature (Gabbett et al., 2017; Halson, 2014; Impellizzeri et al., 2019; Soligard et al., 2016), athlete monitoring measures used in soccer can be broadly categorized as load or response assessments. Load monitoring assessment is used to quantify the TL a player completes in training or match-play. An example of load monitoring is total distances covered during match-play measured by Global Navigation Satellite System (GNSS) sensors. Response monitoring assessment includes a player's response to a TL completed. As individual players respond differently to a given TL, response monitoring can evaluate a player's physical and psychological readiness to play or train. Countermovement jump is a simple response monitoring test used to assess lower-limb neuromuscular performance and fatigue (Andersson et al., 2008; de Hoyo et al., 2016; Oliver et al., 2008; Walker et al., 2019). Response monitoring measures are also used to evaluate physical performance changes that result from training. For example, a sprint test is a universal test to assess maximum running velocity in soccer (Andersson et al., 2008; Nedelec et al., 2014; Robineau et al., 2012; Rollo et al., 2014). Including load monitoring and response monitoring assessment can inform training prescription to improve physical and psychological readiness (Andersson et al., 2008; Nedelec et al., 2014; Robineau et al., 2012;

Rollo et al., 2014). The following section describes common load and response monitoring measures in soccer.

Load Monitoring Measures

The load monitoring measures are classified as internal training load (IL) and external training load (EL). IL is defined as physiological and psychological responses or loads to a given EL (Soligard et al., 2016); many IL variables may also be used as response monitoring measures. Common IL metrics include but are not limited to measures such as session rating of perceived exertion (sRPE) and heart rate (HR). The benefit of IL measures is to appropriately determine physiological loads at a given TL (Impellizzeri et al., 2019; Soligard et al., 2016). When consistently measuring IL, practitioners can allocate optimal physiological loads to maximize performance improvement. EL metrics indicate the work achieved by a player, or serve as a proxy of work, irrespective of IL (Impellizzeri et al., 2019). EL is commonly measured for understanding physical demands and capability such as total distance covered and high speed running (HSR) distance in soccer match-play (Halson, 2014).

Internal Load Assessment

Session rating of perceived exertion.

Session rating of perceived exertion (sRPE, arbitrary units: au), a common IL used sport, is a measure of the subjective perceptive load of training and matches. The sRPE is calculated as the product of duration of the session in minutes and RPE on the 10 points Borg Rating of Perceived Exertion (RPE) scale rating with descriptors from 0 (Rest) to 10 (Maximum) (Borg, 1982). In competitive sports, sRPE is commonly used irrespective of training mode or location

(Casamichana et al., 2013; Coutts et al., 2009; Impellizzeri et al., 2004; Kelly et al., 2016). The quantification of TL using sRPE allows practitioners to manage daily, weekly, and monthly TL while minimizing unfavorable adaptations associated with under-loading. Literature is available regarding sRPE of training and match-play during a competitive season (Campos-Vazquez et al., 2015; Malone et al., 2015; Sams et al., 2020; Scott et al., 2013). By using sRPE data, practitioners can appropriately progress TL and avoid maladaptation (Kelly et al., 2020; Ravé et al., 2020). Current evidence has also indicated that starters in competitive soccer play 1 or 2 matches per week and accumulated higher weekly TL than non-starters (or substitutes) (Anderson et al., 2016; Foster, 1998; Haddad et al., 2017; McFadden et al., 2020; Sams et al., 2020), leading to the difference in sRPE. For example, Sams et al., 2020 showed that starters accumulated statistically greater season sRPE than non-starters in NCAA Division I male soccer (p<0.001, ES=1.91). Therefore, sRPE may allow practitioners to quantify and manage overall athlete's IL of sessions.

Another possible strength of sRPE is the association with other objective markers in soccer (Coppalle et al., 2019; Maya et al., 2016; Owen et al., 2016; Rowell et al., 2018) and other running-based sports (Abe et al., 2015; Balsalobre-Fernández et al., 2014; Moreira et al., 2012). Several investigations have indicated that sRPE and RPE were correlated to acute changes in biochemical and immunological markers following soccer match-play. Maya et al. (2016) revealed that a large positive correlation was also found between RPE and changes in cortisol after Australian competitive female soccer match-play (p=0.008, r=0.57). Owen et al. (2016) also found that a large negative correlation was observed between RPE and post-high intensity training salivary immunoglobulin a in elite male professional soccer players (p≤0.05, r=-0.57 to -0.60). Therefore, the use of sRPE may provide an insight into biological responses to TL.

The use of sRPE is also useful and reliable when monitoring IL of aerobic, anaerobic, and intermittent exercises in soccer (Alexiou & Coutts, 2008; Costa et al., 2020; Impellizzeri et al., 2004). For instance, large to very large correlations have been found between sRPE and HR-based training impulse ($p<0.01$, $r=0.50$ to 0.84) (Alexiou & Coutts, 2008; Costa et al., 2020; Impellizzeri et al., 2004), total distance covered from GPS ($p<0.01$, $r=0.70$ to 0.80) (Casamichana et al., 2013; Scott et al., 2013), PlayerLoad ($p<0.01$, $r=0.74$ to 0.84) (Casamichana et al., 2013; Scott et al., 2013), and high speed running (HSR) ($p<0.01$, $r=0.65$) (Scott et al., 2013). Therefore, sRPE data can aid coaches' decision to provide supplemental training sessions (i.e., recovery, conditioning, tactics) based on playing status while preventing training monotony and strain (Anderson et al., 2016; Foster, 1998; Haddad et al., 2017; Sams et al., 2020). However, care should be taken when and how to measure sRPE. The accuracy of sRPE can be influenced by the final training activity (Foster et al., 2001) and types of training actives (Alexiou & Coutts, 2008; Campos-Vazquez et al., 2015; Impellizzeri et al., 2004). For example, during a 6 week competitive period in high-level female soccer players, Costa et al. (Costa et al., 2020) reported that within- and between-subject sRPE variability was 31.2% and 31.7%, respectively.

Heart Rate

Heart rate is a valid and noninvasive monitoring measure to quantify IL in soccer athletes (Alexiou & Coutts, 2008; Andersson et al., 2008; Costa et al., 2020; Krustrup et al., 2005; McFadden et al., 2020; Walker et al., 2019). Common HR derived metrics include training impulse (TRIMP), mean HR (HR_{mean}), maximum HR (HR_{max}), and time spent in different intensity zones based on percentages of HRmax (Alexandre et al., 2012). In soccer, metrics such as HR_{mean} and time spent in high HR zones, are reflective of physiological demands of training sessions and match-play. Competitive female soccer players maintain an HR_{mean} 80-90% of HR_{max} (HR_{mean} of 159-173 bpm) during match-play (Andersson et al., 2008; Costa et al., 2020; Datson et al., 2014; Krustrup et al., 2005; Stølen et al., 2005). Based on match-play HR data, coaches can set soccer-related training intensity at 80-90% of HR_{max} to improve aerobic performance. For example, coaches often prescribe small-sided soccer games (SSG) (i.e., 3v3, 4v4, and 8v8) because HR_{mean} of SSG is similar to that of a match-play (Dellal et al., 2012; Jones & Drust, 2007; López-Fernández et al., 2018; Owen et al., 2020). Current evidence has shown that the accumulation of SSG at HR_{mean} ranging from 165-178 bpm for a short duration (3 to 10 minutes) provides a match-play physiological stimulus and may improve aerobic performance with minimal doses of training volume during a competitive season (Dellal et al., 2012; Halouani et al., 2014; Hill-Haas et al., 2009; Impellizzeri et al., 2006; Jastrzebski et al., 2014).

A limitation of HR could be the possible overestimation and underestimation of IL due to environmental conditions, hormonal factors and evaluation of HR_{max} and resting HR (HR_{rest}). Environmental and hormonal factors alter HR response to a given TL, potentially complicating HR measurements when the factors are not controlled. For example, exercise HR_{max} at a moderate temperature (22±1 ◦C) was statistically higher during submaximal and maximal aerobic tests than a high (35±1 ◦C) and low (10±1 °C) temperature ($p<0.01$) (No & Kwak, 2016). Inaccurate evaluation of HR_{max} and HR_{rest} also leads to overestimation and underestimation of IL. Due to between-subject HR_{max} and HR_{rest} differences, it is not possible to calculate target HR values and zone distributions without accurately assessing individual HR_{max} and HR_{rest}. (Achten & Jeukendrup, 2003). If the estimation of HR_{max} and HR_{rest} is poor, the calculated IL could be inaccurate. Prescribing HR targets based on percentages of heart rate reserve (%HR_{res}) may help mitigate the problems caused by between-subject HR differences and allow practitioners to better individualize target HR during training (Buchheit et al., 2013; Buchheit, 2014).

External Load Assessment

Global Navigation Satellite Systems.

Global navigation satellite systems have been used in competitive field sports since 2006 and can quantify EL with acceptable reliability and validity (Castellano et al., 2011; Nikolaidis et al., 2018; Rampinini et al., 2015; Scott et al., 2016). A GNSS unit typically is integrated with other microelectromechanical sensors such as tri-axial accelerometers and gyroscopes and can quantify accelerometry-derived EL metrics such as acceleration frequency and PlayerLoad (Hennessy & Jeffreys, 2018). These accelerometry metrics quantify player EL from acceleration and are calculated using the sum of the differences in acceleration from the three axes (anterior-posterior, medial-lateral, and vertical axes). In competitive soccer, common EL metrics include total distance (m), average speed (m per minute), HSR (m), and accelerometry metrics. According to the literature (Datson et al., 2017; Krustrup et al., 2005; Trewin et al., 2018), competitive female soccer players typically cover 9,000m to 11,000m of total distance and 500m to 1,000m of high speed running (HSR) distances during match play. These distances are also influenced by playing position, playing environment, and physical readiness. GNSS data of match-play helps clarify the time-motion characteristics of competitive female soccer players and strategize TL management for physical preparation (Clemente et al., 2019; Coutinho et al., 2015; McFadden et al., 2020; Sausaman et al., 2019; Trewin et al., 2018; Vescovi et al., 2006).

Incorporating GNSS data also allows practitioners to manipulate and periodize TL for optimal physical preparation. Several studies (Clemente et al., 2019; Coutinho et al., 2015; Kelly et al., 2020; Martín-García et al., 2018; Ravé et al., 2020) have quantified daily and weekly EL during a competitive season and recommended optimal training plans using GNSS based EL. For example, Clemente et al. (2019) reported that total distance and HSR were the highest at 72 hours prior to match-play and progressively decreased to the next match in professional soccer players. Although GNSS can provide practitioners with meaningful EL feedback, current literature has indicated use of GNSS may be limited by the practitioner's ability to analyze and implement the data for optimal physical preparation (Halson, 2014; Hennessy & Jeffreys, 2018). Sports coaches may not sufficiently understand the rationale or have experience using GNSS devices to, 1) know why GNSS data are used (i.e., TL manipulation and periodization), 2) be familiar with data reporting (i.e., analysis in types of exercise), 3) have knowledge of the GNSS metrics that should be monitored (i.e., total distance, average speed, and HSR), 4) understand how the data should be visually presented to players (Halson, 2014; Hennessy & Jeffreys, 2018), and 5) manipulate TL based on GNSS data. Despite the potential benefits associated with using GNSS systems, the benefits may be limited by the knowledge and experience of the user or coach deploying the system.

GNSS derived measures of EL have also been found to be related to other objective markers such as neuromuscular performance and biochemical markers in acute and chronic scenarios (Coppalle et al., 2019; de Hoyo et al., 2016; Malone et al., 2018; Thorpe & Sunderland, 2012; Wiig et al., 2019; Zurutuza et al., 2017). Specifically, current evidence (Coppalle et al., 2019; de Hoyo et al., 2016; Malone et al., 2018; Thorpe & Sunderland, 2012; Wiig et al., 2019; Zurutuza et al., 2017) has indicated that HSR and accelerometry derived metrics such as numbers of sprints, accelerations, and decelerations, affect the magnitude of neuromuscular performance decrements, muscle damage, and inflammation markers in soccer.

Thorpe and Sunderland (2012) reported that very large to nearly perfect correlations were observed between changes in CK and sprint distance (p=0.007, r=0.89), high-intensity distance covered (p=0.004, r=0.92), and numbers of sprints (p=0.014, r=0.86) immediately after soccer match-play. Russell et al. (2016) also found that HSR and the number of sprints were moderately correlated to CK (HSR: p=0.03, r= 0.39; the number of sprints: p=0.02, r =0.41) and Countermovement jump (CMJ) peak power (HSR: p=0.05, r =-0.39; the number of sprints: p=0.038; r =-0.37) at 24 hours post-match. Furthermore, Malone et al. (2018) demonstrated that a Z-score of -1 in CMJ corresponded to −3.5±1.1%, −5.3±2.9%, −3.8±2.9%, and −1.1±2.9% reduction in HSR, accelerations, decelerations in competitive soccer players. The relationship was similar between HSR and biochemical markers in a chronic period. Coppalle et al. (Coppalle et al., 2019) found that very large significant correlations were found between sprinting distance (>20 km per hour) and changes in C-reactive protein after 6 weeks of pre-season training (p=0.027, r=-0.86).

Therefore, based on the findings from the literature (Coppalle et al., 2019; de Hoyo et al., 2016; Malone et al., 2018; Thorpe & Sunderland, 2012; Wiig et al., 2019; Zurutuza et al., 2017), monitoring HSR and number of sprints, accelerations, and decelerations may provide practitioners a good estimation in neuromuscular performance and muscle damage in relation to the TL of training and match-play. However, practitioners must be aware that GNSS measures may not be indicative of physiological responses or adaptations to a given EL. Therefore, GNSS measures should be used in conjunction with other response monitoring tools to maximize the efficacy of athlete monitoring programs.

Response Monitoring Measures

Although load monitoring is an integral part of athlete monitoring programs, the use of load monitoring only may be insufficient to optimize player readiness and elicit appropriate adaptations. To quantify the response to a given TL, response monitoring assessment should be performed in soccer. There are numerous response monitoring measures such as subjective recovery and stress questionnaire (Saw et al., 2016, 2017; Taylor et al., 2012; Thorpe, Atkinson, et al., 2017), heart rate (Buchheit, 2014; Lamberts et al., 2009; Schneider et al., 2018), neuromuscular performance tests (Andersson et al., 2008; Claudino et al., 2017; de Hoyo et al., 2016; Nedelec et al., 2014; Romagnoli et al., 2016; Sams et al., 2018; Shearer et al., 2017; Varley et al., 2017), biochemical/hormonal/immunological measures (Andersson et al., 2008; Fatouros et al., 2010; Gravina et al., 2011; McFadden et al., 2020; Nedelec et al., 2014; Romagnoli et al., 2016; Walker et al., 2019; Wiig et al., 2019), muscle characteristic measures, sleep quality, body composition, and other health-related measures. Compared to health-related response monitoring, physical preparation-related response monitoring assessment allows for the quantification of how an athlete copes with a given TL and helps coaches make better training related decisions (Bourdon et al., 2017; Gabbett et al., 2017; Halson, 2014). This review discusses physical preparation-related response assessment for optimizing sports performance in competitive sports. The assessment includes a subjective recovery and stress questionnaire, heart rate, physical performance tests, and biochemical/hormonal/immunological measures.

Subjective recovery and stress questionnaires.

A subjective recovery and stress questionnaire is the most common tool to monitor subjective fatigue and recovery state in relation to TL of training sessions and matches (Saw et al., 2016; Saw et al., 2017; Taylor et al., 2012; Thorpe, Atkinson, et al., 2017). The questionnaire typically consists of subscales relating to physical and psychological-related states such as muscle soreness, sleep quality, and emotional mood. The most common subjective recovery and stress questionnaires include the Short Recovery and Stress Scale (SRSS), the Acute Recovery Stress Scale (ARSS), the Profile of Mood States (POMS), the Recovery-Stress Questionnaire for athletes (RESTQ-Sport), and the Daily Analysis of Life Demands for Athletes (DALDA); custom questionnaires are also commonly used. Reported reasons for using questionnaires such as SRSS, ARSS, POMS, RESTQ-Sport, and DALDA include ease of use, their association with biological markers, and high sensitivity to TL changes (Saw et al., 2016; Taylor et al., 2012). A meta-analysis by Saw, Main, and Gastin (Saw et al., 2016) revealed a positive association between four RESTQ-Sport stress subscales and CK, and negative relationship between POMS total mood disturbance and maximum oxygen consumption. The authors also (Saw et al., 2016) found moderate to strong evidence that an acute TL increase resulted in 13 impaired stress and recovery scales from POMS and DALDA, although only three objective measures (CK, grip strength, and vertical jump) were responsive to acute changes in TL. Additionally, results of a custom subjective recovery and stress state questionnaire has found associations between sRPE, total distance, and HSR among soccer players (Buchheit et al., 2013; Malone, Owen, et al., 2018; Thorpe et al., 2015; Thorpe, Strudwick, et al., 2017). For example, small correlations were observed between changes in sRPE and the ratings of fatigue, muscle soreness, and sleep ($p<0.001$ for all) (Buchheit et al., 2013). Therefore, subjective recovery and stress questionnaires may be useful when assessing athlete responses to training and competition.

According to Taylor et al. (2012), 80% of sports teams adopt customized recovery and stress questionnaires rather than the POMS (2%), RESTQ-Sport (13%), and DALDA (2%). The adoption of custom questionnaires is reportedly due to quicker completion times and the ability to administer the questionnaire more frequently compared to questionnaires such as POMS, RESTQ-Sport, and DALDA (Taylor et al., 2012). Customized questionnaires typically consist of 3 to 6 questions to be completed, while approximately 10 to 15 minutes are required to complete POMS (65 questions), RESTQ-Sport (76 questions), and DALDA (34 questions). Therefore, sports coaches could adopt the customized questionnaires (Carling et al., 2018; Halson, 2014; Saw et al., 2016; Thorpe et al., 2017). However, validation is a primary concern with customized recovery and stress questionnaires. Although the customized questionnaires were used in a research setting (Buchheit et al., 2013; Malone et al., 2018; Thorpe et al., 2015; Thorpe et al., 2017), these studies did not demonstrate the validity and reliability of the questionnaires. Therefore, customized subjective recovery and stress questionnaires often lack scientific support demonstrating association with biological markers and TL.

In competitive sports, SRSS could be an alternative questionnaire to customized questionnaires. The SRSS is designed to measure a player's psychophysical recovery and stress state, while reducing completion time (≤1 min) (Nässi et al., 2017). The questionnaire consists of 8 multidimensional items including Physical Performance Capability (PPC), Mental Performance Capability (MPC), Emotional Balance (EB), Overall Recovery (OR), Muscle Stress (MS), Lack of Activation (LA), Negative Emotional State (NES), and Overall Stress (OS) and is rated using a 7-point Likert scale from 0 (does not fully apply) to 6 (fully applies). SRSS has demonstrated concurrent validity with RESTQ-Sport (r=0.38 to 0.60) and high internal consistency when assessing Recovery (α=0.74) and Stress Scale (α=0.78) (Nässi et al., 2017).

SRSS has been used to assess acute dose of training in a variety of sports including soccer (Pelka et al., 2018), rugby sevens (Marrier et al., 2019), tennis (Wiewelhove et al., 2016), rowing (Kölling et al., 2016). For example, Wiewelhove et al. (2016) demonstrated that SRSS-Recovery Scale and countermovement jump (CMJ) height decreased significantly, while SRSS-Stress Scale and creatine kinase (CK) concentrations increased significantly following 7 sessions of high-intensity interval training ($p<0.05$). Hitzschke et al. (2017) also found that all SRSS subscales returned to the pre-match values within 72 hours after 11 high-intensity interval training sessions in well-trained intermittent players. Furthermore, Pelka et al. (2018) reported that significant large changes were observed for PPC ($p<0.001$, r=−0.85), MPC ($p<0.001$, r=−0.84), OR ($p<0.001$, r=−0.78), MS ($p<0.001$, r=−0.74), and OS ($p<0.001$, r=−0.66) between competitive youth soccer starters (playing time > 60min) and non-starters (playing time < 60min). Therefore, SRSS may be used as a simple and sensitive daily monitoring measure in soccer.

Heart rate measures.

A variety of resting and post-exercise measures of HR have been used as response assessments in soccer. Specifically, it is common to measure HR_{rest} and HR variability (HRV) to assess 1) player fatigue and/or fitness associated with acute changes in training (Botek et al., 2014; Halson et al., 2002; Plews et al., 2012; Plews et al., 2013), 2) the current status of the autonomic nervous system (ANS) (Buchheit, 2014; Lamberts et al., 2009; Schneider et al., 2018), and 3) the likelihood of disease (Treiber et al., 2003). Halson et al. (2002) reported that HR_{rest} during 2 weeks of recovery was statistically lower (by 2-5 bmp) than during 2 weeks of intensified training ($p<0.004$). Plews et al. (2013) also found that a very large correlation was observed between changes in 10-km running performance and HR_{rest} (r=0.73) and resting HRV (r = 0.76). Furthermore, Plews et al. (2012) reported that the rate of change in HR_{rest} and HRV showed a similar trend as athletes prepared for a triathlon (r=0.81 and 0.88, respectively). Therefore, HR_{rest} and HRV may be useful indicators of training related fatigue, fitness and ANS status.

HR recovery (HRR) is also a valuable response assessment and is defined as the difference between HR at the end of exercise and HR at 30-120s post-exercise. (Halson, 2014; Thorpe, Atkinson, et al., 2017). During exercise, HR increases due to elevated sympathetic nervous activity and decreased parasympathetic nervous activity. Upon cessation of exercise, sympathetic withdrawal and increased parasympathetic activity cause HR to decrease. Thus, HRR is considered an assessment of ANS status in response to exercise. According to a systematic review by Daanen et al. (2012), HRR is more rapid in trained individuals than untrained individuals, and may allow for the monitoring of fatigue caused by training. For example, Borresen and Lamber (Borresen & Lambert, 2007) found that the group of physically active participants with higher training impulse had a significantly slower HRR than the lower training impulse group (p=0.03). However, HRR is affected by external and environmental conditions such as running surface, testing time, and temperature (Buchheit, 2014; Schneider et al., 2018). Therefore, further investigation is needed to support the use of HRR to monitor player fatigue and fitness.

Although HR_{rest}, HRV, and HRR are useful indicators of player fatigue and fitness associating with TL, it may not be practical to frequently monitor these variables in collegiate soccer while controlling for confounding factors such as match and travel schedule, the size of a squad (i.e., 25 to 30 players per squad), and financial and human resources (Buchheit, 2014; Schneider et al., 2018). NCAA female soccer players travel for 3 to 5 hours and play 2 matches per week with a limited interval (i.e., ~72 hours between matches). The schedule could result in large differences in measurement conditions (i.e., the time of measurement, player's sleep hours) (Buchheit, 2014; Schneider et al., 2018). Evidence supports that the reliability of HR_{rest}, and HRV ranges from good to acceptable (HR_{rest}=coefficient of variation [CV]=5-10%; HR_{rest}, CV<10%; HRV, CV=5-16%) (Haddad et al., 2011; Buchheit, 2014; Proietti et al., 2017; Schneider et al., 2018). Thus, it is quite difficult to identify meaningful changes in HR measures if the measures are performed in an uncontrolled condition. Additionally, sports coaches in NCAA female soccer simultaneously assist with strength and conditioning sessions in several sports (i.e., female soccer and volleyball). Thus, it may not be possible to collect HR_{rest} and HRV data on a regular basis. Therefore, routine measurements of HR_{rest} and HRV may not be possible in many collegiate settings.

Physical performance tests.

Physical performance tests such as jumping (Andersson et al., 2008; Claudino et al., 2017; de Hoyo et al., 2016; Fatouros et al., 2010; Magalhães et al., 2010; Nedelec et al., 2014; Romagnoli et al., 2016; Sams et al., 2018; Shearer et al., 2017; Varley et al., 2017), sprinting (Andersson et al., 2008; Cortis et al., 2013; Djaoui et al., 2016; Rollo et al., 2014), and isometric or dynamic strength tests (Andersson et al., 2008; Nedelec et al., 2014; Rollo et al., 2014) are used to assess physical and neuromuscular performance changes in relation to acute TL. In applied settings, jump and short sprint assessments (≤20m) are easily administered to quantify TL induced performance changes up to 48 to 72 hours after soccer match-play with minimal fatigue. (Andersson et al., 2008; Claudino et al., 2017; de Hoyo et al., 2016; Djaoui et al., 2016; Fatouros et al., 2010; Hader et al., 2019; Magalhães et al., 2010; Nedelec et al., 2014; Rollo et al., 2014; Romagnoli et al., 2016; Sams et al., 2018; Shearer et al., 2017; Silva et al., 2018;

Varley et al., 2017). For example, Andersson et al. (2008) reported that 20m sprint and CMJ jump height (JH) statistically decreased from baseline to immediately after international female soccer match-play (both, $p<0.05$). Djaoui et al. (2016) also found that 20m sprint time statistically increased from baseline to 24 hours post-match ($p<0.05$) and returned to baseline at 48 hours post-match. Therefore, physical performance could be useful to quantify the alternation associating with match-play TL in soccer players.

Jump tests seem to be more suitable than short sprinting tests for assessing acute neuromuscular performance from immediately up to 72 hours after soccer match-play (Andersson et al., 2008; Gathercole et al., 2015; Hader et al., 2019; Silva et al., 2018). A meta-analysis by Silva et al. (2018) reported that moderate CMJ performance impairment was found at 24, 48, and 72 hours after match-play (ES=-0.5, -0.4, and -0.5, respectively), whereas moderate sprint performance decreases were evident at 24 and 48 hours (ES=0.5 and 0.5). Additionally, Andersson et al. (2008) found a significant decrease in CMJ JH at 48 hours post-match ($p<0.05$) in competitive female soccer players, while the 20m sprint time did not significantly change ($p>0.05$). Furthermore, Gathercole et al. (2015) revealed that CMJ and drop jump (DJ) performance remained impaired up to 72 hours after a 3-stage Yo-Yo fatiguing protocol, although 20m sprint performance recovered by 24 hours after the protocol. Therefore, although sprinting may be more vital soccer-specific movement than jump, jump tests could be more sensitive to neuromuscular performance changes up to 72 hours after soccer match-play.

In competitive soccer, numerous jump test protocols are performed on force plates and a contact mat such as CMJ, squat jump, DJ, and reactive strength index test on force plates (Andersson et al., 2008; Claudino et al., 2017; de Hoyo et al., 2016; Nedelec et al., 2014; Romagnoli et al., 2016; Sams et al., 2018; Shearer et al., 2017; Varley et al., 2017). Numerous investigations

(Andersson et al., 2008; Claudino et al., 2017; de Hoyo et al., 2016; Fatouros et al., 2010; Gathercole et al., 2015; Hader et al., 2019; Nedelec et al., 2014; Rollo et al., 2014; Romagnoli et al., 2016; Silva et al., 2018; Varley et al., 2017) indicate that CMJ testing can be used to monitor acute neuromuscular function up to 72 hours post-exercise due to the mechanical specificity and the feasibility of data collection (Claudino et al., 2017; Halson, 2014; Nicol et al., 2006; Stølen et al., 2005). CMJ is a vertical jump performed after flexing lower limb joints and consists of eccentric and concentric phases (Nicol et al., 2006).

The CMJ test also shows higher sensitivity to neuromuscular performance changes than other jump protocols (Brownstein et al., 2017; Gathercole et al., 2015; Oliver et al., 2008; Silva et al., 2018). This study also showed that CMJ and DJ test performance remained diminished until 72 hours after a fatiguing protocol while the SJ performance was restored by 24 hours after the protocol (Gathercole et al., 2015). Oliver et al. (2008) also reported that CMJ had a greater reduction in JH (-3.0±2.9cm) than SJ (-1.7±1.6cm) after a soccer-specific intermittent exercise test, although the difference was not statistically significant between the conditions ($p>0.05$). Furthermore, there is strong evidence indicating that CMJ performance decrements are possibly associated with structural and neural changes such as muscle damage after soccer match-play (Andersson et al., 2008; de Hoyo et al., 2016; Nedelec et al., 2014). For example, CMJ height statistically decreased from the pre-match value to 24 hours after soccer-match play ($p<0.001$, ES=1.22) while a very large increase was found in CK concentration ($p<0.001$, ES=3.17) in competitive youth soccer players (Nedelec et al., 2014). Therefore, CMJ is a sensitive jumping protocol to understand acute neuromuscular changes in response to soccer-match play.

CMJ performance is assessed by kinematic and kinetic variables such as peak power (PP), mean power, peak force, impulse, velocity, rate of force development (RFD), and duration in each phase (Claudino et al., 2017). Current evidence indicates that JH and PP are sensitive to neuromuscular performance changes and demonstrate low measurement error (Andersson et al., 2008; Carroll et al., 2019; Claudino et al., 2017; de Hoyo et al., 2016; Hader et al., 2019; Hagstrom & Shorter, 2018; Magalhães et al., 2010; Souza et al., 2020). A meta-analysis by Claudino et al. (2017) illustrated that average CMJ JH of the two trials was more sensitive to neuromuscular performance changes (average ES =−0.56, $p<0.001$) than the highest CMJ JH. Another meta-analysis by Hagstrom and Shorter (2018) supported that a significant standardized mean difference was observed for CMJ PP between pre-match and 24 hours after match-play ($p=0.002$). Thus, using CMJ JH and PP is a suitable method for the assessment of neuromuscular performance changes. However, it could be useful to monitor different CMJ variables for neuromuscular performance alterations. Several studies (Cormie et al., 2010; Kawakami et al., 2002) reported that greater force production during the eccentric phase leads to higher force production during the concentric phase. For example, significant very large correlation was observed between peak eccentric PP and concentric PP ($p<0.001$, r=-0.71), concentric peak force ($p<0.001$, r=0.89), and maximum concentric RFD ($p<0.001$, r=0.91). Current evidence supports that overall CMJ performance such as JH and PP could be altered by the changes in both concentric and eccentric phases in response to TL (Cormie et al., 2010; Kennedy & Drake, 2017). Kennedy and Drake (2017) reported that average power, average impulse, and peak velocity statistically decreased at 24 hours after multiple training sessions in rugby players. Therefore, it may be beneficial to monitor eccentric and concentric CMJ variables in relation to soccer match-play.

Biochemical markers.

Biochemical markers such as CK, C-reactive protein (CRP), interleukin 6 (IL-6), uric acid, plasma or saliva cortisol, and testosterone are commonly measured to quantify acute and chronic responses to soccer match-play (Andersson et al., 2008; Fatouros et al., 2010; Gravina et al., 2011; McFadden et al., 2020; Nedelec et al., 2014; Romagnoli et al., 2016; Walker et al., 2019; Wiig et al., 2019). Although these assessments are beyond the scope of this review and require greater resources to analyze these measures than many NCAA soccer programs can afford (Carling et al., 2018; Heisterberg et al., 2014), a brief mention of these measures is warranted as these assessments do provide strong evidence of the physiological disruption and recovery process related to soccer match-play.

A multifactorial process consists of a complex cascade and inter-play between muscle damage, inflammatory and immune responses. TL could be reflective of biological and salivary markers such CK and testosterone up to 72 hours after soccer match-play (de Hoyo et al., 2016; Hader et al., 2019; Malone et al., 2018; Silva et al., 2018; Thorpe & Sunderland, 2012; Walker et al., 2019; Wiig et al., 2019). A meta-analysis by Silva et al. (2018) reported that CK level reached a peak value at 24 hours after match-play (ES=1.60) and remained elevated above baseline up to 72 hours after match-play (ES=0.40). The authors also showed that moderate to very large increases were observed in plasma testosterone:cortisol ratio from pre-match to 24 hours (ES=-1.2), 48 hours (ES=-1.30), and 72 hours after soccer match-play (ES=-0.50), while small to moderate decreases were seen for CRP from pre-match to 24 hours (CRP: ES=0.9) and 48 hours post-match (ES=0.30). Additionally, biochemical marker alternations are associated with EL from soccer match-play (Coppalle et al., 2019; de Hoyo et al., 2016; Gathercole et al., 2015; Hader et al., 2019; Malone et al., 2018; Silva et al., 2018; Thorpe & Sunderland, 2012;

Walker et al., 2019; Wiig et al., 2019; Zurutuza et al., 2017). A meta-analysis by Hader et al. (2019) demonstrated that there was a large pooled correlation between sprint distance (>19.8km per hour) and CK (r=0.54) at 24 hours post-match. Another systematic review by Siliva (2018) also showed that CK, CRP, IL-6 and tumour necrosis factor remains higher up to 48 to 72h post-soccer match than baseline. Therefore, it is likely that biochemical maker changes persist for up to 72 hours after a match- play and are associated with changes in EL.

PHYSICAL PERFORMANCE DEMANDS OF MATCH-PLAY IN FEMALE SOCCER

A comprehensive understanding of physical performance demands in female soccer match-play is important for 1) the quantification of physical performance according to competition level (i.e., collegiate, professional, and international), 2) a systematic approach to developing training plans for physical preparation and performance enhancement, and 3) proper training progressions during a pre-season (Ravé et al., 2020). Although limited research has addressed the physical demands of NCAA DI female soccer, current investigations (McFadden et al., 2020; Sausaman et al., 2019; Vescovi et al., 2006) have shown that NCAA Division I female soccer players accumulated a total distance of 8,310-10,297m and 197-609m of HSR per match (Table 2.1). These demands seem to be lower than at professional and international levels. At higher levels, female soccer players often accumulate more than 10,000m of total distance and 930-2,520m of HSR per match (Datson et al., 2017; Jagim et al., 2020; Mara et al., 2017; Mohr et al., 2008; Ramos et al., 2019; Sausaman et al., 2019; Trewin et al., 2018; Vescovi et al., 2006). For example, Trewin et al. (2018) reported that female soccer players in the 10 highest ranked countries complete 10,368±952m of total distance and 930±348m of HSR. Datson et al. (2017) also found that total distance and HSR were 10,321±859m and 2,520±580m, respectively, among 10 European international female match-plays. Substantial differences in competitive level and subsequent demands can also be seen within NCAA Division I female soccer. For instance, Vescovi and Favero (2006) reported that among 9 highly ranked NCAA Division female programs (6 top 30 teams and 3 top 10 teams), total distance completed ranged from 9,496-10,297m across playing positions, while lower tier teams completed 9,039-9,882m of total distance. Therefore, it seems that the physical demands of female soccer are related to the level of competition and on average, the demands of NCAA Division I female soccer may be marginally lower than professional and international level soccer.

It should also be noted that the physical demands of soccer seem to be influenced by playing position (Table 2.2) and there is a considerable body of literature detailing these difference in female soccer (Datson et al., 2017; Jagim et al., 2020; Mara et al., 2017; Mohr et al., 2008; Ramos et al., 2019; Sausaman et al., 2019; Trewin et al., 2018; Vescovi et al., 2006). For example, Vescovi and Favero (2006) demonstrated that midfielders completed higher total distances than defenders in the first half of match-play among top NCAA Division I female players ($p=0.018$, $ES=0.84$). Likewise, Mara et al. (2017) showed that midfielders accumulated higher total distances and HSR than centerbacks in competitive Australian female soccer. Therefore, players may need different recovery plans after soccer match-play based on their position.

Table 2.1 Physical Demands of Female Soccer Match-Play

Authors	Year	Sample size (n)	Region	Level	Total distance (m)	HSR (km·h^{-1})	HSR (m)
Anderson et al.	2010	17	Scandavian	International	9,900±1,800	18.0	1,530±100
Anderson et al.	2010	17	Scandavian	Domestic Senior	9,700±1,400	18.0	1,330±900
Datson et al.	2017	107	Europe	International	10,321±859	19.8	2,520±580
Jagim et al.	2020	25	USA	NCAA DIII	9,793±2,715	15.0	1,019±560
McFadden et al.	2020	9	USA	NCAA DI	8,310±900	19.0	401±158
Mara et al.	2017	12	Australia	Domestic	10,025±775	19.4	615±258
Mohr et al.	2008	19	USA	Professional	10,330±1500	18.0	1,680±90
Mohr et al.	2008	15	Scandavian	Domestic	10,440±1500	18.0	1,300±100
Sausaman et al.	2019	23	USA	NCAA DI	9,486±300	15.0	1,014±118
Trewin et al.	2017	45	Australia	National team	10,368±952	16.5	930±348

Note. Data are expressed as means (±SD). HSR=High speed running distance. kph=kilometer per hour. NCAA=National Collegiate Athlete Association. DIII=Division III. DI=Division I.

Table 2.2 Positional Physical Demands of Female Soccer Match-Play

Authors	Year	Sample size (n)	Region	Level	Position	Total distance (m)	HSR (km·h^{-1})	HSR (m)
DF								
Sausaman et al.	2019		USA	NCAA DI	DF	9,039	15.0	868
Vescovi and Favero	2014	35	USA	NCAA DI	DF	9,496	15.6	748
Datson et al.	2017	25	Europe	International	CB	9,489±562	19.8	19,01±268
Jagim et al.	2020	56	USA	NCAA DIII	CB	9,956±2511	15.0	1,004±417
Mara et al.	2017	12	Australia	Domestic Senior	CB	9,489±562	19.4	417±116
Mohr et al.	2003	11	Europe	Domestic Senior	CB	9,740±220	18.0	1,690±200
Ramos et al.	2019	13	Brazil	International	CB	10,003±954	15.6	590±104
Ramos et al.	2019	7	Brazil	U20 International	CB	8,202±514	15.6	509±76
Trewin et al.	2017	7	Australia	National Team	CB	9,533±650	16.5	661±594
Mohr et al.	2003	9	Europe	Domestic Senior	FB	10,980±230	18.0	2,460±130
Ramos et al.	2019	8	Brazil	International	FB	10,238±665	15.6	840±137
Ramos et al.	2019	10	Brazil	U20 International	FB	9,073±475	15.6	859±99
Trewin et al.	2017	11	Australia	National Team	FB	10,496±822	16.5	1,191±314
MF								
Mohr et al.	2003	13	Europe	Domestic Senior	MF	11,000±210	18.0	2,230±150
Ramos et al.	2019	9	Brazil	National Team	MF	10,377±981	15.6	811±207
Ramos et al.	2019	26	Brazil	U20 National Team	MF	8,486±703	15.6	552±113
Sausaman et al.	2019		USA	NCAA DI	MF	9,536	15.0	840
Trewin et al.	2017	9	Australia	National Team	MF	10,962±750	16.5	973±334
Vescovi and Favero	2014	45	USA	NCAA DI	MF	10,125	15.6	762
Datson et al.	2017	31	Europe	International	CM	10,985±706	19.8	2,882±500
Jagim et al.	2020		USA	NCAA DIII	CM	10,575±511	15.0	1,145±388
Mara et al.	2017		Australia	Domestic Senior	CM	10,581±221	19.4	484±169
Jagim et al.	2020		USA	NCAA DIII	WM	10,056±2763	15.0	1,264±613
Maya et al.	2017		Australia	Domestic Senior	WM	10,472±878	19.4	850±178
FW								
Datson et al.	2017	16	Europe	International	FW	10,262±798	19.8	1,901±268
Jagim et al.	2020		USA	NCAA DIII	FW	7,831±2180	15.0	798±308
Mara et al.	2017	12	Australia	Domestic Senior	FW	9,661±602	19.4	841±238
Mohr et al.	2003	9	Europe	Domestic Senior	FW	10,480±300	18.0	2,280±140
Ramos et al.	2019	11	Brazil	U20 National Team	FW	9,056±460	15.6	830±191
Ramos et al.	2019	17	Brazil	National Team	FW	9,825±894	15.6	783±251
Sausaman et al.	2019		USA	NCAA DI	FW	9,882	15.0	1,333
Trewin et al.	2017	18	Australia	National Team	FW	10,380±893	16.5	1,037±305
Vescovi and Favero	2014	33	USA	NCAA D1	FW	10,297	15.6	929

Note. Data are expressed as mean(±SD). HSR: High speed running distance. NCAA: National Collegiate Athlete Association. DI=Division I. DIII=Division III. DF=Defender. CB=Centerback. MF: Midfielder. CM: Central midfielder. WM: Wide midfielder or attacker. FW=Forward

Data Analysis in Female Soccer

Inferences made in sports science research are performed using grouped (or aggregated) data. The grouped estimates are often applied to understand overall responses to an intervention (i.e., strength training and fatigue protocols) and generalize findings to the population of interest. However, group analysis is limited by 1) the assessment of team performance, 2) biological heterogeneity, and 3) playing position and status (Bailey, 2019; Kinugasa et al., 2004; Sands et al., 2019). First, overall team match performance in soccer may be determined by the performance of the team's best players. This suggests that group analyses likely do not reflect individual performance, changes, and relationships. For example, FC Barcelona's performance depends substantially on the performance of Lionel Messi and not the performance of substitute players. Monitoring meaningful changes of the best players may better help to maintain or improve team performance across a competitive season. Therefore, sports coaches should be aware of the importance and necessity of individual analysis in athlete monitoring for performance optimization.

Second, heterogeneous biological responses exist between individuals in relation to acute TL (Bagger et al., 2003; Bartlett et al., 2017; Bouchard & Rankinen, 2001; Katch et al., 1982). Individuals respond differently to the same EL, and the TL for optimal adaptation may be different between individuals. The heterogeneous responses to an EL mask meaningful changes and relationships at an individual level when group analysis is performed. There is also strong evidence that individual analysis should be performed to account for biological heterogeneity (Bagger et al., 2003; Bartlett et al., 2017; Bouchard & Rankinen, 2001; Katch et al., 1982). For example, oxygen consumption, HR, and systolic blood pressure respond differently to standardized and controlled exercise-training between subjects (Bouchard & Rankinen, 2001).

Katch and colleagues (1982) also reported that between-subject biological differences accounted for 92.7% of the variance seen in maximum oxygen consumption during 8 to 20 repeated treadmill running tests. Thus, performing individual analysis can minimize the magnitude of individual heterogeneity to identify meaningful changes and relationships.

Third, individual athlete monitoring may be particularly important in soccer due to differences in TL by playing position and status (Anderson et al., 2016; Foster, 1998; Haddad et al., 2017; Martín-García et al., 2018; McFadden et al., 2020; Sams et al., 2020). Positional differences result in large TL differences during training and match-play (Datson et al., 2017; Jagim et al., 2020; Mara et al., 2017; Mohr et al., 2008; Ramos et al., 2019; Sausaman et al., 2019; Trewin et al., 2018; Vescovi et al., 2006). For example, centerbacks accumulated lower total distances and HSR than midfielders in competitive Australian female soccer (Mara et al., 2017) and these differences may affect neuromuscular and biochemical changes after match-play (Hader et al., 2019). Playing status could also influence TL in college soccer players (McFadden et al., 2020; Sams et al., 2020). McFadden et al. (2020) reported that substitute players covered less total distance than starters by 2,000m in NCAA Division I female soccer. Despite anthropometric and physiological similarities, this evidence (McFadden et al., 2020; Sams et al., 2020) indicates that individual players accumulate different TL due to playing position and status during a competitive season.

Based on the literature (Bouchard & Rankinen, 2001; Datson et al., 2017; Jagim et al., 2020; Katch et al., 1982; Mara et al., 2017; McFadden et al., 2020; Sams et al., 2020; Trewin et al., 2018; Vescovi et al., 2006), the necessity of individual level analysis in conjunction with group level analysis is apparent for maximizing sports performance in soccer. Individual load and response monitoring can be useful to ensure the relationship between TL and the response and inform coaches of TL manipulation for optimal physical preparation. However, limited studies (Bartlett et al., 2017; Wiig et al., 2020) are available regarding the quantification of individual relationships between load and response assessments. Therefore, further investigation is required to demonstrate the efficacy of individual level analysis.

Practical Monitoring in Collegiate Female Soccer

In NCAA female soccer, multifaceted athlete monitoring such as load and response monitoring assessment should be incorporated for physical preparation and optimal adaptation during pre- and competitive seasons. Several load monitoring assessments such IL (i.e., sRPE and HR) and EL (i.e., GNSS) are recommended to quantify TL. The combined use of IL and EL can assist practitioners to better understand the physiological and external loads of players. Additionally, SRSS, HR and CMJ testing are applicable response monitoring assessments in NCAA female soccer. Although NCAA Division I female soccer is not as physically demanding as international and professional soccer, female collegiate athletes could experience physically and psychologically cumulative fatigue due to the aforementioned NCAA schedule. Frequent load assessment with SRSS (i.e., every day) and CMJ (i.e., once per week) can provide meaningful insights into player's psychological and neuromuscular status (Bailey, 2019; Kinugasa et al., 2004; Sands et al., 2019). In addition to these assessments, it is beneficial to measure HR_{rest} and HRV for the assessment of overall player's fatigue or fitness if it is financially possible. As a result of periodic response assessments, the information can assist practitioners to determine optimal training plans to maximize sports performance on a match-day.

In the NCAA female soccer, starters typically play 2 matches in conference play and must take a minimum 1 day off per week due to NCAA regulations. The match schedule does not provide starters sufficient time to recover from match TLs and to maximize next match performance. Although it would be ideal to have a physically high TL session at 3-day pre-match for maintaining match physical performance (Clemente et al., 2019; Coutinho et al., 2015; Kelly et al., 2020; Ravé et al., 2020), training sessions may emphasize physical and psychological recovery and tactics during conference play due to the short intervals between match-plays. If meaningful changes are observed in response monitoring assessments at 1 and 2-day post-match (i.e., CMJ JH or PP reduction), an additional recovery session may be provided to promote starter's physical preparedness. If starters are physically recovered, a moderate-volume training session should be planned to provide training stimuli for optimizing physical performance at 2-day pre-match. For non-starters, TL should be manipulated based on the load and response monitoring assessment. Non-starter TL is limited by playing status during a competitive season (Anderson et al., 2016; Foster, 1998; Haddad et al., 2017; McFadden et al., 2020; Sams et al., 2020), so sports coaches should provide supplemental training sessions to bridge the gap of TL between them and starters. The supplemental sessions could prevent non-starters from being underprepared when they need to play a starter role.

CONCLUSION

Athlete monitoring programs play a vital role in physical preparation and optimal adaptation during a competitive season in the NCAA female soccer players. The monitoring measures are classified into load and response monitoring assessments. In the NCAA female soccer, load monitoring assessments should include sRPE, HR, and GNSS, while subjective recovery and stress questionnaire, HR, and CMJ testing are recommended to be included as response monitoring assessments. The physical performance demands may be slightly lower in NCAA female soccer players than those at professional and affected by playing position and playing status. Due to biological heterogeneity, playing position, and playing status, individual analysis should be incorporated to optimize physical performance. Sports coaches can assess a player's current physical and psychological state by analyzing individual load and response monitoring data. In turn, this analysis can assist coaches' training prescription during a competitive season.

REFERENCES

Abe, D., Yoshida, T., Ueoka, H., Sugiyama, K., & Fukuoka, Y. (2015). Relationship between perceived exertion and blood lactate concentrations during incremental running test in young females. BMC Sports Science, Medicine and Rehabilitation, 7. https://doi.org/10.1186/2052-1847-7-5

Achten, J., & Jeukendrup, A. E. (2003). Heart rate monitoring: Applications and limitations. Sports Medicine (Auckland, N.Z.), 33(7), 517–538. https://doi.org/10.2165/00007256-200333070-00004

Agel, J., & Schisel, J. (2013). Practice injury rates in collegiate sports. Clinical Journal of Sport Medicine: Official Journal of the Canadian Academy of Sport Medicine, 23(1), 33–38. https://doi.org/10.1097/JSM.0b013e3182717983

Al Haddad, H., Laursen, P. B., Chollet, D., Ahmaidi, S., & Buchheit, M. (2011). Reliability of resting and postexercise heart rate measures. International Journal of Sports Medicine, 32(8), 598–605. https://doi.org/10.1055/s-0031-1275356

Alexandre, D., da Silva, C. D., Hill-Haas, S., Wong, D. P., Natali, A. J., De Lima, J. R. P., Bara Filho, M. G. B., Marins, J. J. C. B., Garcia, E. S., & Karim, C. (2012). Heart rate monitoring in soccer: Interest and limits during competitive match play and training, practical application. Journal of Strength and Conditioning Research, 26(10), 2890–2906. https://doi.org/10.1519/JSC.0b013e3182429ac7

Alexiou, H., & Coutts, A. J. (2008). A comparison of methods used for quantifying internal training load in women soccer players. International Journal of Sports Physiology and Performance, 3(3), 320–330. https://doi.org/10.1123/ijspp.3.3.320

Anderson, L., Orme, P., Di Michele, R., Close, G. L., Milsom, J., Morgans, R., Drust, B., & Morton, J. P. (2016). Quantification of seasonal-long physical load in soccer players with different starting status from the english premier league: Implications for maintaining squad physical fitness. International Journal of Sports Physiology and Performance, 11(8), 1038–1046. https://doi.org/10.1123/ijspp.2015-0672

Andersson, H. A., Raastad, T., Nilsson, J. E., Paulsen, G., Garthe, I., & Kadi, F. (2008). Neuromuscular fatigue and recovery in elite female soccer: Effects of active recovery. Medicine and Science in Sports and Exercise, 40(2), 372–380. https://doi.org/10.1249/mss.0b013e31815b8497

Bagger, M., Petersen, P. H., & Pedersen, P. K. (2003). Biological variation in variables associated with exercise training. International Journal of Sports Medicine, 24(6), 433–440. https://doi.org/10.1055/s-2003-41180

Bailey, C. (2019). Longitudinal monitoring of athletes: Statistical issues and best practices. Journal of Science in Sport and Exercise. https://doi.org/10.1007/s42978-019-00042-4

Balsalobre-Fernández, C., Tejero-González, C. M., & del Campo-Vecino, J. (2014). Relationships between Training Load, Salivary Cortisol Responses and Performance during Season Training in Middle and Long Distance Runners. PLoS ONE, 9(8). https://doi.org/10.1371/journal.pone.0106066

Bartlett, J. D., O'Connor, F., Pitchford, N., Torres-Ronda, L., & Robertson, S. J. (2017). Relationships between internal and external training load in team-sport athletes: Evidence for an individualized approach. International Journal of Sports Physiology and Performance, 12(2), 230–234. https://doi.org/10.1123/ijspp.2015-0791

Borg, G. A. (1982). Psychophysical bases of perceived exertion. Medicine and Science in Sports and Exercise, 14(5), 377–381.

Borresen, J., & Lambert, M. I. (2007). Changes in heart rate recovery in response to acute changes in training load. European Journal of Applied Physiology, 101(4), 503–511. https://doi.org/10.1007/s00421-007-0516-6

Botek, M., McKune, A. J., Krejci, J., Stejskal, P., & Gaba, A. (2014). Change in performance in response to training load adjustment based on autonomic activity. International Journal of Sports Medicine, 35(6), 482–488. https://doi.org/10.1055/s-0033-1354385

Bouchard, C., & Rankinen, T. (2001). Individual differences in response to regular physical activity. Medicine and Science in Sports and Exercise, 33(6 Suppl), S446-51. https://doi.org/10.1097/00005768-200106001-00013

Bourdon, P. C., Cardinale, M., Murray, A., Gastin, P., Kellmann, M., Varley, M. C., Gabbett, T. J., Coutts, A. J., Burgess, D. J., Gregson, W., & Cable, N. T. (2017). Monitoring Athlete

Training Loads: Consensus Statement. International Journal of Sports Physiology and Performance, 12(Suppl 2), S2161–S2170. https://doi.org/10.1123/IJSPP.2017-0208

Brownstein, C. G., Dent, J. P., Parker, P., Hicks, K. M., Howatson, G., Goodall, S., & Thomas, K. (2017). Etiology and Recovery of Neuromuscular Fatigue following Competitive Soccer Match-Play. Frontiers in Physiology, 8, 831. https://doi.org/10.3389/fphys.2017.00831

Buchheit, M., Racinais, S., Bilsborough, J. C., Bourdon, P. C., Voss, S. C., Hocking, J., Cordy, J., Mendez-Villanueva, A., & Coutts, A. J. (2013). Monitoring fitness, fatigue and running performance during a pre-season training camp in elite football players. Journal of Science and Medicine in Sport, 16(6), 550–555. https://doi.org/10.1016/j.jsams.2012.12.003

Buchheit, Martin. (2014). Monitoring training status with HR measures: Do all roads lead to Rome? Frontiers in Physiology, 5, 73. https://doi.org/10.3389/fphys.2014.00073

Campos-Vazquez, M. A., Mendez-Villanueva, A., Gonzalez-Jurado, J. A., León-Prados, J. A., Santalla, A., & Suarez-Arrones, L. (2015). Relationships between rating-of-perceived-exertion- and heart-rate-derived internal training load in professional soccer players: A comparison of on-field integrated training sessions. International Journal of Sports Physiology and Performance, 10(5), 587–592. https://doi.org/10.1123/ijspp.2014-0294

Carling, C., Lacome, M., McCall, A., Dupont, G., Le Gall, F., Simpson, B., & Buchheit, M. (2018). Monitoring of Post-match Fatigue in Professional Soccer: Welcome to the Real World. Sports Medicine (Auckland, N.Z.), 48(12), 2695–2702. https://doi.org/10.1007/s40279-018-0935-z

Carroll, K. M., Wagle, J. P., Sole, C. J., & Stone, M. H. (2019). Intrasession and Intersession Reliability of Countermovement Jump Testing in Division-I Volleyball Athletes. Journal of Strength and Conditioning Research, 33(11), 2932–2935. https://doi.org/10.1519/JSC.0000000000003353

Casamichana, D., Castellano, J., Calleja-Gonzalez, J., San Román, J., & Castagna, C. (2013). Relationship between indicators of training load in soccer players. Journal of Strength and Conditioning Research, 27(2), 369–374. https://doi.org/10.1519/JSC.0b013e3182548af1

Castellano, J., Casamichana, D., Calleja-González, J., Román, J. S., & Ostojic, S. M. (2011). Reliability and Accuracy of 10 Hz GPS Devices for Short-Distance Exercise. Journal of Sports Science & Medicine, 10(1), 233–234.

Claudino, J. G., Cronin, J., Mezêncio, B., McMaster, D. T., McGuigan, M., Tricoli, V., Amadio, A. C., & Serrão, J. C. (2017). The countermovement jump to monitor neuromuscular status: A meta-analysis. Journal of Science and Medicine in Sport, 20(4), 397–402. https://doi.org/10.1016/j.jsams.2016.08.011

Clemente, F. M., Owen, A., Serra-Olivares, J., Nikolaidis, P. T., van der Linden, C. M. I., & Mendes, B. (2019). Characterization of the weekly external load profile of professional soccer teams from portugal and the netherlands. Journal of Human Kinetics, 66, 155–164. https://doi.org/10.2478/hukin-2018-0054

Coppalle, S., Rave, G., Ben Abderrahman, A., Ali, A., Salhi, I., Zouita, S., Zouita, A., Brughelli, M., Granacher, U., & Zouhal, H. (2019). Relationship of Pre-season Training Load With

In-Season Biochemical Markers, Injuries and Performance in Professional Soccer Players. Frontiers in Physiology, 10, 409. https://doi.org/10.3389/fphys.2019.00409

Cormie, P., McGuigan, M. R., & Newton, R. U. (2010). Changes in the eccentric phase contribute to improved stretch-shorten cycle performance after training. Medicine and Science in Sports and Exercise, 42(9), 1731–1744. https://doi.org/10.1249/MSS.0b013e3181d392e8

Cortis, C., Tessitore, A., Lupo, C., Perroni, F., Pesce, C., & Capranica, L. (2013). Changes in jump, sprint, and coordinative performances after a senior soccer match. Journal of Strength and Conditioning Research, 27(11), 2989–2996. https://doi.org/10.1519/JSC.0b013e3182897a46

Costa, J. A., Brito, J., Nakamura, F. Y., Figueiredo, P., & Rebelo, A. (2020). Using the Rating of Perceived Exertion and Heart Rate to Quantify Training Intensity in Female Soccer Players: Validity and Utility. The Journal of Strength & Conditioning Research, Publish Ahead of Print. https://doi.org/10.1519/JSC.0000000000003407

Coutinho, D., Gonçalves, B., Figueira, B., Abade, E., Marcelino, R., & Sampaio, J. (2015). Typical weekly workload of under 15, under 17, and under 19 elite Portuguese football players. Journalof Sports Sciences, 33(12), 1229–1237. https://doi.org/10.1080/02640414.2015.1022575

Coutts, A. J., Rampinini, E., Marcora, S. M., Castagna, C., & Impellizzeri, F. M. (2009). Heart rate and blood lactate correlates of perceived exertion during small-sided soccer games. Journal of Science and Medicine in Sport, 12(1), 79–84. https://doi.org/10.1016/j.jsams.2007.08.005

Daanen, H. A. M., Lamberts, R. P., Kallen, V. L., Jin, A., & Van Meeteren, N. L. U. (2012). A systematic review on heart-rate recovery to monitor changes in training status in athletes. International Journal of Sports Physiology and Performance, 7(3), 251–260. https://doi.org/10.1123/ijspp.7.3.251

Datson, N., Drust, B., Weston, M., Jarman, I. H., Lisboa, P. J., & Gregson, W. (2017). Match Physical Performance of Elite Female Soccer Players During International Competition. Journal of Strength and Conditioning Research, 31(9), 2379–2387. https://doi.org/10.1519/JSC.0000000000001575

Datson, N., Hulton, A., Andersson, H., Lewis, T., Weston, M., Drust, B., & Gregson, W. (2014). Applied physiology of female soccer: An update. Sports Medicine, 44(9), 1225–1240. https://doi.org/10.1007/s40279-014-0199-1

de Hoyo, M., Cohen, D. D., Sañudo, B., Carrasco, L., Álvarez-Mesa, A., Del Ojo, J. J., Domínguez-Cobo, S., Mañas, V., & Otero-Esquina, C. (2016). Influence of football match time-motion parameters on recovery time course of muscle damage and jump ability. Journal of Sports Sciences, 34(14), 1363–1370. https://doi.org/10.1080/02640414.2016.1150603

Dellal, A., Cristiano Diniz, da S., Stephen, H.-H., Del P., W., Antonio J., N., De Lima, J. R. P., Bara Filho, M. G. B., Marins, J. J. C. B., Garcia, E. S., & Karim, C. (2012). Heart rate monitoring in soccer: Interest and limits during competitive match play and training, practical application. Journal of Strength and Conditioning Research, 26(10), 2890–2906. https://doi.org/10.1519/JSC.0b013e3182429ac7

Dellal, A., Varliette, C., Owen, A., Chirico, E. N., & Pialoux, V. (2012). Small-sided games versus interval training in amateur soccer players: Effects on the aerobic capacity and the ability to perform intermittent exercises with changes of direction. Journal of Strength and Conditioning Research, 26(10), 2712–2720. https://doi.org/10.1519/JSC.0b013e31824294c4

DeWeese, B. H., Hornsby, G., Stone, M., & Stone, M. H. (2015a). The training process: Planning for strength–power training in track and field. Part 1: Theoretical aspects. Journal of Sport and Health Science, 4(4), 308–317. https://doi.org/10.1016/j.jshs.2015.07.003

DeWeese, B. H., Hornsby, G., Stone, M., & Stone, M. H. (2015b). The training process: Planning for strength–power training in track and field. Part 2: Practical and applied aspects. Journal of Sport and Health Science, 4(4), 318–324. https://doi.org/10.1016/j.jshs.2015.07.002

Djaoui, L., Diaz-Cidoncha Garcia, J., Hautier, C., & Dellal, A. (2016). Kinetic Post-match Fatigue in Professional and Youth Soccer Players During the Competitive Period. Asian Journal of Sports Medicine, 7(1). https://doi.org/10.5812/asjsm.28267

Dupont, G., Nedelec, M., McCall, A., McCormack, D., Berthoin, S., & Wisløff, U. (2010). Effect of 2 soccer matches in a week on physical performance and injury rate. The American Journal of Sports Medicine, 38(9), 1752–1758. https://doi.org/10.1177/0363546510361236

Fatouros, I. G., Chatzinikolaou, A., Douroudos, I. I., Nikolaidis, M. G., Kyparos, A., Margonis, K., Michailidis, Y., Vantarakis, A., Taxildaris, K., Katrabasas, I., Mandalidis, D., Kouretas, D., & Jamurtas, A. Z. (2010). Time-course of changes in oxidative stress and antioxidant status responses following a soccer game. Journal of Strength and Conditioning Research, 24(12), 3278–3286. https://doi.org/10.1519/JSC.0b013e3181b60444

Foster, C. (1998). Monitoring training in athletes with reference to overtraining syndrome. Medicine and Science in Sports and Exercise, 30(7), 1164–1168. https://doi.org/10.1097/00005768-199807000-00023

Foster, C., Florhaug, J. A., Franklin, J., Gottschall, L., Hrovatin, L. A., Parker, S., Doleshal, P., & Dodge, C. (2001). A new approach to monitoring exercise training. Journal of Strength and Conditioning Research, 15(1), 109–115.

Gabbett, T. J., Nassis, G. P., Oetter, E., Pretorius, J., Johnston, N., Medina, D., Rodas, G., Myslinski, T., Howells, D., Beard, A., & Ryan, A. (2017). The athlete monitoring cycle: A practical guide to interpreting and applying training monitoring data. British Journal of Sports Medicine, 51(20), 1451–1452. https://doi.org/10.1136/bjsports-2016-097298

Gallo, T. F., Cormack, S. J., Gabbett, T. J., & Lorenzen, C. H. (2016). Pre-training perceived wellness impacts training output in australian football players. Journal of Sports Sciences, 34(15), 1445–1451. https://doi.org/10.1080/02640414.2015.1119295

Gathercole, R. J., Sporer, B. C., Stellingwerff, T., & Sleivert, G. G. (2015). Comparison of the capacity of different jump and sprint field tests to detect neuromuscular fatigue. Journal of Strength and Conditioning Research, 29(9), 2522–2531. https://doi.org/10.1519/JSC.0000000000000912

Gathercole, R., Sporer, B., Stellingwerff, T., & Sleivert, G. (2015). Alternative countermovement-jump analysis to quantify acute neuromuscular fatigue. International Journal of Sports Physiology and Performance, 10(1), 84–92. https://doi.org/10.1123/ijspp.2013-0413

Gravina, L., Ruiz, F., Lekue, J. A., Irazusta, J., & Gil, S. M. (2011). Metabolic impact of a soccer match on female players. Journal of Sports Sciences, 29(12), 1345–1352. https://doi.org/10.1080/02640414.2011.597420

Haddad, M., Stylianides, G., Djaoui, L., Dellal, A., & Chamari, K. (2017). Session-RPE method for training load monitoring: Validity, ecological usefulness, and influencing factors. Frontiers in Neuroscience, 11. https://doi.org/10.3389/fnins.2017.00612

Hader, K., Rumpf, M. C., Hertzog, M., Kilduff, L. P., Girard, O., & Silva, J. R. (2019). Monitoring the athlete match response: Can external load variables predict post-match acute and residual fatigue in soccer? a systematic review with meta-analysis. Sports Medicine - Open, 5(1), 48. https://doi.org/10.1186/s40798-019-0219-7

Hagstrom, A. D., & Shorter, K. A. (2018). Creatine kinase, neuromuscular fatigue, and the contact codes of football: A systematic review and meta-analysis of pre- and post-match differences. European Journal of Sport Science, 18(9), 1234–1244. https://doi.org/10.1080/17461391.2018.1480661

Halouani, J., Chtourou, H., Dellal, A., Chaouachi, A., & Chamari, K. (2014). Physiological responses according to rules changes during 3 vs. 3 small-sided games in youth soccer players: Stop-ball vs. small-goals rules. Journal of Sports Sciences, 32(15), 1485–1490. https://doi.org/10.1080/02640414.2014.899707

Halson, S. L. (2014). Monitoring Training Load to Understand Fatigue in Athletes. Sports Medicine (Auckland, N.z.), 44(Suppl 2), 139–147. https://doi.org/10.1007/s40279-014-0253-z

Halson, S. L., Bridge, M. W., Meeusen, R., Busschaert, B., Gleeson, M., Jones, D. A., & Jeukendrup, A. E. (2002). Time course of performance changes and fatigue markers during intensified training in trained cyclists. Journal of Applied Physiology (Bethesda, Md.: 1985), 93(3), 947–956. https://doi.org/10.1152/japplphysiol.01164.2001

Heisterberg, M. F., Fahrenkrug, J., & Andersen, J. L. (2014). Multiple blood samples in elite soccer players. Is it worthwhile? Journal of Sports Sciences, 32(13), 1324–1327. https://doi.org/10.1080/02640414.2014.898859

Hennessy, L., & Jeffreys, I. (2018). The current use of GPS, its potential, and limitations in soccer. Strength & Conditioning Journal, 40(3), 83–94. https://doi.org/10.1519/SSC.0000000000000386

Hill-Haas, S. V., Coutts, A. J., Rowsell, G. J., & Dawson, B. T. (2009). Generic versus small-sided game training in soccer. International Journal of Sports Medicine, 30(9), 636–642. https://doi.org/10.1055/s-0029-1220730

Hitzschke, B., Wiewelhove, T., Raeder, C., Ferrauti, A., Meyer, T., Pfeiffer, M., Kellmann, M., & Kölling, S. (2017). Evaluation of psychological measures for the assessment of recovery and stress during a shock-microcycle in strength and high-intensity interval training. Performance Enhancement & Health, 5(4), 147–157. https://doi.org/10.1016/j.peh.2017.08.001

Impellizzeri, F.M., Marcora, S. M., Castagna, C., Reilly, T., Sassi, A., Iaia, F. M., & Rampinini, E. (2006). Physiological and performance effects of generic versus specific aerobic training in soccer players. International Journal of Sports Medicine, 27(6), 483–492. https://doi.org/10.1055/s-2005-865839

Impellizzeri, F.M., Marcora, S. M., & Coutts, A. J. (2019). Internal and External Training Load: 15 Years On. International Journal of Sports Physiology and Performance, 14(2), 270–273. https://doi.org/10.1123/ijspp.2018-0935

Impellizzeri, Franco M., Rampinini, E., Coutts, A. J., Sassi, A., & Marcora, S. M. (2004). Use of RPE-based training load in soccer. Medicine and Science in Sports and Exercise, 36(6), 1042–1047. https://doi.org/10.1249/01.mss.0000128199.23901.2f

Jagim, A. R., Murphy, J., Schaefer, A. Q., Askow, A. T., Luedke, J. A., Erickson, J. L., & Jones, M. T. (2020). Match demands of women's collegiate soccer. Sports, 8(6), 1–10. https://doi.org/10.3390/sports8060087

Jastrzebski, Z., Barnat, W., Dargiewicz, R., Jaskulska, E., Szwarc, A., & Radzimiński, Ł. (2014). Effect of in-season generic and soccer-specific high-intensity interval training in young soccer players. International Journal of Sports Science & Coaching, 9(5), 1169–1179. https://doi.org/10.1260/1747-9541.9.5.1169

Jones, S., & Drust, B. (2007). Physiological and technical demands of 4 v 4 and 8 v 8 games in elite youth soccer players. Kinesiology, 39(2), 150–156.

Katch, V. L., Sady, S. S., & Freedson, P. (1982). Biological variability in maximum aerobic power. Medicine and Science in Sports and Exercise, 14(1), 21–25. https://doi.org/10.1249/00005768-198201000-00004

Kawakami, Y., Muraoka, T., Ito, S., Kanehisa, H., & Fukunaga, T. (2002). In vivo muscle fibre behaviour during counter-movement exercise in humans reveals a significant role for tendon elasticity. The Journal of Physiology, 540(Pt 2), 635–646. https://doi.org/10.1113/jphysiol.2001.013459

Kelly, D. M., Strudwick, A. J., Atkinson, G., Drust, B., & Gregson, W. (2016). The within-participant correlation between perception of effort and heart rate-based estimations of training load in elite soccer players. Journal of Sports Sciences, 34(14), 1328–1332. https://doi.org/10.1080/02640414.2016.1142669

Kelly, D. M., Strudwick, A. J., Atkinson, G., Drust, B., & Gregson, W. (2020). Quantification of training and match-load distribution across a season in elite English Premier League soccer players. Science and Medicine in Football, 4(1), 59–67. https://doi.org/10.1080/24733938.2019.1651934

Kennedy, R. A., & Drake, D. (2017). The effect of acute fatigue on countermovement jump performance in rugby union players during preseason. The Journal of Sports Medicine and Physical Fitness, 57(10), 1261–1266. https://doi.org/10.23736/S0022-4707.17.06848-7

Kinugasa, T., Cerin, E., & Hooper, S. (2004). Single-subject research designs and data analyses for assessing elite athletes' conditioning. Sports Medicine (Auckland, N.Z.), 34(15), 1035–1050. https://doi.org/10.2165/00007256-200434150-00003

Kölling, S., Steinacker, J. M., Endler, S., Ferrauti, A., Meyer, T., & Kellmann, M. (2016). The longer the better: Sleep-wake patterns during preparation of the World Rowing Junior

Championships. Chronobiology International, 33(1), 73–84. https://doi.org/10.3109/07420528.2015.1118384

Krustrup, P., Mohr, M., Ellingsgaard, H., & Bangsbo, J. (2005). Physical demands during an elite female soccer game: Importance of training status. Medicine and Science in Sports and Exercise, 37(7), 1242–1248. https://doi.org/10.1249/01.mss.0000170062.73981.94

Lamberts, R. P., Swart, J., Noakes, T. D., & Lambert, M. I. (2009). Changes in heart rate recovery after high-intensity training in well-trained cyclists. European Journal of Applied Physiology, 105(5), 705–713. https://doi.org/10.1007/s00421-008-0952-y

López-Fernández, J., Sánchez-Sánchez, J., Rodríguez-Cañamero, S., Ubago-Guisado, E., Colino, E., & Gallardo, L. (2018). Physiological responses, fatigue and perception of female soccer players in small-sided games with different pitch size and sport surfaces. Biology of Sport, 35(3), 291–299. https://doi.org/10.5114/biolsport.2018.77829

Magalhães, J., Rebelo, A., Oliveira, E., Silva, J. R., Marques, F., & Ascensão, A. (2010). Impact of Loughborough Intermittent Shuttle Test versus soccer match on physiological, biochemical and neuromuscular parameters. European Journal of Applied Physiology, 108(1), 39–48. https://doi.org/10.1007/s00421-009-1161-z

Malone, J. J., Di Michele, R., Morgans, R., Burgess, D., Morton, J. P., & Drust, B. (2015). Seasonal training-load quantification in elite english premier league soccer players. International Journal of Sports Physiology and Performance, 10(4), 489–497. https://doi.org/10.1123/ijspp.2014-0352

Malone, S., Mendes, B., Hughes, B., Roe, M., Devenney, S., Collins, K., & Owen, A. (2018). Decrements in neuromuscular performance and increases in creatine kinase impact training outputs in elite soccer players. Journal of Strength and Conditioning Research, 32(5), 1342–1351. https://doi.org/10.1519/JSC.0000000000001997

Malone, S., Owen, A., Newton, M., Mendes, B., Tiernan, L., Hughes, B., & Collins, K. (2018). Wellbeing perception and the impact on external training output among elite soccer players. Journal of Science and Medicine in Sport, 21(1), 29–34. https://doi.org/10.1016/j.jsams.2017.03.019

Mara, J. K., Thompson, K. G., Pumpa, K. L., & Morgan, S. (2017). Quantifying the high-speed running and sprinting profiles of elite female soccer players during competitive matches using an optical player tracking system. Journal of Strength and Conditioning Research, 31(6), 1500–1508. https://doi.org/10.1519/JSC.0000000000001629

Marrier, B., Durguerian, A., Robineau, J., Chennaoui, M., Sauvet, F., Servonnet, A., Piscione, J., Mathieu, B., Peeters, A., Lacome, M., Morin, J.-B., & Le Meur, Y. (2019). Preconditioning Strategy in Rugby-7s Players: Beneficial or Detrimental? International Journal of Sports Physiology and Performance, 14(7), 918–926. https://doi.org/10.1123/ijspp.2018-0505

Martín-García, A., Gómez Díaz, A., Bradley, P. S., Morera, F., & Casamichana, D. (2018). Quantification of a professional football team's external load using a microcycle structure. Journal of Strength and Conditioning Research, 32(12), 3511–3518. https://doi.org/10.1519/JSC.0000000000002816

Maya, J., Marquez, P., Peñailillo, L., Contreras-Ferrat, A., Deldicque, L., & Zbinden-Foncea, H. (2016). Salivary Biomarker Responses to Two Final Matches in Women's Professional Football. Journal of Sports Science & Medicine, 15(2), 365–371.

McFadden, B. A., Walker, A. J., Bozzini, B. N., Sanders, D. J., & Arent, S. M. (2020). Comparison of internal and external training loads in male and female collegiate soccer players during practices vs. Games. Journal of Strength and Conditioning Research, 34(4), 969–974. https://doi.org/10.1519/JSC.0000000000003485

McLellan, C. P., Lovell, D. I., & Gass, G. C. (2011). Markers of postmatch fatigue in professional Rugby League players. Journal of Strength and Conditioning Research, 25(4), 1030–1039. https://doi.org/10.1519/JSC.0b013e3181cc22cc

Mohr, M., Krustrup, P., Andersson, H., Kirkendal, D., & Bangsbo, J. (2008). Match activities of elite women soccer players at different performance levels. Journal of Strength and Conditioning Research, 22(2), 341–349. https://doi.org/10.1519/JSC.0b013e318165fef6

Moreira, A., McGuigan, M. R., Arruda, A. F. s, Freitas, C. G., & Aoki, M. S. (2012). Monitoring internal load parameters during simulated and official basketball matches. Journal of Strength and Conditioning Research, 26(3), 861–866. https://doi.org/10.1519/JSC.0b013e31822645e9

Nässi, A., Ferrauti, A., Meyer, T., Pfeiffer, M., & Kellmann, M. (2017). Development of two short measures for recovery and stress in sport. European Journal of Sport Science, 17(7), 894–903. https://doi.org/10.1080/17461391.2017.1318180

Nedelec, M., McCall, A., Carling, C., Legall, F., Berthoin, S., & Dupont, G. (2014). The influence of soccer playing actions on the recovery kinetics after a soccer match. Journal of Strength and Conditioning Research, 28(6), 1517–1523. https://doi.org/10.1519/JSC.0000000000000293

Nicol, C., Avela, J., & Komi, P. V. (2006). The stretch-shortening cycle: A model to study naturally occurring neuromuscular fatigue. Sports Medicine (Auckland, N.Z.), 36(11), 977–999. https://doi.org/10.2165/00007256-200636110-00004

Nikolaidis, P. T., Clemente, F. M., van der Linden, C. M. I., Rosemann, T., & Knechtle, B. (2018). Validity and reliability of 10-Hz global positioning system to assess in-line movement and change of direction. Frontiers in Physiology, 9(228), 1–7. https://doi.org/10.3389/fphys.2018.00228

No, M., & Kwak, H.-B. (2016). Effects of environmental temperature on physiological responses during submaximal and maximal exercises in soccer players. Integrative Medicine Research, 5(3), 216–222. https://doi.org/10.1016/j.imr.2016.06.002

Oliver, J., Armstrong, N., & Williams, C. (2008). Changes in jump performance and muscle activity following soccer-specific exercise. Journal of Sports Sciences, 26(2), 141–148. https://doi.org/10.1080/02640410701352018

Owen, Adam L., Wong, D. P., Dunlop, G., Groussard, C., Kebsi, W., Dellal, A., Morgans, R., & Zouhal, H. (2016). High-intensity training and salivary immunoglobulin A responses in professional top-level soccer players: Effect of training intensity. Journal of Strength and Conditioning Research, 30(9), 2460–2469. https://doi.org/10.1519/JSC.0000000000000380

Owen, Adam Lee, Newton, M., Shovlin, A., & Malone, S. (2020). The use of small-sided games as an aerobic fitness assessment supplement within elite level professional soccer. Journal of Human Kinetics, 71, 243–253. https://doi.org/10.2478/hukin-2019-0086

Pelka, M., Schneider, P., & Kellmann, M. (2018). Development of pre- and post-match morning recovery-stress states during in-season weeks in elite youth football. Science and Medicine in Football, 2(2), 127–132. https://doi.org/10.1080/24733938.2017.1384560

Plews, D. J., Laursen, P. B., Kilding, A. E., & Buchheit, M. (2012). Heart rate variability in elite triathletes, is variation in variability the key to effective training? A case comparison. European Journal of Applied Physiology, 112(11), 3729–3741. https://doi.org/10.1007/s00421-012-2354-4

Plews, D. J., Laursen, P. B., Kilding, A. E., & Buchheit, M. (2013). Evaluating training adaptation with heart-rate measures: A methodological comparison. International Journal of Sports Physiology and Performance, 8(6), 688–691. https://doi.org/10.1123/ijspp.8.6.688

Proietti, R., di Fronso, S., Pereira, L. A., Bortoli, L., Robazza, C., Nakamura, F. Y., & Bertollo, M. (2017). Heart rate variability discriminates competitive levels in professional soccer players. Journal of Strength and Conditioning Research, 31(6), 1719–1725. https://doi.org/10.1519/JSC.0000000000001795

Ramos, G. P., Nakamura, F. Y., Penna, E. M., Wilke, C. F., Pereira, L. A., Loturco, I., Capelli, L., Mahseredjian, F., Silami-Garcia, E., & Coimbra, C. C. (2019). Activity profiles in U17, U20, and senior women's brazilian national soccer teams during international competitions: Are there meaningful differences? Journal of Strength and Conditioning Research, 33(12), 3414–3422. https://doi.org/10.1519/JSC.0000000000002170

Rampinini, E., Alberti, G., Fiorenza, M., Riggio, M., Sassi, R., Borges, T. O., & Coutts, A. J. (2015). Accuracy of GPS devices for measuring high-intensity running in field-based team sports. International Journal of Sports Medicine, 36(1), 49–53. https://doi.org/10.1055/s-0034-1385866

Ravé, G., Granacher, U., Boullosa, D., Hackney, A. C., & Zouhal, H. (2020). How to use global positioning systems (GPS) data to monitor training load in the "real world" of elite soccer. Frontiers in Physiology, 11, 1–11. https://doi.org/10.3389/fphys.2020.00944

Robineau, J., Jouaux, T., Lacroix, M., & Babault, N. (2012). Neuromuscular fatigue induced by a 90-minute soccer game modeling. Journal of Strength and Conditioning Research, 26(2), 555–562. https://doi.org/10.1519/JSC.0b013e318220dda0

Rollo, I., Impellizzeri, F. M., Zago, M., & Iaia, F. M. (2014). Effects of 1 versus 2 games a week on physical and subjective scores of subelite soccer players. International Journal of Sports Physiology and Performance, 9(3), 425–431. https://doi.org/10.1123/ijspp.2013-0288

Romagnoli, M., Sanchis-Gomar, F., Alis, R., Risso-Ballester, J., Bosio, A., Graziani, R. L., & Rampinini, E. (2016). Changes in muscle damage, inflammation, and fatigue-related parameters in young elite soccer players after a match. The Journal of Sports Medicine and Physical Fitness, 56(10), 1198–1205.

Rowell, A. E., Aughey, R. J., Hopkins, W. G., Esmaeili, A., Lazarus, B. H., & Cormack, S. J. (2018). Effects of training and competition load on neuromuscular recovery, testosterone, cortisol, and match performance during a season of professional football. Frontiers in Physiology, 9. https://doi.org/10.3389/fphys.2018.00668

Russell, M., Sparkes, W., Northeast, J., Cook, C. J., Bracken, R. M., & Kilduff, L. P. (2016). Relationships between match activities and peak power output and Creatine Kinase responses to professional reserve team soccer match-play. Human Movement Science, 45, 96–101. https://doi.org/10.1016/j.humov.2015.11.011

Sams, M. L., Sato, K., DeWeese, B. H., Sayers, A. L., & Stone, M. H. (2018). Quantifying changes in squat jump height across a season of men's collegiate soccer. Journal of Strength and Conditioning Research, 32(8), 2324–2330. https://doi.org/10.1519/JSC.0000000000002118

Sams, M. L., Wagle, J. P., Sato, K., DeWeese, B. H., Sayers, A. L., & Stone, M. H. (2020). Using the session rating of perceived exertion to quantify training load in a men's college soccer team. Journal of Strength and Conditioning Research, 34(10), 2793–2799. https://doi.org/10.1519/JSC.0000000000003793

Sands, W., Cardinale, M., McNeal, J., Murray, S., Sole, C., Reed, J., Apostolopoulos, N., & Stone, M. (2019). Recommendations for measurement and management of an elite athlete. Sports (Basel, Switzerland), 7(5). https://doi.org/10.3390/sports7050105

Sausaman, R. W., Sams, M. L., Mizuguchi, S., DeWeese, B. H., & Stone, M. H. (2019). The physical demands of NCAA division I women's college soccer. Journal of Functional Morphology and Kinesiology, 4(73), 1–7. https://doi.org/doi:10.3390/jfmk4040073

Saw, A. E., Kellmann, M., Main, L. C., & Gastin, P. B. (2017). Athlete self-report measures in research and practice: Considerations for the discerning reader and fastidious practitioner. International Journal of Sports Physiology and Performance, 12(Suppl 2), S2127–S2135. https://doi.org/10.1123/ijspp.2016-0395

Saw, A. E., Main, L. C., & Gastin, P. B. (2016). Monitoring the athlete training response: Subjective self-reported measures trump commonly used objective measures: a systematic review. British Journal of Sports Medicine, 50(5), 281–291. https://doi.org/10.1136/bjsports-2015-094758

Schneider, C., Hanakam, F., Wiewelhove, T., Döweling, A., Kellmann, M., Meyer, T., Pfeiffer, M., & Ferrauti, A. (2018). Heart Rate Monitoring in Team Sports-A Conceptual Framework for Contextualizing Heart Rate Measures for Training and Recovery Prescription. Frontiers in Physiology, 9, 639. https://doi.org/10.3389/fphys.2018.00639

Scott, B. R., Lockie, R. G., Knight, T. J., Clark, A. C., & Janse de Jonge, X. A. K. (2013). A comparison of methods to quantify the in-season training load of professional soccer players. International Journal of Sports Physiology and Performance, 8(2), 195–202. https://doi.org/10.1123/ijspp.8.2.195

Scott, M. T. U., Scott, T. J., & Kelly, V. G. (2016). The validity and reliability of global positioning systems in team sport: A brief review. Journal of Strength and Conditioning Research, 30(5), 1470–1490. https://doi.org/10.1519/JSC.0000000000001221

Sekiguchi, Y., Huggins, R. A., Curtis, R. M., Benjamin, C. L., Adams, W. M., Looney, D. P., West, C. A., & Casa, D. J. (2018). Relationship between heart rate variability and acute: Chronic load ratio throughout a season in ncaa d1 men's soccer players. The Journal of Strength & Conditioning Research, [e-pub ahead of print]. https://doi.org/10.1519/JSC.0000000000002853

Shearer, D. A., Sparkes, W., Northeast, J., Cunningham, D. J., Cook, C. J., & Kilduff, L. P. (2017). Measuring recovery: An adapted Brief Assessment of Mood (BAM+) compared to biochemical and power output alterations. Journal of Science and Medicine in Sport, 20(5), 512–517. https://doi.org/10.1016/j.jsams.2016.09.012

Silva, J. R., Rumpf, M. C., Hertzog, M., Castagna, C., Farooq, A., Girard, O., & Hader, K. (2018). Acute and residual soccer match-related fatigue: A systematic review and meta-analysis. Sports Medicine (Auckland, N.Z.), 48(3), 539–583. https://doi.org/10.1007/s40279-017-0798-8

Soligard, T., Schwellnus, M., Alonso, J.-M., Bahr, R., Clarsen, B., Dijkstra, H. P., Gabbett, T., Gleeson, M., Hägglund, M., Hutchinson, M. R., Janse van Rensburg, C., Khan, K. M., Meeusen, R., Orchard, J. W., Pluim, B. M., Raftery, M., Budgett, R., & Engebretsen, L. (2016). How much is too much? (Part 1) International Olympic Committee consensus statement on load in sport and risk of injury. British Journal of Sports Medicine, 50(17), 1030–1041. https://doi.org/10.1136/bjsports-2016-096581

Souza, A. A., Bottaro, M., Rocha, V. A., Lage, V., Tufano, J. J., & Vieira, A. (2020). Reliability and test-retest agreement of mechanical variables obtained during countermovement jump. International Journal of Exercise Science, 13(4), 6–17.

Stølen, T., Chamari, K., Castagna, C., & Wisløff, U. (2005). Physiology of soccer: An update. Sports Medicine (Auckland, N.Z.), 35(6), 501–536. https://doi.org/10.2165/00007256-200535060-00004

Taylor, K.-L., Chapman, D. W., Cronin, J., Michael, N. J., & Gill, N. D. (2012). Fatigue monitoring in high performance sport: A survey of current trends. Journal of Australian Strength and Conditioning, 20(1), 12–23.

Thorpe, R., & Sunderland, C. (2012). Muscle damage, endocrine, and immune marker response to a soccer match. Journal of Strength and Conditioning Research, 26(10), 2783–2790. https://doi.org/10.1519/JSC.0b013e318241e174

Thorpe, R. T., Atkinson, G., Drust, B., & Gregson, W. (2017). Monitoring fatigue status in elite team-sport athletes: Implications for practice. International Journal of Sports Physiology and Performance, 12(s2), S2-27-S2-34. https://doi.org/10.1123/ijspp.2016-0434

Thorpe, R. T., Strudwick, A. J., Buchheit, M., Atkinson, G., Drust, B., & Gregson, W. (2015). Monitoring fatigue during the in-season competitive phase in elite soccer players. International Journal of Sports Physiology and Performance, 10(8), 958–964. https://doi.org/10.1123/ijspp.2015-0004

Thorpe, R. T., Strudwick, A. J., Buchheit, M., Atkinson, G., Drust, B., & Gregson, W. (2017). The influence of changes in acute training load on daily sensitivity of morning-measured fatigue variables in elite soccer players. International Journal of Sports Physiology and Performance, 12(Suppl 2), S2107–S2113. https://doi.org/10.1123/ijspp.2016-0433

Treiber, F. A., Kamarck, T., Schneiderman, N., Sheffield, D., Kapuku, G., & Taylor, T. (2003). Cardiovascular reactivity and development of preclinical and clinical disease states. Psychosomatic Medicine, 65(1), 46–62. https://doi.org/10.1097/00006842-200301000-00007

Trewin, J., Meylan, C., Varley, M. C., & Cronin, J. (2018). The match-to-match variation of match-running in elite female soccer. Journal of Science and Medicine in Sport, 21(2), 196–201. https://doi.org/10.1016/j.jsams.2017.05.009

Varley, I., Lewin, R., Needham, R., Thorpe, R. T., & Burbeary, R. (2017). Association between Match Activity Variables, Measures of Fatigue and Neuromuscular Performance Capacity Following Elite Competitive Soccer Matches. Journal of Human Kinetics, 60, 93–99. https://doi.org/10.1515/hukin-2017-0093

Vescovi, J. D., Brown, T. D., & Murray, T. M. (2006). Positional characteristics of physical performance in Division I college female soccer players. The Journal of Sports Medicine and Physical Fitness, 46(2), 221–226.

Walker, A. J., McFadden, B. A., Sanders, D. J., Rabideau, M. M., Hofacker, M. L., & Arent, S. M. (2019). Biomarker response to a competitive season in division I female soccer players. Journal of Strength and Conditioning Research, 33(10), 2622–2628. https://doi.org/10.1519/JSC.0000000000003264

Wiewelhove, T., Raeder, C., Meyer, T., Kellmann, M., Pfeiffer, M., & Ferrauti, A. (2016). Effect of repeated active recovery during a high-intensity interval-training shock microcycle on markers of fatigue. International Journal of Sports Physiology and Performance, 11(8), 1060–1066. https://doi.org/10.1123/ijspp.2015-0494

Wiig, H., Andersen, T. E., Luteberget, L. S., & Spencer, M. (2020). Individual response to external training load in elite football players. International Journal of Sports Physiology and Performance, 15(5), 696–704. https://doi.org/10.1123/ijspp.2019-0453

Wiig, H., Raastad, T., Luteberget, L. S., Ims, I., & Spencer, M. (2019). External load variables affect recovery markers up to 72 h after semiprofessional football matches. Frontiers in Physiology, 10, 689. https://doi.org/10.3389/fphys.2019.00689

Zurutuza, U., Castellano, J., Echeazarra, I., & Casamichana, D. (2017). Absolute and relative training load and its relation to fatigue in football. Frontiers in Psychology, 8. https://doi.org/10.3389/fpsyg.2017.00878

Chapter 3. Study I

Title: Individual and Grouped Relationship between Soccer Match-Derived Training Loads, Recovery Stress State and Neuromuscular Performance.

Authors: Ai Ishida[1], Caleb D. Bazyler[1], Adam Sayers[2], Satoshi Mizuguchi[1], Jeremy A. Gentles[1]

Affiliations: [1]Center of Excellence for Sport Science and Coach Education, East Tennessee State University.

[2]Department of Sport, Exercise, Recreation, and Kinesiology East Tennessee State University, Johnson City, TN.

Formatted as published in Journal of Strength and Conditioning Research.

ABSTRACT

The purposes of this study were to investigate the individualized and group relationships between match-derived training loads (TL) and changes in subjective recovery stress state and between pre-match subjective recovery stress state and neuromuscular performance. Fourteen female soccer players were included (19.9±1.5yrs; 62.3±8.0kgs; 165.9±6.2cm). TL, Short Recovery Stress Scale (SRSS), and countermovement jump (CMJ) with a polyvinyl chloride pipe (CMJ0) and 20kgs bar (CMJ20) were measured during 14 matches of the competitive season. TL included total distance, average speed, high speed running distance, PlayerLoad, and average PlayerLoad. SRSS included Physical Performance Capability (PPC), Mental Performance Capability (MPC), Emotional Balance (EB), Overall Recovery (OR), Muscular Stress (MS), Lack of Activation (LA), Negative Emotional State (NES), and Overall Stress (OS). CMJ included jump height (JH), peak force (PF), and peak power (PP). Twelve individual players demonstrated negative correlations between total distance and MPC ($p \leq 0.05$, r=-0.78 to -0.34, number of significant individual correlations [N]=3) and OR ($p \leq 0.05$, r= -0.91 to -0.08, N=3). Positive correlations were observed between MS and total distance among all individual players ($p \leq 0.05$, r=0.21 to 0.82, N=3) while the group correlations were moderate to large (MPC, $p \leq 0.001$, r=-0.38; OR, $p \leq 0.001$, r=0.60; MS, $p \leq 0.001$, r=0.55). Several positive and negative significant correlations were observed between between SRSS and CMJ0 JH ($p \leq 0.05$, r=-0.78 to 0.80, N=4). SRSS changes may be more reflective of total distance than other TL variables. Correlations between TL, SRSS and CMJ demonsterated heterogenous reponses between players.

Keywords: Individualized data analysis, dose-response relationship, soccer, female athlete

INTRODUCTION

Athlete monitoring programs are commonly integrated into competitive soccer teams to maximize sports performance during a competitive season. The assessment of training load (TL), subjective recovery and stress, and neuromuscular performance are frequently performed using a Global Navigation Satellite System (GNSS), questionnaires, and force plates, respectively. These assessments are often components of an athlete monitoring program aimed at quantifying a dose and response relationship and maximizing an athlete's physical and psychological preparedness. Athlete monitoring programs are particularly important for National Collegiate Athlete Association (NCAA) sports, where athletes participate in congested match-play and training restrictions throughout the year interfere with their preparedness. For instance, NCAA soccer players often only spend 2 weeks of intense preseason training (i.e., 2 training sessions per day) preparing for the season and during this time demonstrate profound increases in injury risk, muscle damage, hematological markers (1,39). These athletes then complete 20 to 30 matches during the 16-week fall season, limiting time to focus on improving physical capacity and skills during the competitive season. Furthermore, the NCAA restricts student-athletes from participating in mandatory training sessions during summer break. As a result, athlete physical and psychological preparation for the fall season may be compromised. Therefore, data from athlete monitoring programs allow sports scientists to assess athlete's physical and psychological preparedness and modify training programs leading up to and throughout a competitive season.

A measure of TL such as GNSS provides a comprehensive understanding of the external loads performed by an athlete. GNSS metrics include total distance covered, average speed, total distance in high speed running (HSR). Accelerometer and gyroscopes are typically embedded into a GNSS device and provide accelerometry derived TL such as the Catapult PlayerLoad, and the STATSport dynamic stress load (41). Based on previous literature (9,11,30,40,41), GNSS metrics such as total distance, HSR, and accelerometry-derived TL correspond to the changes in other monitoring measures such as neuromuscular performance, the ratings of subjective recovery and stress state, and physiological markers. A systematic review by Hader et al. (11) found moderate evidence of a large, negative correlation between post-match countermovement jump (CMJ) peak power and high accelerations (r =-0.61). Wiig et al. (41) also reported that HSR demonstrated the strongest relationship with the changes in creatine kinase at 1, 24, and 48 hours post-match (ES=0.60 to 1.08). Therefore, measuring TL in conjunction with other monitoring measures may be useful to maximize match performance.

Measures of subjective recovery and stress state and countermovement jump (CMJ) are also commonly used in sport to assess an athlete's physical and psychological response to TL (33,34,37). The combined use of these monitoring measures indicates athlete's response to TL, which can inform training prescription for the forthcoming match. The Short Recovery Stress Scale (SRSS) is a simple, valid, and reliable, 8-item questionnaire that is commonly used to evaluate the subjective physiological and psychological recovery and stress state of athletes (20,24). Current evidence shows that SRSS subscales are sensitive to acute high TLs (12,30,40). For example, Hitzschke et al. (12) reported that Physical Performance Capability, Mental Performance Capability, Overall Recovery, Muscular Stress, Lack of Activation, and Overall Stress returned to baseline values 3 days after 6-days of high-intensity interval training in well-trained intermittent sport athletes. CMJ is also a useful athlete monitoring tool to assess neuromuscular preparedness in soccer (2,8,16,25). CMJ metrics such as jump height, peak power, and peak force decrease with structural and physiological disturbance in response to soccer match-play (2,16,25,26). For example, Andersson et al. (2) found that significant decreases were observed in CMJ jump height with significantly increased CK at 21 hours after a soccer-match play in elite female soccer players. Therefore, SRSS and CMJ measures provide a better understanding of the response to a given TL.

Previously, athlete monitoring data has primarily reported group level changes and relationships (23,29). Although group data analysis is useful, analyzing data at an individual athlete level is highly recommended in a practical setting (19,32). Practitioners understand that team success can be determined by the performance of the team's best athletes, highlighting the importance of individual athlete monitoring. Determining meaningful changes in the best athletes can inform decision-making processes regarding the planning and manipulation of training to maximize physical and psychological preparation for a match, in turn, increasing the likelihood of winning. Further underscoring the importance of individual athlete monitoring, previous literature has shown that heterogeneous biological responses exist in relation to acute TLs (3,4,6,17). For example, Katch and colleagues (17) reported that within-subject biological variability accounted for 92.7% of the variation in maximum oxygen consumption in 8 to 20 repeated treadmill running tests. Based on the evidence from previous literature (3,4,6,17), biological heterogeneity should be considered as a possible source of measurement error when monitoring TL, subjective recovery and stress, and neuromuscular performance. Therefore, the necessity of individual level analysis in conjunction with group level analysis may be apparent for sports performance enhancement.

Although group level athlete monitoring is commonly used, the advantages of individual level athlete monitoring have not been thoroughly evaluated. Furthermore, a limited number of investigations have assessed the relationship between TLs, subjective recovery and stress state, and neuromuscular performance at the group level in female soccer athletes. Specifically, to the authors' knowledge, no research has been conducted which examined the relationship between subjective recovery and stress state and neuromuscular performance changes resulting from match-play in female soccer players. Therefore, the purpose of this study was to investigate the relationships between match-derived TL, recovery and stress state, and neuromuscular performance at individual and group levels in Division I collegiate female soccer players. Particularly, this study examined the relationship 1) between match-derived TL and the changes from pre-match to post-match in SRSS and 2) between pre-match SRSS and CMJ kinetics at individual and group levels in Division I female soccer players.

METHODS

Experimental Approach to the Problem

This study was an exploratory investigation using data routinely collected as a part of an on-going athlete monitoring program. Data collection occurred throughout the 2019 NCAA soccer season. This study included TL data collected during 14 matches and assessments performed pre- and post-match play. Six matches of the season were not included due to traveling. TL data included GNSS and accelerometry derived measures from each match. The Short Recovery Stress Scale (SRSS), and countermovement (CMJ) jump performance were assessed 2 to 3 hours before a match (Pre) and Post SRSS was assessed again the day following a match (Post). The players completed Post SRSS immediately after they woke up from 6 am to 12 pm. Several relationships were assessed, including 1) TLs of soccer match-play and Pre-to-Post SRSS changes at individual and group levels, and 2) between Pre SRSS and CMJ performance at individual and group levels.

Subjects

Fourteen NCAA Division I female soccer players were included in this investigation (Age, 19.9±1.5 yrs; Body mass, 62.3±8.0 kgs; height, 165.9±6.2 cm). Demographic information was collected on the first day of the pre-season. The inclusion criteria for this study were as follows: (a) players must have been a field player (defender, midfielder, or forward), (b) worn a GNSS sensor during all matches and (c) completed at least 70% of jump testing sessions. Four players were not eligible for this study because they could not complete all jump testing sessions due to lower limb injuries. Fourteen players met the inclusion criteria and were included in this study. Each player was randomly assigned a number (ID#) from 01 to 14 that was used for data analysis. All participants signed an informed consent after being informed of the risks and benefits of the study. This study was approved by the university's Institutional Review Board.

Methodology

Short Recovery Stress Scale. Athlete's recovery and stress state were assessed via SRSS using an online-based application (Google Forms, Google, California, US). All participants were fully familiarized with the procedures using a pre-season game as a familiarization session. Players completed the SRSS at Pre and Post. Prior to the Pre SRSS assessment, hydration status was measured using a refractometer (ATAGO, Tokyo, Japan). If urine specific gravity was below 1.02, players were considered hydrated. Players completed pre-SRSS after the hydration test. At Post SRSS, they completed SRSS immediately after they woke up between 6 am to 12 pm (18). SRSS consists of 8 subscales including Physical Performance Capability (PPC; arbitrary unit: au), Mental Performance Capability (MPC; au), Emotional Balance (EB; au), Overall Recovery (OR; au), Muscular Stress (MS; au), Lack of Activation (LA; au), Negative

Emotional State (NES; au), and Overall Stress (OS; au). Recovery Scale (RS) consists of PPC, MPC, EB, and OR while Stress Scale (SS) consists of MS, LA, NES, and OS. Each subscale is rated using a 7-point Likert scale from 0 (does not fully apply) to 6 (fully applies). The internal reliability ($\alpha = 0.74$ and $\alpha=0.78$) and validity ($r =-0.29$ to -0.64) of SRSS has previously been established (18). The changes from Pre-to-Post were calculated for all 4 subscales.

Match-Derived Training Load. Global Navigation Satellite System (10 Hz) and accelerometry (triaxial; 100 Hz) were used to measure match-derived TLs using Catapult Innovation GNSS units (Optimeye S5, Catapult Innovation, Melbourne, Australia). According to previous literature (27,28,35), the validity and reliability of a 10-Hz GNSS unit are good to moderate (CV=1.9% for total distance, CV=4.7% for high speed running, and CV=1.9 to 4.3% for running involving accelerations, PlayerLoad CV=0.0 to 3.0% in anterior-posterior, medial-lateral, and vertical axes). Players placed the wearable sensor unit in a vest worn between the shoulder blades. All units were powered on at least 10 minutes prior to use. Data from all units were transferred into Catapult Innovation software and then summarized in an Excel spreadsheet (Microsoft, Redmond, WA). The data of soccer match-derived TLs included warm-up and match-play. GNSS derived TL included total distance (m), average speed ($m{\bullet}min^{-1}$), and total distance in high speed running (HSR; m). Average speed was calculated by dividing total distance by total time in minutes. HSR was defined as running above 15 km/h. Accelerometry derived TLs included total PlayerLoad expressed in arbitrary units and average PlayerLoad ($au{\bullet}min^{-1}$). PlayerLoad is defined as the summation of differences of accelerations on the anterior-posterior, medial-lateral, and vertical axes (27).

Countermovement Vertical Jump. Players performed a standardized dynamic warm-up and two submaximal CMJs at 75% and 100% of perceived maximal efforts. Participants then completed three maximal CMJ trials with a polyvinyl chloride pipe (CMJ0) and a 20kgs barbell (CMJ20) on two portable force plates (PASPORT Force Platform, PASCO, CA, USA) at a sampling frequency of 1,000 Hz. The players held each load across the back of the shoulders. For CMJ tests, the players were instructed to stand still on force plates at least one second and then vertically jump after flexing hip, knee, and ankle joints on the command of "3,2,1, jump". At least one-minute rest was given between CMJ 0 and CMJ 20 trials. The mean of the best two jumps in jump height calculated from impulse (JH) was used for data analysis. After CMJ tests, the raw data were converted into a comma-separated value file and then analyzed using an excel sheet (7). As measures of interests, CMJ variables included JH (cm), peak force (PF; N), and peak power (PP; W). CMJ variables were assessed prior to each of the 14 matches. The test re-test reliability in CMJ variables were good to excellent intra-class correlations (ICC) with low coefficient of variations (CV) for CMJ0 (CV=2.6 to 6.5%; ICC=0.79 to 0.96) and CMJ20 (CV=2.8 to 5.5%, ICC=0.80 to 0.95) (13,21).

Statistical Analysis

Spearman correlation coefficient tests were used to evaluate the relationship between match-derived TLs and Pre-to-Post SRSS changes and between SRSS at Pre and CMJ variables. All statistical procedures were performed using the statistical software Rstudio (version 1.1.463) and the package stats (3.5.3) and boot (1.3-20). Spearman correlation coefficient test was chosen to consider the independence of error. For individual analysis, correlations were calculated using individual data from 14 matches. Range of correlation (Min and Max) and number of individual correlations (N) were also reported. Group analysis of correlations was performed using all the data from 14 matches. Correlations were classified as trivial (r <0.1), small (0.1 ≤r <0.3), moderate (0.3≤ r <0.5), large (0.5≤ r <0.7), very large (0.7≤ r <0.9), nearly perfect (0.9≤ r <1.0), and perfect (r=1.0) (15). Statistical significance for the analysis was set at $p \leq 0.05$. Bias-corrected and accelerated bootstrapping was performed to calculate 95% confidence intervals (CIs) for the correlations at individual and group levels. Bootstrapping repetitions were set at 2000. 95%CIs were not calculated if no changes were seen in SRSS subscales across all tests.

RESULTS

Table 3.1 desribes match-derived TL and pre CMJ kinetic varaibles. Mean Pre-match SRSS subscales reported were, 5.0±0.6 for PPC, 5.4±0.4 for MPC, 5.3±0.5 for EB, 4.9±0.6 for OR, 5.1±0.5 for RS, 1.2±0.6 for MS, 0.6±0.7 for LA, 0.6±0.5 for NES, 0.8±0.4 for OS, and 0.8±0.5 for SS. Mean post-match SRSS were 4.1±0.9 for PPC, 4.8±1.0 for MPC, 4.6±0.9 for EB, 3.8±1.1 for OR, 2.1±0.9 for MS, 1.2±1.0 for LA, 1.1±0.9 for NES, and 1.6±0.6 for OS. At Post, means for SRSS were 4.1±0.9 for PPC, 4.8±1.0 for MPC, 4.6±0.9 for EB, 3.8±1.1 for OR, 2.1±0.9 for MS, 1.2±1.0 for LA, 1.1±0.9 for NES, and 1.6±0.6 for OS.

Table 3.1 Group mean and standard deviations in match-derived training loads and countermovement jump

Items	Mean±SD
Match-derived training loads	
Total distance (m)	7,366.2±3,550.1
Average speed (mmin^{-1})	71.2±15.5
HSR (m)	693.0±389.6
Total PlayerLoad (au)	775.0±363.5
Average PL (au min^{-1})	7.6±1.7
CMJ0	
Jump height (cm)	25.3±4.2
Peak force (N)	742.4±82.2
Peak power (W)	2,636.7±150.7
CMJ20	
Jump height (cm)	16.7±2.3
Peak force (N)	705.4±76.8
Peak power (W)	2,569.0±153.9

HSR= High speed running distance. PL=PlayerLoad. CMJ0=Countermovement jump with a polyvinyl chloride pipe. CMJ20=Countermovement jump with a 20kgs barbell.

Correlations between Match-Derived Training Loads and Changes in Short Recovery Stress Scale

Figure 3.1 to 5 demonstrates individual and group correlation and 95% CI between match-derived TLs and changes in SRSS. Among 8 players, large to nearly perfect correlation were observed between Pre-to-Post PPC, MPC, EB and OR and total distance (p≤0.05, r= -0.91 to -0.55, N=8) (Figure 3.1), average speed (p≤0.05, r= -0.73 to 0.63, N=5) (Figure 3.2), HSR (p<0.05, r=-0.79 to -0.64, N=2) (Figure 3.1), total PlayerLoad (p≤0.05, r=-0.93 to -0.62, N=5) (Figure 3.4), and average PlayerLoad (p≤0.05, r=-0.75 to 0.63, N=5) (Figure 3.5) (Table 3.2). Interestingly, 12 players demonstrated non-significant and significant correlations between total distance and Pre-to-Post MPC p≤0.05, r=-0.78 to -0.34, N=3) and OR (p≤0.05, r= -0.91 to -0.08, N=3) (Figure 3.1).

However, no significant correlations were observed between Pre-to-Post PPC, MPC, EB, and PR and match-derived TLs among 6 individual players ($p \le 0.05$). Signifincant large to nearly perfect correlations were also observed between Pre-to-Post MS, LA, NES and OS and total distance ($p<0.05$, r= 0.68 to 0.82, N=6), average speed ($p \le 0.05$, r= -0.68 to 0.90, N=5), HSR ($p \le 0.05$, r=-0.61 to 0.69, N=4), total PlayerLoad ($p \le 0.05$, r=-0.69 to 0.82, N=6), and average PlayerLoad ($p \le 0.05$, r=-0.75 to 0.85, N=4) among 8 players. Interestingly, all players demonstrated positive correlations between Pre-Post MS and total distance in all individual players (p≤0.05, r=0.21 to 0.82, N=3). However, no siginificant correlations were found between MS, LA, NES, and OS and match-derived TLs among 6 individual players ($p>0.05$).

At the group level, negative small to large correlations were found between PPC, MPC, EB, and OR and total distance ($p<0.001$, r=-0.60 to -0.38), average speed ($p<0.001$, r=-0.48 to -0.20), HSR ($p<0.001$, r=-0.43 to -0.23), total PlayerLoad ($p<0.001$, r=-0.52 to -0.31), and average PlayerLoad ($p<0.01$, r=-0.32 to -0.17). Additionally, small to large correlations were observed between MS, LA, NES, and OS and total distance ($p<0.001$, r=0.21 to 0.55), average speed ($p<0.001$, r=0.23 to 0.40), HSR ($p<0.001$, r=0.20 to 0.35), total PlayerLoad ($p<0.001$, r=0.28 to 0.47), and average PlayerLoad ($p \le 0.05$, r=0.16 to 0.26) (Table 3.3).

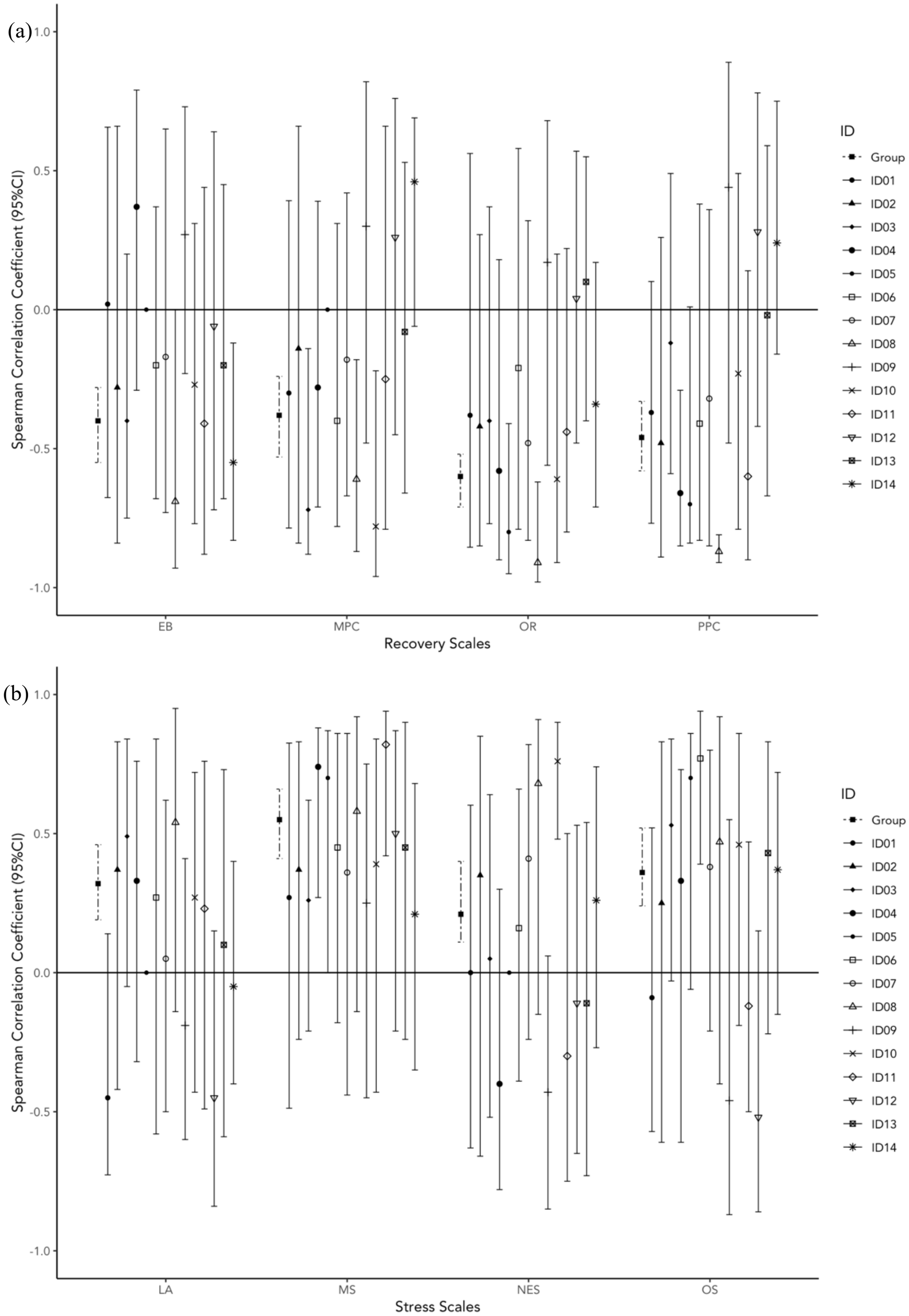

Figure 3.1. Individual and group correlation between total distance and Recovery Scales (a) and (b) Stress Scales (b). Dots with error bars represent a Spearman correlation coefficient and 95% confidence intervals (CI; lower and upper limits).

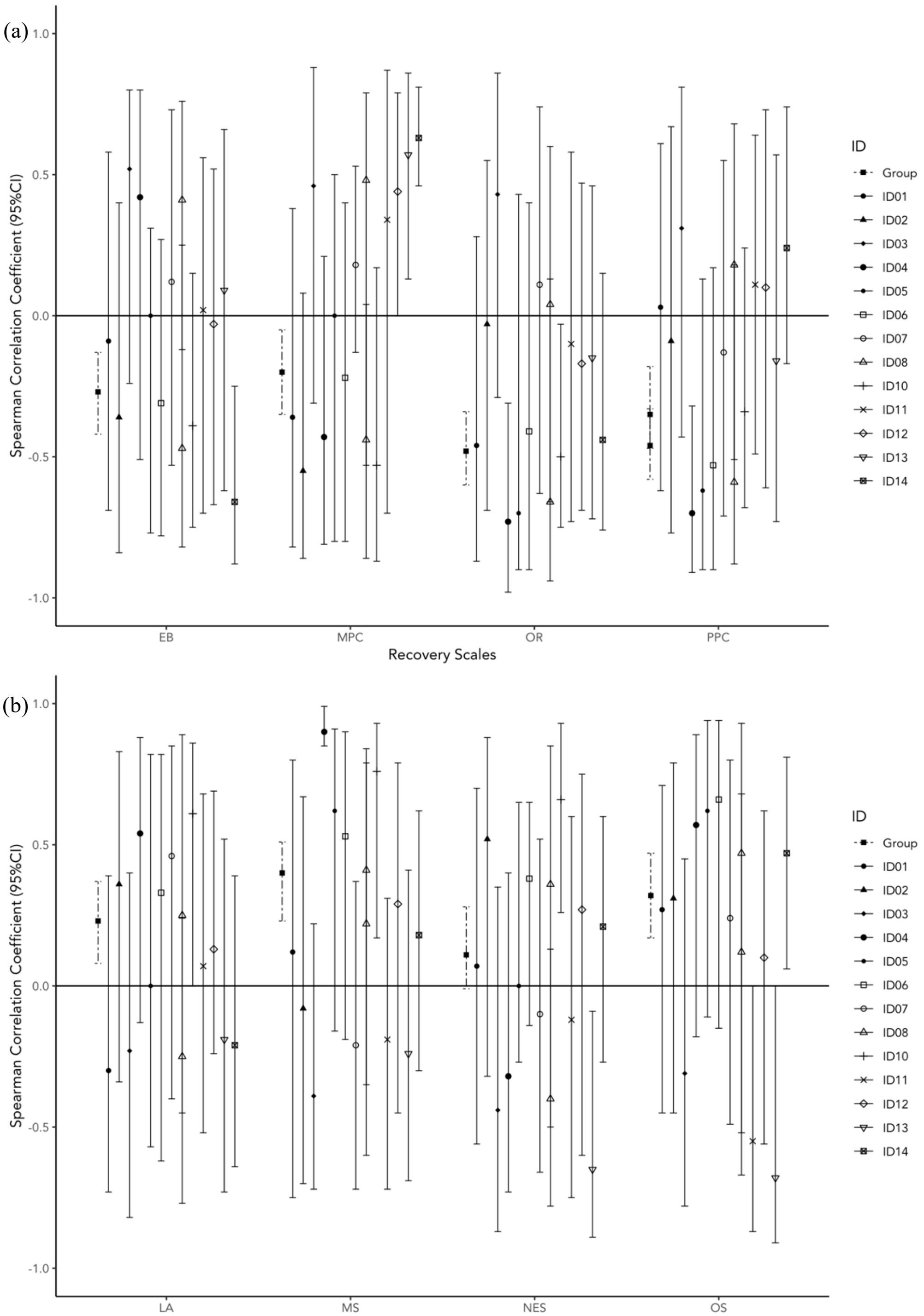

Figure 3.2. Individual and group correlation between average speed and Recovery Scales (a) and (b) Stress Scales (b). Dots with error bars represent a Spearman correlation coefficient and 95% confidence intervals (CI; lower and upper limits).

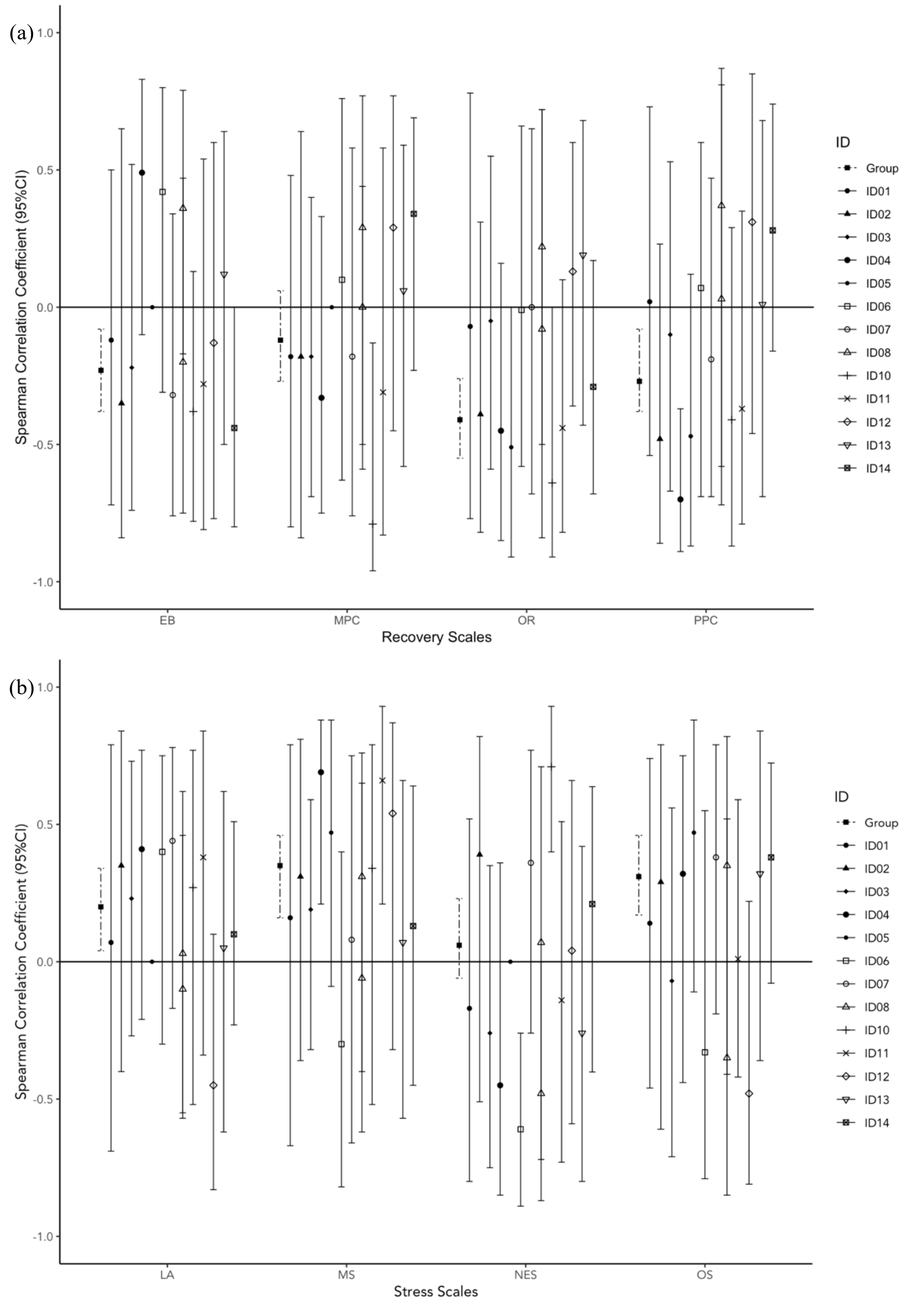

Figure 3.3. Individual and group correlation between high speed running and Recovery Scales (a) and (b) Stress Scales (b). Dots with error bars represent a Spearman correlation coefficient and 95% confidence intervals (CI; lower and upper limits).

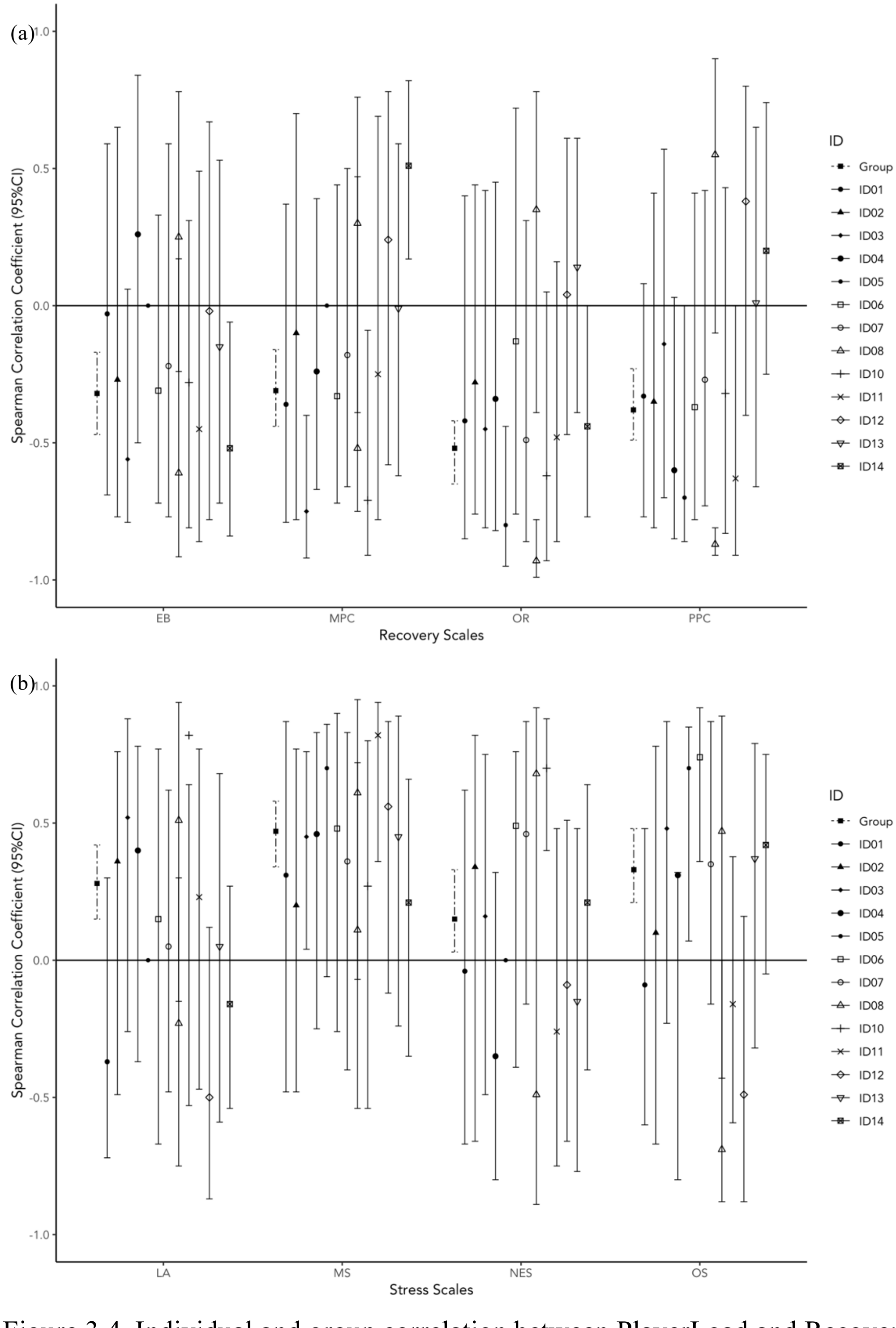

Figure 3.4. Individual and group correlation between PlayerLoad and Recovery Scales (a) and (b) Stress Scales (b). Dots with error bars represent a Spearman correlation coefficient and 95% confidence intervals (CI; lower and upper limits).

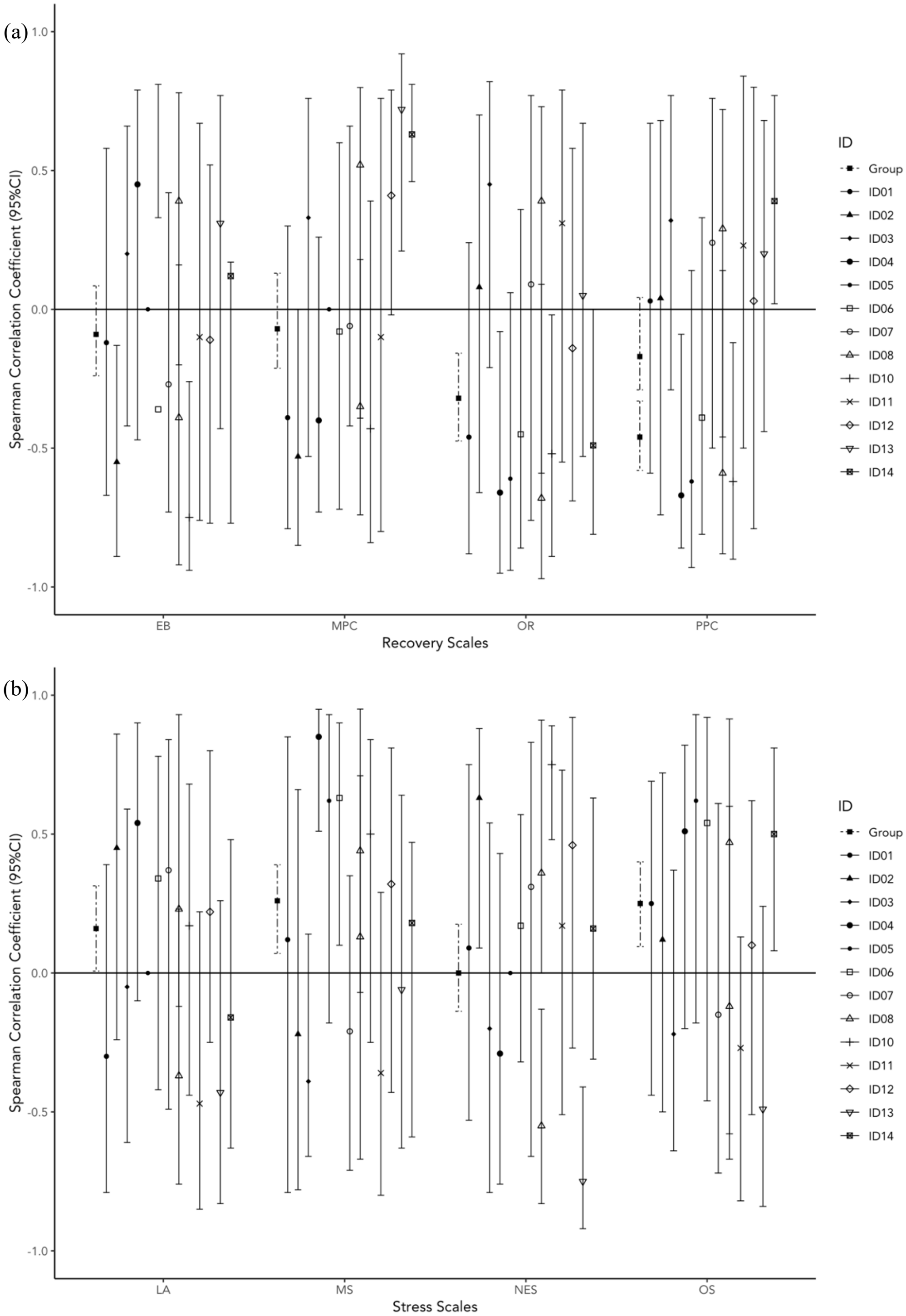

Figure 3.5. Individual and group correlation between average PlayerLoad and Recovery Scales (a) and (b) Stress Scales (b). Dots with error bars represent a Spearman correlation coefficient and 95% confidence intervals (CI; lower and upper limits).

Table 3.2. Range of individual correlation between match-derived training loads and the changes in short recovery stress scale.

	Total distance		Average speed		HSR		Total PlayerLoad		Average PlayerLoad	
Item	**Min, Max**	***p*<0.05**	**Min, Max**	***p*<0.05**	**Min, Max**	***p*<0.05**	**Min, Max**	***p*<0.05**	**Min, Max**	***p*<0.05**
PPC	-0.87, 0.44	-0.87[ID08],-0.70[ID05], -0.66[ID04],-0.60[ID11]	-0.70, 0.31	-0.70[ID04]	-0.70, 0.37	-0.70[ID04]	-0.87, 0.55	-0.87[ID8],-0.75[ID3], -0.70[ID5],-0.63[ID11]	-0.67, 0.39	-0.67[ID4], -0.62[ID10]
MPC	-0.78, 0.46	-0.78[ID10],-0.72[ID03]	-0.55, 0.63	0.63[ID14]	-0.79, 0.34	-0.79 [ID10]	-0.75, 0.52	-0.71[ID10]	-0.53, 0.72	0.63[ID14]
EB	-0.69, 0.37	-0.69[ID08],-0.55[ID05]	-0.66, 0.52	-0.66[ID14]	-0.44, 0.49	None	-0.61, 0.26	None	-0.75, 0.45	-0.75[ID10]
OR	-0.91, 0.17	-0.91[ID08],-0.80[ID05], -0.61[ID10]	-0.64, 0.43	-0.73[ID04],-0.70[ID05], -0.66[ID08]	-0.64, 0.22	-0.64[ID10]	-0.93, 0.35	-0.93[ID8],-0.80[ID5], -0.62[ID10]	-0.68, 0.45	-0.68[ID8], -0.66[ID4]
MS	0.21,0.82	0.70 [ID5], 0.74[ID04], 0.82[ID11]	-0.39, 0.90	0.76[ID10],0.90[ID02]	-0.30, 0.69	0.66[ID11],0.69[ID04]	0.11, 0.82	0.70[ID8],0.82[ID11]	-0.39, 0.85	0.63[ID6], 0.85[ID4]
LA	-0.45, 0.54	None	-0.30, 0.61	0.61[ID10]	-0.45, 0.44	None	-0.50, 0.82	None	-0.47, 0.54	None
NES	-0.43, 0.76	0.68[ID08],0.76[ID10]	-0.65, 0.66	-0.65[ID13],0.66[ID10]	-0.61, 0.71	-0.61[ID06],0.71[ID10]	-0.49, 0.70	0.68[ID8],0.70[ID10]	-0.75, 0.75	-0.75[ID13], 0.63[ID02], 0.75[ID10]
OS	-0.52, 0.77	0.70[ID05],0.77[ID06]	-0.68, 0.66	-0.68[ID13],0.60[ID10], 0.66[ID06]	-0.48, 0.47	None	-0.69, 0.74	-0.69[ID9],0.70[ID10], 0.74[ID6]	-0.33, 0.62	None

Note. HSR= high speed running distance. Superscript number on righthand corner of Sig Cor denotes ID of individual players. PPC=Physical Performance Capacity. MPC=Mental Performance Capacity. EB=Emotional Balance. OR=Overall Recovery. MS=Muscle Stress. LA=Lack of Activation. NES=Negative Emotional State.
OS=Overall Stress.

Table 3. Group correlation between match-derived training loads and the changes in short recovery stress scale.

Items	Total distance	Average speed	HSR	Total PL	Average PL
PPC	-0.46$ (-0.58, -0.33)	-0.35$ (-0.47, -0.27)	-0.27$ (-0.38, -0.08)	-0.38$ (-0.49, -0.23)	-0.17* (-0.29, 0.05)
MPC	-0.38$ (-0.53, -0.24)	-0.20* (-0.35, -0.05)	-0.12 (-0.27, -0.06)	-0.31$ (-0.44, -0.16)	-0.07 (-0.21, 0.13)
EB	-0.40$ (-0.55, -0.28)	-0.27$ (-0.42, -0.13)	-0.23$ (-0.38, -0.08)	-0.32$ (-0.47, -0.17)	-0.09 (-0.24, 0.08)
OR	-0.60$ (-0.71, -0.52)	-0.48$ (-0.60, -0.34)	-0.41$ (-0.55, -0.26)	-0.52$ (-0.65, -0.42)	-0.32$ (-0.47, -0.16)
MS	0.55$ (0.41, 0.66)	0.40$ (0.23 0.51)	0.35$ (0.16, 0.46)	0.47$ (0.34, 0.58)	0.26$ (0.07, 0.39)
LA	0.32$ (0.19, 0.46)	0.23$ (0.08, 0.37)	0.20* (0.04, 0.34)	0.28$ (0.15, 0.42)	0.16* (0.01, 0.31)
NES	0.21* (0.11, 0.40)	0.11(-0.01, 0.28)	0.06 (-0.06, 0.23)	0.15 (0.03, 0.33)	0.00 (-0.14, 0.18)
OS	0.36$ (0.24, 0.52)	0.32$ (0.17, 0.47)	0.30$ (0.17, 0.46)	0.33$ (0.21, 0.48)	0.25$ (0.10, 0.40)

Note. HSR=High speed running. PL=PlayerLoad. PPC=Physical Performance Capacity. MPC=Mental Performance Capacity. EB=Emotional Balance. OR=Overall Recovery. MS=Muscle Stress. LA=Lack of Activation. NES=Negative Emotional State. OS=Overall Stress. *=denotes $p<0.05$. $=denotes $p<0.001$. Value is expressed as Spearman correlation coefficient and 95% confidence interval (lower limit, upper limit).

Correlations between Pre Short Recovery Stress Scale and Countermovement Jump

Figure 3.6 to 3.8 demonstrates individual and group correlation and 95%CI between CMJ0 and Pre SRSS. Among 7 players, PPC, MPC, EB and OR were found to be correlated with CMJ0 JH (p<0.05, r=-0.78 to 0.65, N=5) (Figure 3.6), PF (p<0.05, r=-0.62 to 0.85, N=3) (Figure 3.7), and PP (p<0.05, r=-0.73 to 0.57) (Figure 3.8) (Table 3.3). MS, LA, NES, or OS were significantly correlated with JH (p<0.05, r=-0.78 to 0.80, N=3), PF (p<0.05, r=-0.85 to -0.61, N=1), and PP (p<0.05, r=-0.77 to 0.57, N=3) among 6 players (r=-0.85 to 0.83, p<0.05). At the group level, significant correlations were found between CMJ0 JH and PPC (p<0.001, r=0.34), MPC (p<0.001, r=0.40), EB (p=0.005, r=0.22), and OR(p<0.001, r=0.37) (Table 3.4). Additionally, moderate correlations were observed between CMJ0 JH and MS (p<0.001, r=-0.40), LA(p=0.001, r=-0.26), NES (p<0.001, r=-0.29), and OS (p=0.007, r=-0,21).

Figure 3.9 to 3.11 illustrates individual and group correlation and 95% CI between CMJ20 and Pre SRSS (Table 3.5). Among 8 players, several moderate to very large correlations were found between CMJ20 kinetic variables and PPC (p<0.05, r=-0.70 to -0.61, N=2), MPC (p<0.05, r=-0.74 to 0.63, N=3), EB (p=0.05, r=0.58, N=1 (ID7)), and OR (p<0.05, r=-0.80 to 0.68, N=4). Large to very large correlations were also found between CMJ20 kinetic variables and MS (p<0.05, r=0.56 to 0.63,N=3), LA (p<0.05, r=0.58 to 0.72, N=1), NES (p<0.05, r=-0.76 to 0.59, N=3), and OS (p<0.05, r=0.58 to 0.80, N=3) among 6 players. At the group level, CMJ20 JH was correlated to PPC (p<0.001, r=-0.32), MPC (p<0.001, r=0.44), EB (p<0.001, r=0.28), OR (p=0.001, r=0.25), LA (p<0.001, r=-0.27), and NES (p<0.001, r=-0.32).

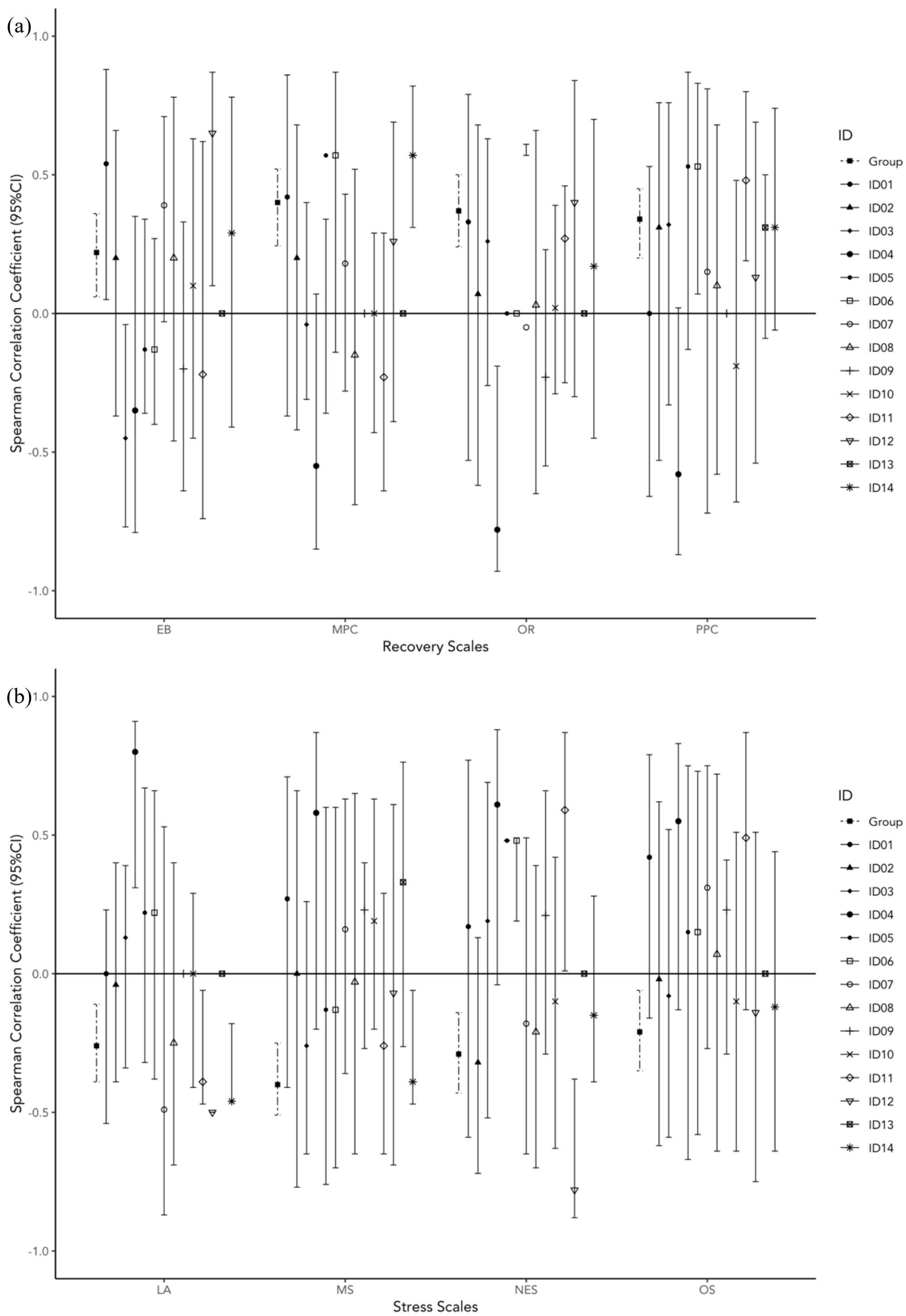

Figure 3.6. Individual and group correlation between unloaded countermovement jump height and Recovery Scales (a) and (b) Stress Scales (b). Dots with error bars represent a Spearman correlation coefficient and 95% confidence intervals (CI; lower and upper limits).

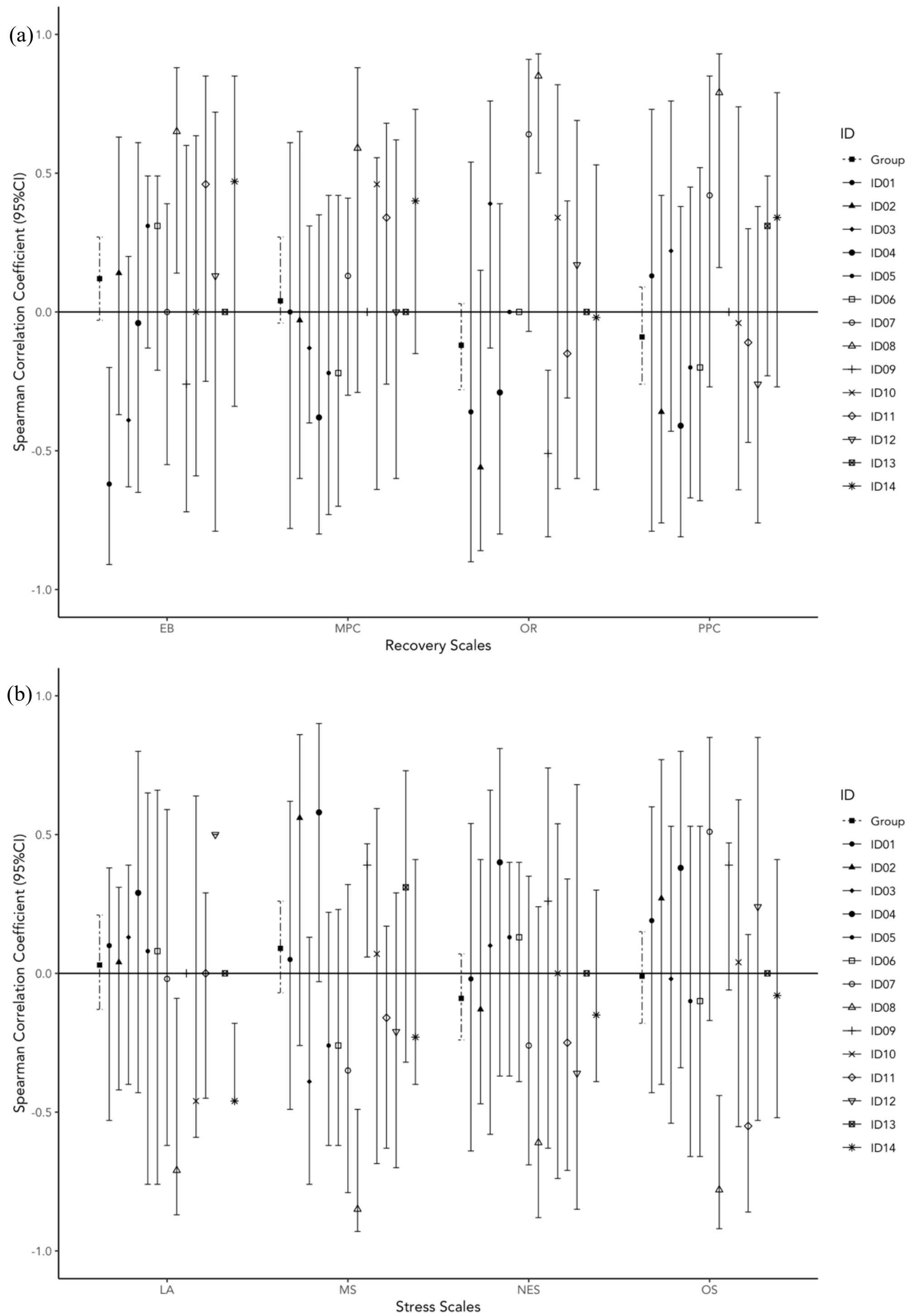

Figure 3.7. Individual and group correlation between unloaded countermovement jump peak force and Recovery Scales (a) and (b) Stress Scales (b). Dots with error bars represent a Spearman correlation coefficient and 95% confidence intervals (CI; lower and upper limits).

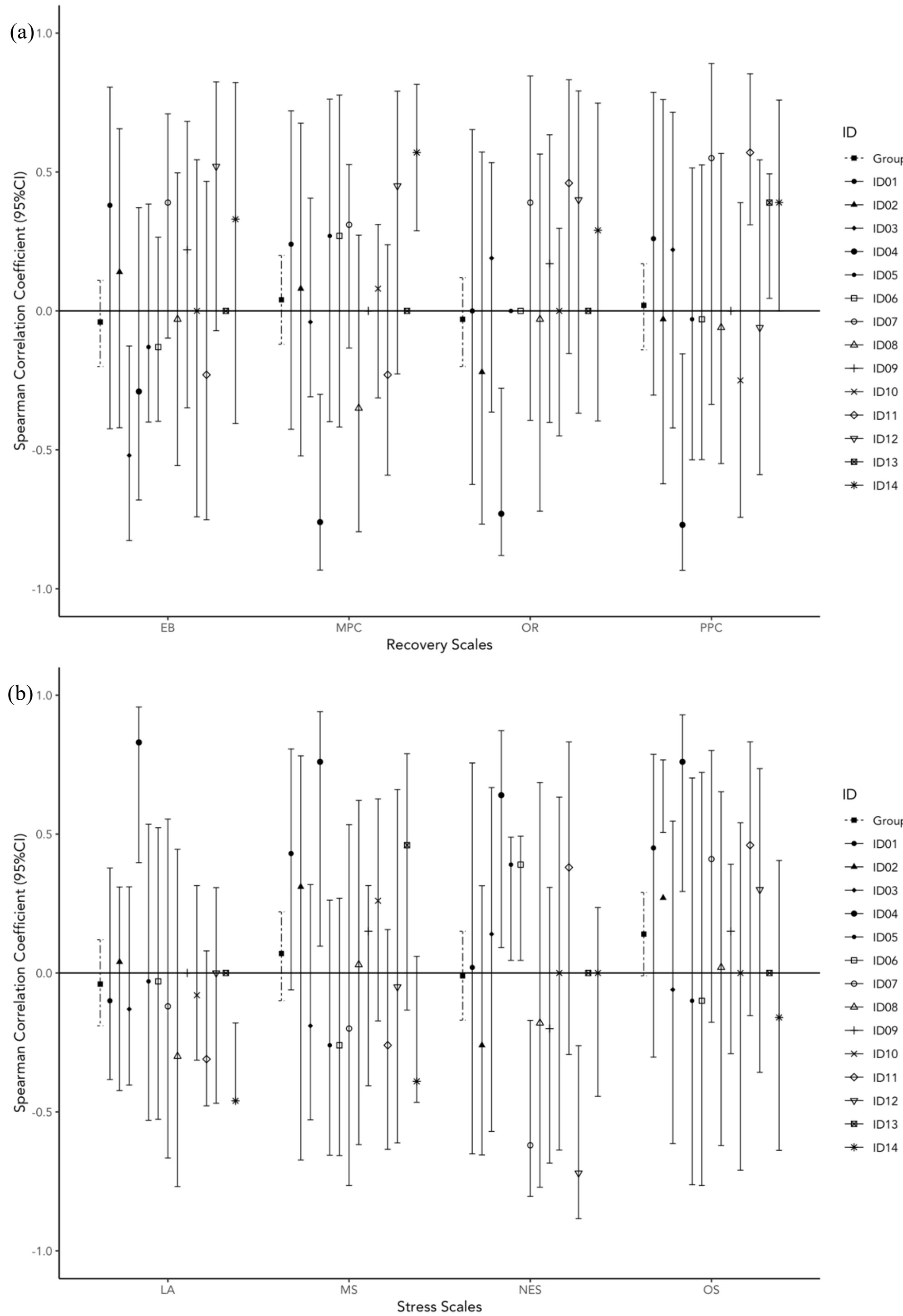

Figure 3.8. Individual and group correlation between unloaded countermovement jump peak power and Recovery Scales (a) and (b) Stress Scales (b). Dots with error bars represent a Spearman correlation coefficient and 95% confidence intervals (CI; lower and upper limits).

Table 3.4. Individual correlation between countermovement jump and short recovery stress scale

Item	Jump Height		Peak force		Peak power	
	Min, Max	*p*<0.05	Min, Max	*p*<0.05	Min, Max	*p*<0.05
CMJ0						
PPC	-0.58, 0.53	None	-0.41, 0.79	-0.41^{ID04},0.79^{ID8}	-0.77, 0.57	$-0,77^{ID04}$,0.57^{ID11}
MPC	-0.55, 0.57	0.57^{ID14}	-0.38, 0.59	0.59^{ID05}	-0.76, 0.57	-0.76^{ID04},0.57^{ID14}
EB	-0.45, 0.65	0.65^{ID12}	-0.61, 0.65	-0.62^{ID01},0.65^{ID08}	-0.51, 0.52	None
OR	-0.78, 0.40	-0.78^{ID04}	-0.56, 0.85	0.64^{ID07},0.85^{ID08}	-0.73, 0.46	-0.73^{ID04}
MS	-0.39, 0.58	None	-0.85, 0.58	-0.85^{ID08}	-0.38, 0.76	0.76^{ID04}
LA	-0.50, 0.80	0.80^{ID04}	-0.71, 0.50	-0.71^{ID08}	-0.46, 0.83	0.83^{ID04}
NES	-0.78, 0.61	-0.78^{ID12},0.59^{ID11}, 0.61^{ID04}	-0.61, 0.40	-0.61^{ID08}	-0.72, 0.64	-0.72^{ID12},-0.62^{ID07}, 0.64^{ID04}
OS	-0.14, 0.55	None	-0.78, 0.51	-0.78^{ID08}	-0.16, 0.76	0.76^{ID04}
CMJ20						
PPC	-0.51, 0.48	None	-0.70, 0.52	-0.70^{ID06},-0.61^{ID04}	-0.70, 0.48	-0.70^{ID04}
MPC	-0.52, 0.63	0.57^{ID14},0.63^{ID01}	-0.66, 0.63	-0.66^{ID4},0.63^{ID11}	-0.74, 0.57	-0.74^{ID04},0.57^{ID14}
EB	-0.32, 0.53	None	-0.26, 0.27	None	-0.35, 0.58	0.58^{ID07}
OR	-0.50, 0.37	None	-0.80, 0.68	-0.80^{ID05}, -0.61^{ID04}, 0.68^{ID07}	-0.72, 0.23	-0.72^{ID05},-0.57^{ID04}
MS	-0.39, 0.48	None	-0.41, 0.61	0.61^{ID04},0.61^{ID05}	-0.26, 0.63	0.63^{ID04},0.63^{ID10}
LA	-0.46,0.58	0.58^{ID04}	-0.46,0.59	0.59^{ID04}	-0.46,0.72	0.72^{ID05}
NES	-0.37,0.59	0.59^{ID11}	-0.60,0.46	-0.60^{ID01}	-0.76,0.58	-0.76^{ID07},0.58^{ID04}
OS	-0.20, 0.52	None	-0.47, 0.80	0.66^{ID04},0.80^{ID05}	-0.22, 0.74	0.59^{ID11},0.72^{ID05}, 0.74^{ID04}

Note. CMJ0=Countermovement jump with a polyvinyl chloride pipe. PPC=Physical Performance Capacity. MPC=Mental Performance Capacity. EB=Emotional Balance. OR=Overall Recovery. MS=Muscle Stress. LA=Lack of Activation. NES=Negative Emotional State. OS=Overall Stress. CMJ20=Countermovement jump with a 20kgs bar. *=denotes p<0.05. $=denotes p<0.001.

Table 3.5. Group correlation between countermovement jump and short recovery stress scale

Items	Jump height	Peak force	Peak power
CMJ0			
PPC	0.34$ (0.20, 0.45)	-0.09 (-0.26, 0.09)	0.02 (-0.14, 0.17)
MPC	0.40$ (0.24, 0.52)	0.04 (-0.04, 0.27)	0.04 (-0.12, 0.20)
EB	0.22$ (0.06, 0.36)	0.12 (-0.03, 0.27)	-0.04 (-0.20, 0.11)
OR	0.37$ (0.24, 0.50)	-0.12 (-0.28, 0.03)	-0.03 (-0.20, 0.12)
MS	-0.40$ (-0.40, -0.25)	0.09 (-0.07, 0.26)	0.07 (-0.10, 0.22)
LA	-0.26$ (-0.39, -0.11)	0.03 (-0.13, 0.21)	-0.04 (-0.19, 0.12)
NES	-0.29$ (-0.43, -0.14)	-0.09 (-0.24, 0.07)	-0.01 (-0.17, 0.15)
OS	-0.21$ (-0.35, -0.06)	-0.01 (-0.18, 0.15)	0.14 (-0.01, 0.29)
CMJ20			
PPC	0.32$ (0.20, 0.43)	-0.19* (-0.34, -0.03)	0.04 (-0.09, 0.17)
MPC	0.44$ (0.20, 0.55)	-0.06 (-0.03, 0.27)	0.10 (-0.05, 0.24)
EB	0.28$ (0.14, 0.41)	0.06 (-0.10, 0.20)	0.04 (-0.10, 0.18)
OR	0.25$ (0.10, 0.37)	-0.14 (-0.28, 0.00)	-0.14 (-0.26, -0.01)
MS	-0.29$ (-0.42, -0.16)	0.18* (0.02, 0.32)	0.11 (-0.03, 0.24)
LA	-0.27$ (-0.39, -0.12)	0.13 (-0.02, 0.29)	0.02 (-0.13, 0.24)
NES	-0.32$ (-0.44, -0.17)	-0.05 (-0.19, 0.11)	-0.07 (-0.21, 0.06)
OS	-0.14 (-0.28, -0.01)	0.06 (-0.11, 0.20)	0.15 (0.02, 0.27)

Note. CMJ0=Countermovement jump with a polyvinyl chloride pipe. PPC=Physical Performance Capacity. MPC=Mental Performance Capacity. EB=Emotional Balance. OR=Overall Recovery. MS=Muscle Stress. LA=Lack of Activation. NES=Negative Emotional State. OS=Overall Stress. CMJ20=Countermovement jump with a 20kgs bar. *=denotes $p<0.05$. $=denotes $p<0.001$. Value is expressed as Spearman correlation coefficient and 95% confidence interval (lower limit, upper limit).

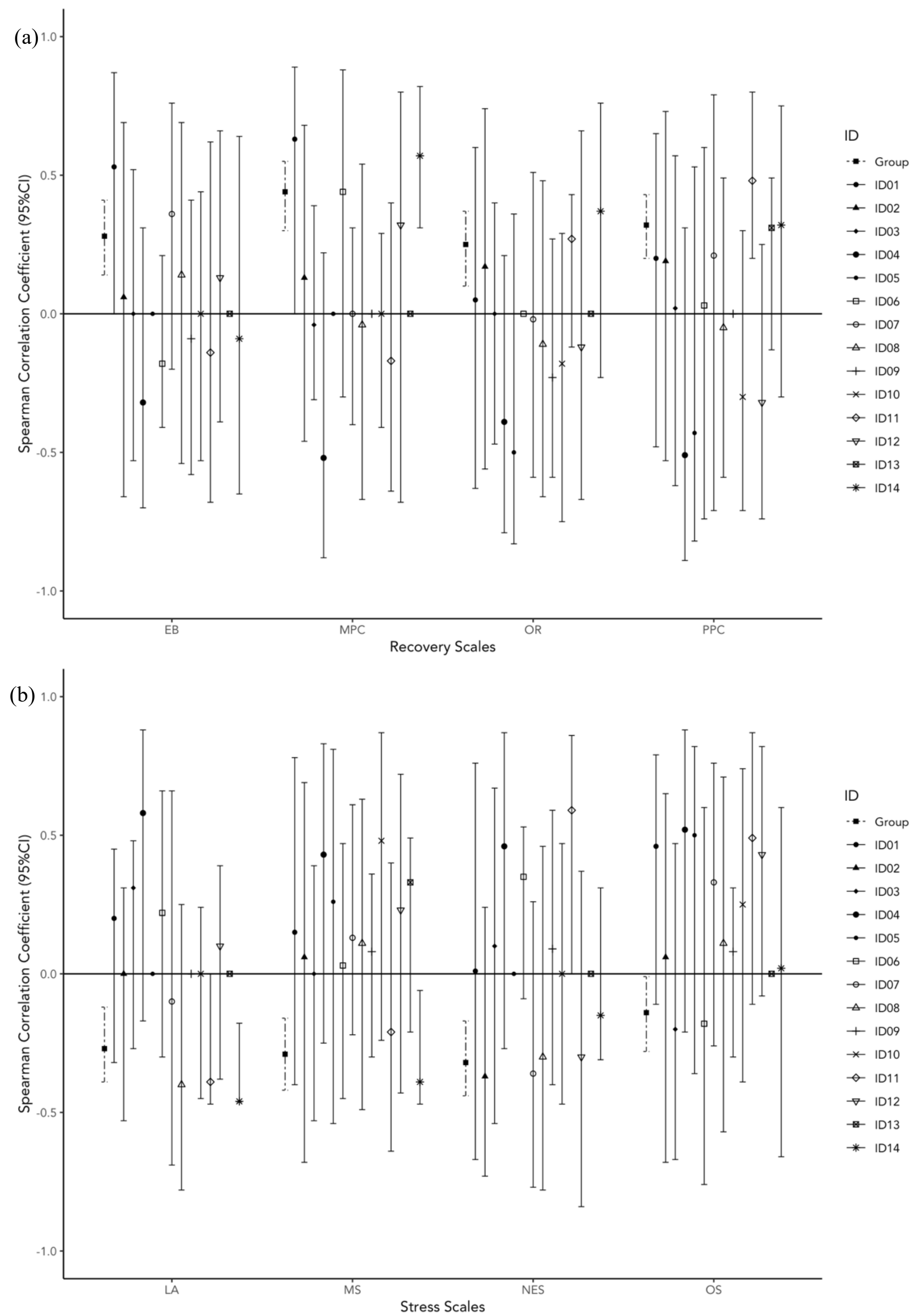

Figure 3.9. Individual and group correlation between loaded countermovement jump height and Recovery Scales (a) and (b) Stress Scales (b). Dots with error bars represent a Spearman correlation coefficient and 95% confidence intervals (CI; lower and upper limits).

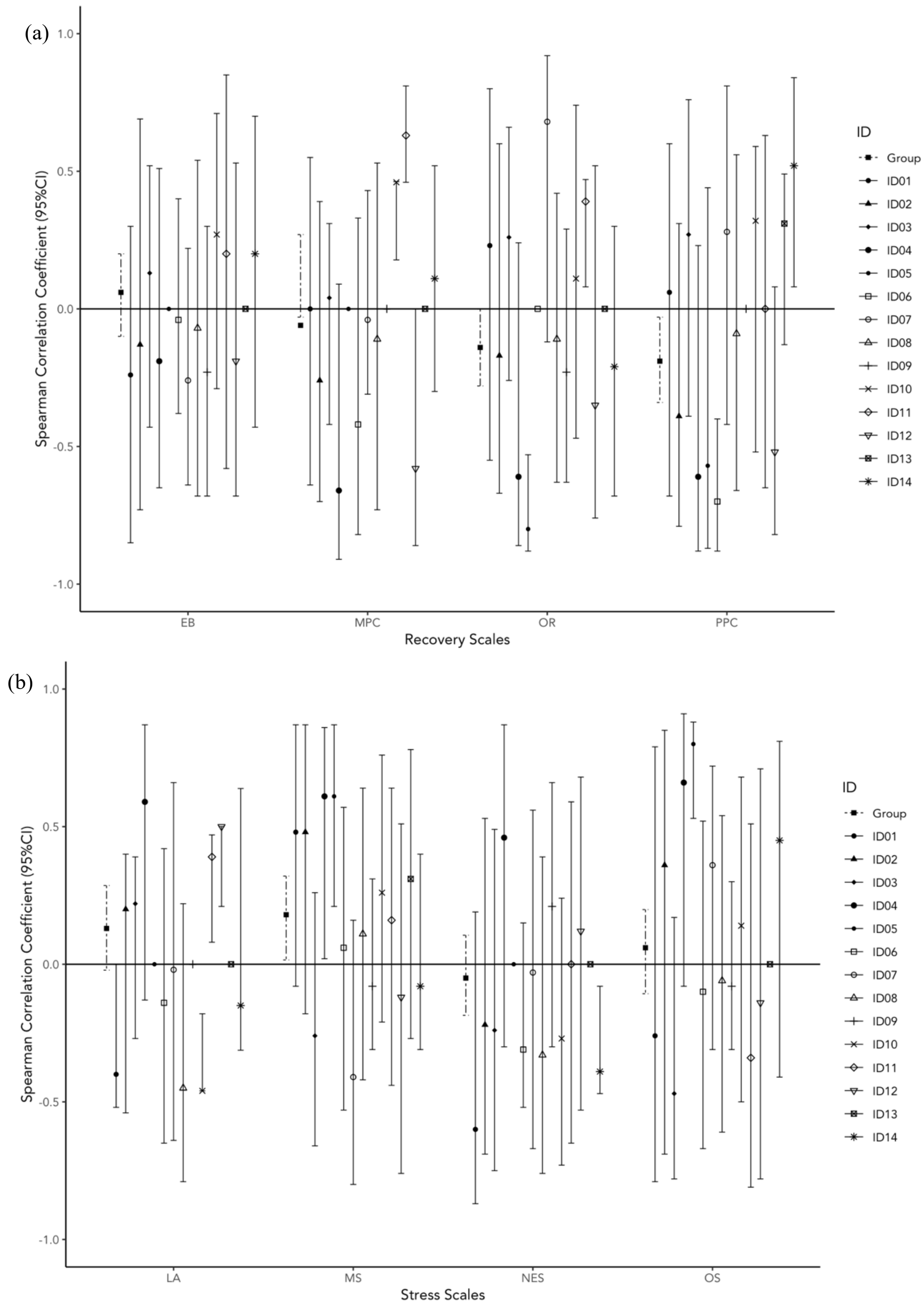

Figure 3.10. Individual and group correlation between loaded countermovement jump peak force and Recovery Scales (a) and (b) Stress Scales (b). Dots with error bars represent a Spearman correlation coefficient and 95% confidence intervals (CI; lower and upper limits).

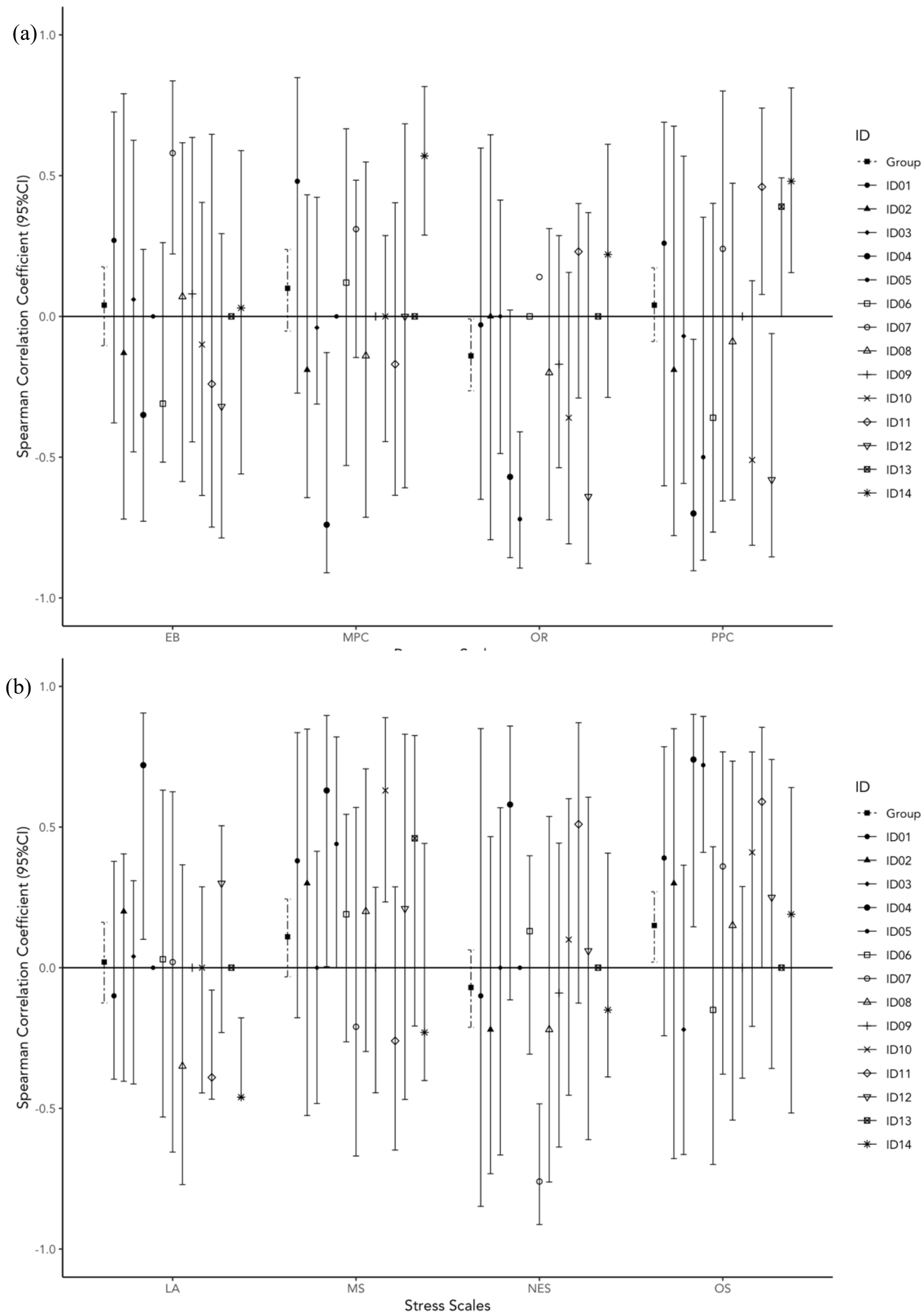

Figure 3.11. Individual and group correlation between loaded countermovement jump peak power and Recovery Scales (a) and (b) Stress Scales (b). Dots with error bars represent a Spearman correlation coefficient and 95% confidence intervals (CI; lower and upper limits).

DISCUSSION

The purpose of this study was to quantify the relationships between match-derived TLs and the changes from Pre to Post in SRSS and between Pre SRSS and CMJ kinetics in Division I female soccer players at the individual and group level. This is an explanatory study, and the main findings were (a) individualized analysis showed stronger correlations between match-derived TLs and the changes in SRSS than group analysis although variation in individual correlations existed, (b) the physical-related subscales changed largely in relation to soccer match-derived TLs at individual and group levels compared to psychological-related scales, and (c) positive and negative correlations were found between Pre SRSS and CMJ at individual and group levels. Our findings indicate that the magnitude of correlations between TLs, subjective recovery and stress state, and neuromuscular performance at individual levels are stronger than the group level. Our findings also confirmed that assessing individual athlete subjective recovery and stress state may be useful to quantify the response to soccer match-derived TLs.

At both individual and group levels, significant correlations were found between match-derived TLs and SRSS changes. Similar to previous literature (9,30,31,40), our study confirms that subjective recovery and stress state decreased corresponding to TLs. For instance, Pelka et al. (30) reported that significant differences were seen between starters and non-starting players in the changes from pre-match to post-match PPC, MPC, OR, MS, and OS (p=0.001). However, our study may suggest that the magnitude of the relationship varied between individual and group analysis with within-athlete variability. Although individual correlations were underpowered relative to group correlations, 11 individual players (ID02, ID03, ID04, ID05, ID06, ID08, ID09, ID10, ID11, ID13, and ID14) had moderate to nearly perfect relationships between match-derived TLs and the changes in RS (r=-0.91 to -0.55) and SS (r=0.63 to 0.82), while the magnitude of the relationship at the group level ranged from trivial to large (RS: r=-0.60 to -0.17; SS: r=-0.23 to 0.55). The difference in magnitude may be explained by the heterogeneous response to exercises (4,6,17). Bartlet et al. (4) demonstrated that the magnitude of the relationship between match-derived TLs and the session rating of perceived exertion varies at an individual level. Additionally, three players (ID01, ID07, and ID12) showed small to moderate correlations between match-derived TL and the changes in RS (r=-0.49 to 0.44) and SS (r= -0.52 to 0.56). Specifically, the individual correlations in ID 01 and ID12 may be weaker than other individual players due to limited match playing time. The two players are non-starters and could accumulate less TLs than other players. In addition to group level analysis, assessing individual relationships between soccer-match derived TLs and subjective recovery and stress state may be warranted in conjunction with group analysis due to heterogeneous responses.

Of importance, 12 individual players demonstrated moderate to strong correlations between the changes in one subscale of SRSS and match-derived total distance at an individual level. At a group level, the correlation also showed stronger magnitudes (RS: r=-0.60 to -0.46; SS: r=0.21 to 0.55) than other match-derived TLs (RS: r=-0.52 to -0.17; SS: r=0.16 to 0.57). Additionally, all the players demonstrated positive correlations between Pre-Post MS and total distance (r=0.21 to 0.82). Therefore, it seems that the total distance of soccer match-play could consistently relate to the changes in MS. Our finding may be supported by the finding by Bartlett et al. (4), which indicates that total distance was the strongest predictor of the rating of perceived exertion (relative importance=0.49) at an individual level. The authors also reported that total distance was the main predictor of the rating of perceived exertion among 36 of 41 players. Although limited data are available, it may be possible that total distance has more influence on MS compared to other GNSS derived variables.

The SRSS was designed to measure the current athlete's psychophysical recovery and stress state with 8 multidimensional items regarding emotional, mental, physical, and overall levels (18). Interestingly, changes in the physical-related SRSS subscales such as PPC, OR, MS, and OS were more strongly related to soccer match-derived volume-related TLs (i.e., total distance and total PlayerLoad) than psychological-related subscales (MPC, EB, LA, and NES) at individual and group levels. At the group level, weak to large correlations were found between the physical-related SRSS (PPC: r=-0.46; OR: r=-0.60; MS: r=0.55; OS: r=0.36) and total PlayerLoad (PPC: r=-0.38; OR: r=-0.52; MS: r=0.47; OS: r=0.33), while the psychological-related scales were weak to moderately correlated with match-derived total distance (MPC: r=-0.38; EB: r=-0.40; LA: r=0.32; NES: r=0.21) and total PlayerLoad (MPC: r=-0.31; EB: r=-0.42; LA: r=0.28; NES: r=0.25). Although all the SRSS items are perceptual, previous literature (30,40) agrees with our finding that physical-related SRSS subscales can be greatly affected by an acute TL when compared to psychological-related subscales. For example, Wiewelhove et al. (40) demonstrated that physical-related scales showed large to very large changes (ES= 1.79 to 3.36) in response to 7 interval training sessions while the magnitude of change for psychological-related scales ranged from small to large (ES=0.45 to 1.34). Therefore, it may be possible that perceptual physical-related scales may be more sensitive to acute TL of soccer match-play than the psychological-related scales.

Our study confirms that large between-athlete variability exists in the relationship between Pre-SRSS and CMJ variables at an individual level. The 95% CI in the group partially included individual correlations, and the direction of the correlation was not consistent between individual and group analysis (Figure 3.6 to Figure 3.11). For example, the group correlation was positive between MPC and CMJ0 JH while the 4 individual players (ID03, ID04, ID08, and

ID11) showed negative correlations. The inconsistency between the individual and group correlations may be supported by the current evidence regarding the relationship between subjective recovery and stress state and neuromuscular performance (22,36). Lombard et al. (22) found that no significant differences were found between in CMJ PF and JH between baseline, 24 hours, and 48 hours after a multi-stage shuttle run test, although the subjective ratings of muscle soreness remained lower at 48 hours compared to baseline. The evidence (22,36) and our findings support that group correlations do not necessarily agree with individual correlations.The disagreement between our findings and previous research (5,10,34,38) may be explained by the mode of performance testing. CMJ was chosen as a performance test in our study, Lombard et al. (22), and Tavares et al. (36), while the study by Grove et al. (10) used endurance swimming performance as the performance test. Additionally, our study confirmed that the direction of individual and group correlations was not consistent between CMJ and Pre-SRSS. Based on the evidence from our findings and the current literature (10,22,34,36), it may be possible that SRSS subscales do not correspond to meaningful neuromuscular performance changes at individual and group levels.

There are several limitations to our study. First, physiological measures such as blood and saliva were not collected. This data may have provided additional insights into what factors specifically influenced the changes in SRSS after soccer match-play. Second, the sample size of this study was limited. The group of only 14 Division I female soccer might be underpowered, limiting the ability to detect significant correlations at an individual level.

In conclusion, the results of this study indicate match-derived TL was significantly correlated with subjective recovery and stress state at individual and group levels. The magnitude of the correlations at the individual level was stronger and weaker than the group level. Our findings also demonstrated a heterogeneous relationship between match-derived TLs, CMJ variables, and the ratings of subjective recovery and stress state. Based on our findings, total distance of soccer match-play may be strongly related to the changes in subjective recovery and stress state at both individual level in conjunction with group levels.

PRACTICAL APPLICATION

This study highlights the importance of individualized analyses to assess the relationship between match-derived TL and the ratings of subjective recovery. The individual relationship between match-derived TL and the ratings of subjective recovery may not be reflective of the group relationship due to heterogeneity and playing status. The direction of the correlations may also be inconsistent between individual and group analysis. Therefore, individualized analyses may be warranted in addition to group analyses to aid training plans and match preparation in soccer players. Additionally, this study indicates that subjective recovery and stress state may not be an appropriate indicator of physical preparedness in soccer players.

REFERENCES

1. Agel, J and Schisel, J. Practice injury rates in collegiate sports. *Clin J Sport Med* 23: 33–38, 2013.

2. Andersson, HA, Raastad, T, Nilsson, JE, Paulsen, G, Garthe, I, and Kadi, F. Neuromuscular fatigue and recovery in elite female soccer: effects of active recovery. *Med Sci Sports Exerc* 40: 372–380, 2008.

3. Bagger, M, Petersen, PH, and Pedersen, PK. Biological variation in variables associated with exercise training. *Int J Sports Med* 24: 433–440, 2003.

4. Bartlett, JD, O'Connor, F, Pitchford, N, Torres-Ronda, L, and Robertson, SJ. Relationships between internal and external training load in team-sport athletes: Evidence for an individualized approach. *Int J Sports Physiol Perform* 12: 230–234, 2017.

5. Beedie, CJ, Terry, PC, and Lane, AM. The profile of mood states and athletic performance: Two meta-analyses. *Journal of Applied Sport Psychology* 12: 49–68, 2000.

6. Bouchard, C and Rankinen, T. Individual differences in response to regular physical activity. *Med Sci Sports Exerc* 33: S446-51, 2001.

7. Chavda, S, Bromley, T, Jarvis, P, Williams, S, Bishop, C, Turner, AN, et al. Force-time characteristics of the countermovement jump: analyzing the curve in excel. *Strength Cond J* 40: 67–77, 2018.

8. Claudino, JG, Cronin, J, Mezêncio, B, McMaster, DT, McGuigan, M, Tricoli, V, et al. The countermovement jump to monitor neuromuscular status: A meta-analysis. *J Sci Med Sport* 20: 397–402, 2017.

9. Collette, R, Kellmann, M, Ferrauti, A, Meyer, T, and Pfeiffer, M. Relation between training load and recovery-stress state in high-performance swimming. *Front Physiol* 9: 1–14, 2018.

10. Grove, JR, Main, LC, Partridge, K, Bishop, DJ, Russell, S, Shepherdson, A, et al. Training distress and performance readiness: laboratory and field validation of a brief self-report measure. *Scand J Med Sci Sports* 24: e483-490, 2014.

11. Hader, K, Rumpf, MC, Hertzog, M, Kilduff, LP, Girard, O, and Silva, JR. Monitoring the athlete match response: can external load variables predict post-match acute and residual fatigue in soccer? a systematic review with meta-analysis. *Sports Medicine - Open* 5: 48, 2019.

12. Hitzschke, B, Wiewelhove, T, Raeder, C, Ferrauti, A, Meyer, T, Pfeiffer, M, et al. Evaluation of psychological measures for the assessment of recovery and stress during a shock-microcycle in strength and high-intensity interval training. *Performance Enhancement & Health* 5: 147–157, 2017.

13. Hopkins, WG. Measures of reliability in sports medicine and science. *Sports Med* 30: 1–15, 2000.

14. Hopkins, WG, Marshall, SW, Batterham, AM, and Hanin, J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 41: 3–13, 2009.

15. de Hoyo, M, Cohen, DD, Sañudo, B, Carrasco, L, Álvarez-Mesa, A, Del Ojo, JJ, et al. Influence of football match time-motion parameters on recovery time course of muscle damage and jump ability. *J Sports Sci* 34: 1363–1370, 2016.

16. Katch, VL, Sady, SS, and Freedson, P. Biological variability in maximum aerobic power. *Med Sci Sports Exerc* 14: 21–25, 1982.

17. Kellmann, M and Kölling, S. Recovery and stress in sport: A manual for testing and assessment. Abingdon, UK: Routledge, 2019.

18. Kinugasa, T, Cerin, E, and Hooper, S. Single-subject research designs and data analyses for assessing elite athletes' conditioning. *Sports Med* 34: 1035–1050, 2004.

19. Kölling, S, Hitzschke, B, Holst, T, Ferrauti, A, Meyer, T, Pfeiffer, M, et al. Validity of the acute recovery and stress scale: training monitoring of the german junior national field hockey team. *Int J Sports Sci Coach* 10: 529–542, 2015.

20. Koo, TK and Li, MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J Chiropr Med* 15: 155–163, 2016.

21. Lombard, W, Starling, L, Wewege, L, and Lambert, M. Changes in countermovement jump performance and subjective readiness-to-train scores following a simulated soccer match. *Eur J Sport Sci* 1–9, 2020.

22. McLellan, CP, Lovell, DI, and Gass, GC. Markers of postmatch fatigue in professional Rugby League players. *J Strength Cond Res* 25: 1030–1039, 2011.

23. Nässi, A, Ferrauti, A, Meyer, T, Pfeiffer, M, and Kellmann, M. Development of two short measures for recovery and stress in sport. *Eur J Sport Sci* 17: 894–903, 2017.

24. Nedelec, M, McCall, A, Carling, C, Legall, F, Berthoin, S, and Dupont, G. The influence of soccer playing actions on the recovery kinetics after a soccer match. *J Strength Cond Res* 28: 1517–1523, 2014.

25. Nicol, C, Avela, J, and Komi, PV. The stretch-shortening cycle: a model to study naturally occurring neuromuscular fatigue. *Sports Med* 36: 977–999, 2006.

26. Nicolella, DP, Torres-Ronda, L, Saylor, KJ, and Schelling, X. Validity and reliability of an accelerometer-based player tracking device. *PLoS ONE* 13: 1–13, 2018.

27. Nikolaidis, PT, Clemente, FM, van der Linden, CMI, Rosemann, T, and Knechtle, B. Validity and reliability of 10-Hz global positioning system to assess in-line movement and change of direction. *Front Physiol* 9: 1–7, 2018.

28. Oliver, J, Armstrong, N, and Williams, C. Changes in jump performance and muscle activity following soccer-specific exercise. *J Sports Sci* 26: 141–148, 2008.

29. Pelka, M, Schneider, P, and Kellmann, M. Development of pre- and post-match morning recovery-stress states during in-season weeks in elite youth football. *Science and Medicine in Football* 2: 127–132, 2018.

30. Raeder, C, Wiewelhove, T, Simola, RÁDP, Kellmann, M, Meyer, T, Pfeiffer, M, et al. Assessment of fatigue and recovery in male and female athletes after 6 days of intensified strength training. *J Strength Cond Res* 30: 3412–3427, 2016.

31. Sands, W, Cardinale, M, McNeal, J, Murray, S, Sole, C, Reed, J, et al. Recommendations for measurement and management of an elite athlete. *Sports (Basel)* 7, 2019.

32. Saw, AE, Kellmann, M, Main, LC, and Gastin, PB. Athlete self-report measures in research and practice: considerations for the discerning reader and fastidious practitioner. *Int J Sports Physiol Perform* 12: S2127–S2135, 2017.

33. Saw, AE, Main, LC, and Gastin, PB. Monitoring the athlete training response: subjective self-reported measures trump commonly used objective measures: a systematic review. *Br J Sports Med* 50: 281–291, 2016.

34. Scott, MTU, Scott, TJ, and Kelly, VG. The validity and reliability of global positioning systems in team sport: A brief review. *J Strength Cond Res* 30: 1470–1490, 2016.

35. Tavares, F, Healey, P, Smith, TB, and Driller, M. The effect of training load on neuromuscular performance, muscle soreness and wellness during an in-season non-competitive week in elite rugby athletes. *J Sports Med Phys Fitness* 58: 1565–1571, 2018.

36. Thorpe, RT, Atkinson, G, Drust, B, and Gregson, W. Monitoring fatigue status in elite team-sport athletes: implications for practice. *Int J Sports Physiol Perform* 12: S227–S234, 2017.

37. Travis, SK, Mizuguchi, S, Stone, MH, Sands, WA, and Bazyler, CD. Preparing for a National Weightlifting Championship: A Case Series. *J Strength Cond Res* 34: 1842–1850, 2020.

38. Walker, AJ, McFadden, BA, Sanders, DJ, Rabideau, MM, Hofacker, ML, and Arent, SM. Biomarker response to a competitive season in division I female soccer players. *J Strength Cond Res* 33: 2622–2628, 2019.

39. Wiewelhove, T, Raeder, C, Meyer, T, Kellmann, M, Pfeiffer, M, and Ferrauti, A. Effect of repeated active recovery during a high-intensity interval-training shock microcycle on markers of fatigue. *Int J Sports Physiol Perform* 11: 1060–1066, 2016.

40. Wiig, H, Raastad, T, Luteberget, LS, Ims, I, and Spencer, M. External load variables affect recovery markers up to 72 h after semiprofessional football matches. *Front Physiol* 10: 689, 2019.

Chapter 4. Study II

Title: Acute Effects of Match-Play on Neuromuscular and Subjective Recovery and Stress State in Division I Collegiate Female Soccer

Authors: Ai Ishida[1], Caleb D. Bazyler[1], Adam Sayers[2], Satoshi Mizuguchi[1], Jeremy A. Gentles[1]

Affiliations: [1]Center of Excellence for Sport Science and Coach Education, East Tennessee State University

[2]Department of Sport, Exercise, Recreation, and Kinesiology East Tennessee State University, Johnson City, TN.

Formatted as published in Journal of Strength and Conditioning Research.

ABSTRACT

The purpose of this study was to investigate acute effects of match-play on neuromuscular performance and subjective recovery and stress state and the relationship between the training load (TL) and changes in neuromuscular performance in female soccer players. The Thirteen National Collegiate Athlete Association Division I players participated (20.7±2.3yrs; 64.4±7.2kg; 164.5±6.0cm) and completed countermovement jump (CMJ) at 0kg (CMJ0) and 20kg CMJ20) and the Short Recovery Stress Scale (SRSS) at 3 hours pre-match (Pre), 12 hours post-match (Post12), and 38 hours post-match (Post38). CMJ variables included body mass (BdM), jump height (JH), modified reactive strength index (RSI), peak force (PF), relative peak force (RPP), eccentric impulse (EI), concentric impulse (CI), peak power (PP), relative peak power (RPP), eccentric average peak power (EAP), and concentric average power (CAP). SRSS consists of 4 Stress Scales (SS) and 4 Recovery Scales (RS) . TLs included total distance, total PlayerLoad, high-speed running, and session ratings of perceived exertion. Significant moderate to large decreases were observed from Pre to Post12 in JH, RSI, CI, PP, RPP, and CPA in CMJ0 and CMJ20 ($p<0.05$, ES=0.63 to 1.35). Significant changes were observed from Pre to Post12 in all RS ($p<0.05$, ES=0.65 to 0.79) and 3 SS ($p<0.05$, ES=0.71 to 0.77). Significant correlations were observed between CMJ20 PP from Pre to Post12 and all TLs ($p<0.05$, r=-0.58 to -0.68). CMJ JH and PP may indicate acute neuromuscular changes after match-play. Pre to Post12 changes in CMJ20 PP may be affected by soccer match-play volumes.

Key Words: fatigue monitoring; female soccer players; dose-response relationship

INTRODUCTION

Soccer is one of the most popular sports and is played by men and women at different competitive levels. A soccer team consists of 11 players and is played on a field of 90-120m long and 45-90m wide. Soccer is characterized as an intermittent physical activity due to the combination of repeated and prolonged sprints and walking, jogging, jumping, kicking, heading, and changing directions. The physical demands of soccer match-play may acutely reduce performance and cause muscle damage and fatigue as indicated by a variety of physiological, biomechanical, and performance measures (1,18). For example, Andersson et al. (1) found that statistically increased creatine kinase (CK), reduced countermovement jump (CMJ) height, and increased uric acid were observed 21 hours after match-play in elite female soccer players.

In the National Collegiate Athletic Association (NCAA) Division I women's soccer, players are required to play approximately 20 to 25 matches over 12 to 14 weeks, which is equivalent to 1-2 matches per week. Previous literature has indicated that at least 48 to 72 hours should be allowed between matches to provide sufficient recovery for neuromuscular performance (1,26) and mitigate injury risk (5). According to Rollo and colleagues (26), playing 2 soccer matches per week (72 hours interval between matches) significantly decreased sprint, jump, intermittent endurance performances at 6 weeks post-baseline compared to playing 1 match per week ($p<0.05$). Considering the neuromuscular performance decrements and increased injury risk <48 hours after a match, some conferences in the NCAA Division I female soccer do not provide a sufficient recovery interval between matches when 2 matches are allocated per week. The undesirable match schedules are a product of the NCAA educational and athletic regulations (i.e., NCAA student-athletes can participate in athletic-related activities for less than 20 hours per week during a competitive season).

Countermovement jump is a vertical jump performed after flexing lower limb joints and is a common performance assessment. CMJ includes the stretch-shortening cycle (SSC), which is an important component of soccer-specific movements such as sprinting, jumping, kicking, and changing directions. The repeated loading associated with soccer-specific locomotion during match-play causes mechanical and structural damage (i.e., delayed onset of muscle soreness, elevated creatine kinase levels, etc.), which impairs an athletes' ability to generate force post-match play (19). CMJ testing has served as a useful athlete monitoring tool to assess neuromuscular status (i.e., fatigue and preparedness) in soccer (3,11,18). Based on the findings from previous literature, exercise-induced decrements in CMJ peak power and height were associated with negative changes in neuromuscular status as well as structural and physiological damage (11,18,19). For instance, CMJ height has been shown to be inversely associated with CK concentration 24 hours post-match in elite youth soccer players. Thus, monitoring CMJ kinetic variables can provide sports scientists with insights into neuromuscular fatigue and preparedness in soccer. However, previous literature suggests that CMJ performance change results from the mechanical changes in concentric and eccentric phases (4,13). Kennedy and Drake (13) reported that average power, average impulse, and peak velocity statistically decreased at 24 hours post-baseline after multiple training sessions in rugby players. Therefore, it would be interesting for sports scientists to specify what CMJ variables are affected by an acute dose of training loads (TL) from match-play in soccer.

Short Recovery Stress Scale (SRSS) is a self-reported questionnaire to assess an athlete's subjective recovery and stress state on a daily or weekly basis (12). Measurement of athlete subjective recovery and stress measures are commonly used in competitive team sports due to ease of use and the non-invasive nature of this type of assessment (33). SRSS consists of 8 subscales including Physical Performance Capability (PPC), Mental Performance Capability (MPC), Emotional Balance (EB), Overall Recovery (OR), Muscle Stress (MS;), Lack of Activation (LA), Negative Emotional State (NES), and Overall Stress (OS). The SRSS subscales have been demonstrated to be a valid and reliable evaluation of an athlete's recovery stress state (14,17,36). The SRSS has also shown to be reflective of training loads in soccer. For example, Pelka and colleagues (23) showed that PPC, MPC, OR, MS, LA, and OS were negatively affected by playing duration in elite youth soccer players.

Countermovement jump testing and SRSS are time-efficient monitoring tools that may be used to quantify an athlete's neuromuscular status, subjective recovery, and stress state. As described above, the match schedule of NCAA female soccer is quite demanding and may not provide sufficient recovery between matches. Thus, monitoring an athlete's neuromuscular status and subjective recovery and stress state is useful to maintain their sports performance across a competitive season in the NCAA female soccer. Although the monitoring measures provide worthwhile information to evaluate an athlete's status, limited data are available describing the neuromuscular status and subjective recovery and stress state after soccer match-play in the female soccer players. Additionally, CMJ testing can be used to assess a variety of kinetic variables (i.e., eccentric and concentric rate of force development, eccentric and concentric impulse, etc.), but it is still unknown whether specific variables are better indicators of neuromuscular status in female soccer players. Therefore, the purpose of this study was to investigate the acute effects of a soccer match on neuromuscular performance and athlete's subjective recovery and stress state in Division I collegiate female soccer players. The secondary purpose of this study was to identify the relationship between TLs of match-play and the acute changes in neuromuscular performance.

METHODS

Experimental Approach to the Problem

Neuromuscular performance and athlete's subjective recovery and stress state were measured using CMJ and SRSS. The CMJ and SRSS data were collected at three different times: 3 hours before a match (Pre), 12 hours post-match (Post12), and 38 hours post-match (Post38) (Figure 4.1). All athletes were participating in an ongoing athlete monitoring program and were familiar with CMJ testing and the completion of SRSS. Match-derived TLs were measured using Global Positioning System (GPS) and session ratings of perceived exertion (sRPE). TLs in a pool recovery session 13 hours after the match (Post13) was also measured using sRPE.

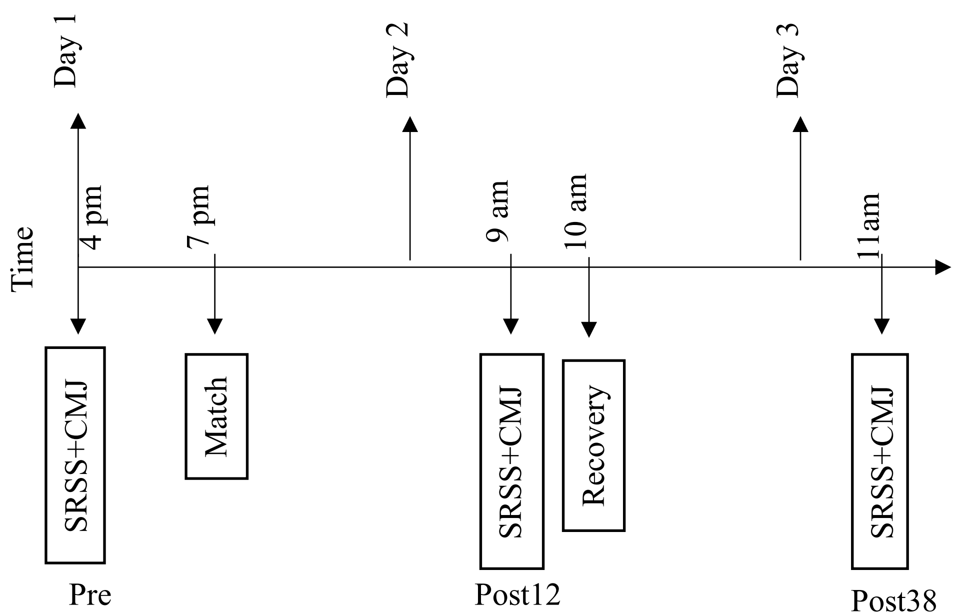

Figure 4.1. Testing Schedule. SRSS=Short Recovery and Stress Scale. CMJ=Countermovement jump. Pre=3 hours before the match. Post12=12 hours after the match. Post13=13 hours after the match. Post38=38 hours after the match.

Subjects

Twelve NCAA Division I female soccer players (age 20.7±2.3; height 164.5±6.0cm; body mass 64.4±7.2kg) participated in this study. Player data was only included for analysis if the player had, 1) played as an outfielder (defender, midfielder or forward), 2) participated in the specific soccer match of interest (sRPE: 720.0±644.6 arbitrary units), 3) completed the recovery session at Post13 (sRPE: 46.3±15.0 arbitrary units), and 4) completed all three testing sessions. All players signed an informed consent, and this study was approved by the univerisities Institutional Review Board.

Methodology

Short Recovery Stress Scale. Short Recovery Stress Scale was used to assess player recovery and stress state using an online-based application (Google Forms, Google, California, US) prior to CMJ testing. SRSS consists of eight subscales including PPC, MPC, EB, OR, MS, LA, NES, and OS (12). Additionally, the subscales are characterized into two groups: Recovery Scale (RS) for PPC, MPC, EB, and OR and Stress Scale (SS) for MS, LA, NES, and OS. Each subscale is rated using a 7-point Likert scale from 0 (does not fully apply) to 6 (fully applies). According to previous literature (17,23), SRSS showed a good internal consistency in recovery and stress items ($\alpha = 0.74$ and $\alpha = 0.78$).

Countermovement Vertical Jump. Players performed a standardized dynamic warm-up, and two submaximal CMJs at 75% and 100% of perceived maximal efforts. The players then performed three maximum CMJ trials with a polyvinyl chloride pipe (CMJ0) and a 20kg barbell (CMJ20) on two portable force plates (PASPORT Force Platform, PASCO, CA, USA) at a sampling frequency of 1,000 Hz. Each load was held across the back of the shoulders. During CMJ testing, players were instructed to stand still on force plates for at least two seconds and then vertically jump after flexing hip, knee, and ankle joints on the command of "3,2,1, jump". Approximately 20s of rest was provided between each jump trial of the same loading condition, and one-minute of rest was given between CMJ0 and CMJ20 conditions. After CMJ testing, the raw kinetic data were analyzed using a custom excel spreadsheet (2). CMJ variables included body mass (BdM; kg), jump height (JH; cm), modified reactive strength index (RSI; $m\bullet s^{-1}$), peak force (PF; N), relative peak (RPF; $N\bullet kg^{-1}$), eccentric impulse (EI; N•s), concentric impulse (CI; N•s), peak power (PP; W), relative peak power (RPP; $W\bullet kg^{-1}$), eccentric average peak power (EAP; W), and concentric average power (CAP; W). RSI was calculated by dividing jump height (m) by time to take off (s) (2). Mean JH and other kinetic variables were calculated using the two jumps with the highest jump height (JH) for each loading condition.

The test-retest reliability of kinetic variables was good to excellent in CMJ0 and CMJ20 JH, RSI, RPF, EI, CI, PP, RPP, and CAP (intraclass correlation coefficient (ICC)=0.76 to 0.97). The coefficient of variation ranged from 2.1% to 10.4%. PF and EAP showed moderate and good test-retest reliability (ICC=0.66 to 0.81) with the CV ranging from 5.3% to 13.2%.

Global Positioning Derived Training Load. Global positioning system (10 Hz) and accelerometry (triaxial; 100 Hz) derived TLs were measured using Catapult Innovation GPS units (Optimeye S5, Catapult Innovation, Melbourne, Australia). According to previous literature (21,31), the validity and reliability of a 10-Hz GPS unit are good to moderate (CV = 1.9% for total distance, CV = 4.7% for high-speed running, and CV= 1.9– 4.3% for running involving accelerations). Players wore the GPS units in a vest worn harness between the shoulder blades.

All units were powered on at least 10 minutes prior to use. Data from all units were transferred into Catapult Innovation software and then summarized in an Excel spreadsheet (Microsoft, Redmond, WA). Match derived TLs data included a warm-up and a match-play. GPS TLs include total distance (m), average speed (m•min-1.), and total distance in high-speed running (HSR; m). HSR was defined as running above 15 km•h^{-1}. Accelerometry derived TLs included Total PlayerLoad expressed in arbitrary units. Total Playerload is defined as the summation of differences of accelerations from the anterior-posterior, medial-lateral, and vertical axes (20).

Session Rating of Perceived Exertion. Participant rating of perceived exertion (RPE) was collected using a modified Borg scale ranging from 0 to 10 in an online-based application (Google Forms, Google, California, US). The RPE measurement was completed 30 minutes after each the match and recovery sessions Session rating of perceived exertion (sRPE) was calculated as the product of RPE and session duration (minutes).

Statistical Analysis

The statistical software RStudio (1.1.463) and the packages dplyr (0.8.5), rstatix(0.4.0), and stats (3.5.3), WRS2 (1.1-0) were used to analyze CMJ and SRSS data. The Shapiro-Wilks test and Mauchly's test were used to assess normality and sphericity. One-way repeated measure ANOVA was used to examine the mean differences of CMJ variables (JH, RSI, PF, EI, PP, EAP, CAP in CMJ0 and CMJ20, RPP in CMJ0, and EAP in CMJ20) between Pre, Post12, and Post38. When data violated the assumption of normality and homoscedasticity (SRSS, CI and EAP in CMJ0, and CI and RPP in CMJ20), robust one-way repeated ANOVA was performed to assess differences between Pre, Post12, and Post38. CMJ variables that violated the assumption of normality include EI, CI, and EAP from CMJ0, and CI and RPP from CMJ20. When necessary, post hoc testing was performed using a Bonferroni correction. A corrected p-value was expressed in the result section. The magnitude of the effect was calculated using Cohen's d_z effect size (ES) t-value divided by the number of participants). Post-hoc test with Bonferroni approach was performed for SRSS and CMJ variables that violated the assumptions. Robust Cohen's dz (ES) was also performed for EI, CI, and EAP from CMJ0, and CI and RPP from CMJ20. ES values were classified as follows; < 0.2=trivial, 0.2–0.6=small, 0.6–1.2=moderate, 1.2–2.0=large, and >2.0=very large (14). The mean individual percentage was calculated in CMJ and SRSS to quantify the differences across Pre, Post12, and Post 38 (Pre-Post12 and Pre-Post38). Additionally, a Pearson or Spearman correlation test was performed to examine the relationship between TLs of match-play or and the changes from Pre to Post12 or Post38 in CMJ kinetic variables (JH, PP, RSI, and PF). A Pearson correlation was classified as follow; r <0.10=trivial, 0.10 ≤ r <0.30=small, 0.30≤ r <0.50=moderate, 0.5≤ r <0.7=large, 0.70≤ r <0.90= very large, 0.90≤ r <1.00= nearly perfect, and 1.0=perfect. All data were expressed as mean ± standard deviation (SD). Statistical significance was set at p<0.05.

RESULTS

Training Loads from Match-Play and Recovery Session

During match play, athletes accumulated a mean PlayerLoad of 905±645au and completed a mean total distance of 10036±5206m and 1049±525m of HSR. The mean sRPE for the match-play and the recovery session was 1045.0±546.5 and 46.7±15.6, respectively.

Changes in Coutnermovment Jump and Short Recovery Stress Scale

Countermovement Jump. Significant moderate to large decreases were observed between Pre and Post12 in CMJ0 JH (*p*=0.02, ES=0.95), RSI (*p*=0.03, ES=0.89),), PP (*p*=0.008, ES=1.10), EI (p= 0.024, ES=0.93), RPP (*p*=0.03, ES=0.91), and CAP (*p*=0.002, ES=1.35) (Table 4.1). Additionally, statistically significant moderate to large decrements were observed in CMJ 20 JH from Pre to Post12 (*p*=0.01, ES=1.05), RSI (*p*=0.01, ES=1.06), EI (*p*=0.049, ES=0.82), PP (*p*=0.005, ES=1.21), and CAP (*p*=0.006, ES=1.15) (Table 4.2). However, no significant differences were seen between Pre and Post38 for all CMJ0 and CMJ20 variables (*p*>0.05).

Table 4.1. Changes in Unloaded Countermovement Jump across Three Days

				Percent Change (ES)	
Variables	**Pre**	**Post12**	**Post38**	**Pre-Post12**	**Pre-Post38**
BdM (kg)	64.4±8.0	63.9±7.9	64.7±8.2	-0.8±1.9 (ES=0.48)	0.5±1.9 (ES=0.28)
JH (cm)	25.4±4.7	22.3±4.5	24.9±4.6	-11.6±12.8*(ES=0.95)	-1.7±6.6(ES=0.30)
RSI ($m•s^{-1}$)	0.29±0.07	0.30±0.06	0.28±0.07	-13.3±14.3*(ES=0.89)	-4.5±12.4(ES=0.36)
PF (N)	739.6±92.8	714.0±66.8	718.2±73.4	-2.7±9.8(ES=0.35)	-2.1±10.1(ES=0.28)
RPF ($N•kg^{-1}$)	11.7±2.1	11.3±1.8	11.3±1.8	-1.8±9.8(ES=0.29)	-2.6±9.8(ES=0.32)
EI (N•s)	74.3±10.9	67.8±10.8	73.9±9.2	-12.3±13.3*(ES=0.93)	1.0±6.2(ES=0.12)
CI (N•s)	143.7±12.9	132.9±12.4	143.1±11.4	-7.3±7.2(ES=0.49)	-0.2±4.9(ES=0.12)
PP (W)	2665.6±154.4	2540.7±156.5	2631.8±164.9	-7.8±7.1$(ES=1.10)	-1.2±3.7(ES=0.34)
RPP ($W•kg^{-1}$)	41.9±5.0	38.7±4.1	41.1±5.0	-7.0±7.8* (ES=0.91)	-1.6±4.2(ES=0.40)
EAP (W)	337.9±68.3	327.1±72.0	331.6±58.6	-2.4±13.8(ES=0.13)	2.2±19.8 (ES=0.05)
CAP (W)	1379.4±104.0	1232.3±105.0	1342.9±109.7	-10.4±7.4$(ES=1.35)	-2.6±4.8(ES=0.55)

Note. Pre=3 hours before the match. Post12=12 hours after the match. Post38=38 hours after the match. BdM=Body mass. JH=Jump height. RSI=Modified reactive strength index. PF=Peak force. EI=Eccentric impulse. CI=Concentric impulse. RPF=Relative peak force. PP=Peak power. RPP=Relative peak force. EAP=Eccentric average power. CAP=Concentric average power. *=denotes corrected *p*<0.05. $=denotes corrected *p*<0.01.

Table 4.2. Changes in Loaded Countermovement Jump across Three Days

Variables	Pre	Post12	Post38	Percent Change (ES)	
				Pre-Post12	Pre-Post38
JH (cm)	16.9±3.0	14.5±2.7	16.6±2.5	-13.2±14.8*(ES=1.05)	-1.1±7.6(ES=0.26)
RSI ($m•s^{-1}$)	0.18±0.04	0.15±0.04	0.18±0.04	-13.2±12.9*(ES=1.06)	0.2±11.4(ES=0.02)
PF (N)	707.0±73.0	684.6±83.0	719.1±86.0	-3.1±6.7(ES=0.48)	1.7±5.6 (ES=0.29)
RPF ($N•kg^{-1}$)	8.5±1.2	8.3±1.3	8.6±1.5	-2.5±6.7(ES=0.40)	1.2±5.6(ES=0.17)
EI (N•s)	87.7±11.2	79.5.3±12.0	87.7±10.9	-9.0±10.6*(ES=0.82)	0.3±7.0(ES=0.00)
CI (N•s)	153.9±14.1	141.1±11.8	152.3±11.5	-7.9±8.3 (ES=0.52)	-0.8±4.5(ES=0.12)
PP (W)	2617.3±169.7.8	2400.9±138.6	2602.2±166.3	-8.0±6.7$(ES=1.21)	-0.5±3.0(ES=0.20)
RPP ($W•kg^{-1}$)	31.4±3.1	29.0±2.6	31.1±2.6	-7.4±6.9 (ES=0.60)	-1.0±3.0(ES=0.25)
EAP (W)	430.6±82.8	374.55±109.1	437.9±87.1	-12.0±21.8(ES=0.54)	2.4±16.2(ES=0.12)
CAP (W)	1279.5±117.6	1154.6±107.6	1265.8±133.6	-9.4±8.1$(ES=1.15)	-1.0±6.8(ES=0.16)

Note. Pre=3 hours before the match. Post12=12 hours after the match. Post38=38 hours after the match. JH=Jump height. RSI=Modified reactive strength index. PF=Peak force. EI: Eccentric impulse. CI=Concentric impulse. RPF=Relative peak force. PP=Peak power. RPP=Relative peak force. EAP=Eccentric average power. CAP=Concentric average power. *=denotes corrected *p*<0.05. $=denotes corrected *p*<0.01.

Short Recovery Stress Scale. Significant moderate decreases were found between Pre and Post12 in all PPC (*p*=0.04 , ES=0.70), MPC (*p*=0.03, ES=0.65), EB (*p*=0.006, ES=0.79), and OR (*p*=0.03, ES=0.65). No statistically significant decreases were not found between Pre and Post38 in PPC, MPC, EB, and OR (*p*>0.05). Additionally, significant moderate increases were observed between Pre and Post12 in MS (*p*=0.02, ES=0.67), LA (*p*=0.01, ES=0.74), and OS (*p*=0.01, ES=0.71) (Table 4.3). However, no significant differences were observed between Pre and Post38 in MS, LA, NES, and OS (*p*>0.05).

Table 4.3. Changes of Short Recovery Stress Scale across Three Days

Items	Pre	Post12	Post38	Percentage Changes (ES)	
				Pre-Post12	**Pre-Post38**
PPC	5.0±0.8	3.9±1.1	4.7±1.0	-1.4±1.1$(ES=0.69)	-0.3±0.5(ES=0.00)
MPC	5.6±0.5	3.7±1.3	5.3±0.5	-1.9±1.4$(ES=0.74)	-0.3±0.5(ES=0.33)
EB	5.2±0.6	3.5±0.5	5.3±0.6	-1.7±0.7$(ES=0.89)	0.1±0.7(ES=0.12)
OR	5.0±0.7	3.7±1.3	4.7±1.1	-1.5±1.2*(ES=0.71)	-0.3±0.7(ES=0.27)
MS	1.2±0.5	2.6±1.2	1.3±1.1	1.4±1.2*(ES=0.68)	0.2±0.7 ES=0.12)
LA	0.5±0.9	2.3±1.1	0.8±0.6	1.8±1.1(ES=0.73)	0.3±0.6(ES=0.44)
NES	0.6±0.5	2.5±1.1	0.8±0.8	1.9±0.8*(ES=0.75)	0.3±1.0(ES=0.11)
OS	0.8±0.6	2.1±0.8	0.9±0.7	1.2±0.8*(ES=0.68)	0.1±0.9(ES=0.00)

Note. Pre=3 hours before the match. Post12=12 hours after the match. Post38=38 hours after the match. PPC=Physical Performance Capacity. MPC=Mental Performance Capacity. EB=Emotional Balance. OR=Overall Recovery. MS=Muscle Stress. LA=Lack of Activation. NES=Negative Emotional State. OS=Overall Stress. *=denotes corrected $p<0.05$. $=denotes corrected p<0.01.

Correlations of Training Loads with Changes in Coutnermovment Jump.

Significant, negative large correlations were observed between all TLs of a match-play and the change in CMJ20 PP from Pre to Post 12 (total distance: p=0.02, r=-0.65; total PlayerLoad: p=0.049, r=-0.58; HSR: p=0.049, r=-0.58; sRPE: p=0.02, r=-0.64) (Figure 4.2). However, no significant correlations were seen between the TLs and the changes in CMJ0 from Pre to Post12 (Table 4). Additionally, no significant correlations were found between TLs of a match-play and the changes in CMJ20 JH, RSI, and PF from Pre to Post 38 (Table 4.4).

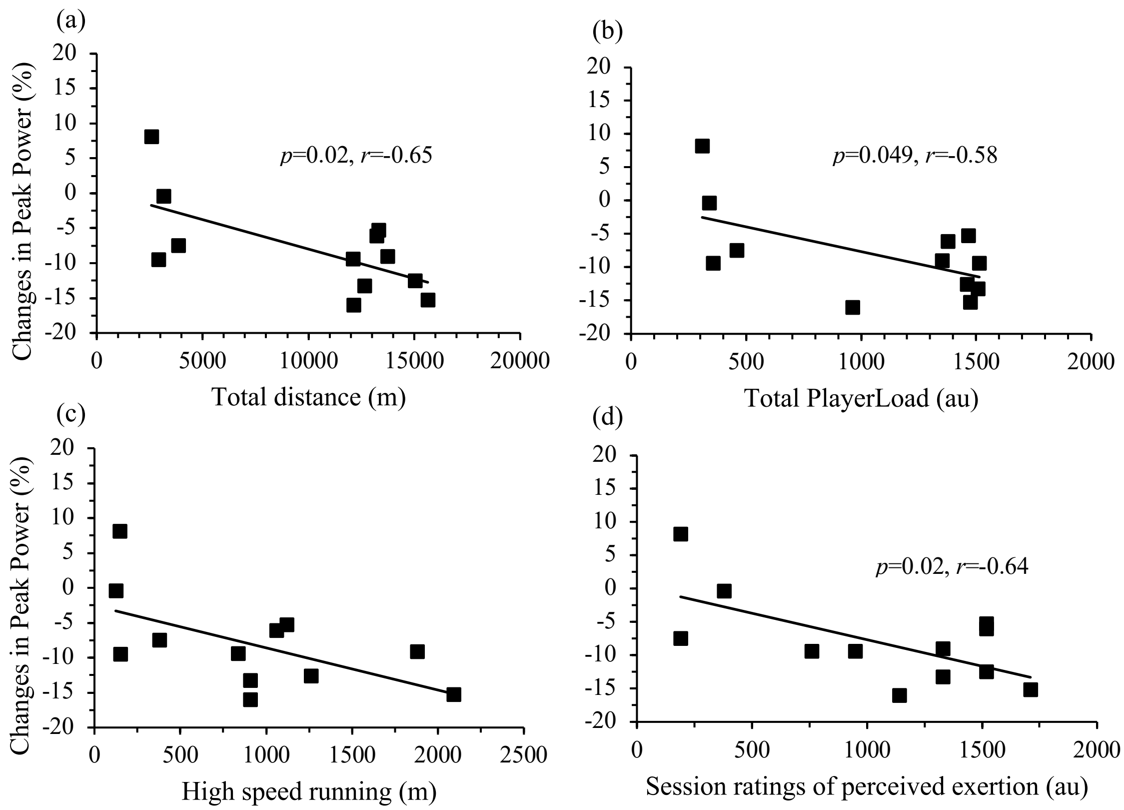

Figure 4.2. Correlations of Training Loads of Total Distance (a), Total PlayerLoad (b), High Speed Running (c), or Session Ratings of Perceived Exertion (d) and the Changes in 20kg Countermovement Jump Peak Power from 3 hours before the match to 12 hours after the Match.

Table 4.4. Correlations of Match-Derived Training Loads with Changes in Countermovement Jump

	Pre-Post12				Pre-Post38			
Items	**JH**	**RSI**	**PF**	**PP**	**JH**	**RSI**	**PF**	**PP**
CMJ0								
TD	-0.46	-0.40	-0.21	-0.50	-0.22	-0.41	0.06	-0.24
TPL	-0.41	-0.42	-0.18	-0.47	-0.25	-0.42	0.09	-0.30
HSR	-0.35	-0.23	-0.42	-0.46	-0.16	-0.47	-0.19	-0.26
sRPE	-0.43	-0.28	-0.23	-0.53	-0.19	-0.22	0.07	-0.28
CMJ20								
sRPE	-0.43	-0.28	-0.23	-0.53	-0.19	-0.22	0.07	-0.28
TD	-0.54	-0.54	-0.13	-0.65*	-0.21	-0.09	-0.23	0.01
TPL	-0.49	-0.47	0.00	-0.58*	-0.15	0.01	-0.17	0.11
HSR	-0.38	-0.43	-0.30	-0.58*	-0.30	-0.19	-0.42	-0.26
sRPE	-0.52	-0.44	-0.15	-0.64*	-0.16	0.02	-0.05	-0.08

Note: Pre=3 hours before the match. Post12=12 hours after the match. Post38=38 hours after the match. JH=Jump height. RSI=Modified reactive strength index. PF=Peak force. PP=Peak power. TD=Total distance. TPL=Total PlayerLoad. HSR=High speed running distance. sRPE=Session ratings of perceived exertion. *=denotes $p<0.05$

DISCUSSION

This study aimed to examine the acute effects of match derived workloads on CMJ kinetic variables and SRSS items across two days in Division I collegiate female soccer players. The secondary purpose was to identify the relationship between match play TLs and the acute changes in neuromuscular performance. The main findings of this study were (a) neuromuscular performance decrements were observed in JH, RSI, EI, CI, PP, RPP, and CAP in unloaded and loaded conditions from Pre to Post12, (b) PF in unloaded and loaded conditions did not change from Pre to Post12, (c) all the items in SRSS significantly decreased from Pre to Post12, and (d) large negative correlations were found between TLs of match play and the changes in CMJ20 PP from Pre to Post12. Our study confirms that the changes in neuromuscular performance are associated with match-play.

In this study, JH and PP significantly lower at Post12 compared to Pre. Our study provides further evidence that monitoring CMJ JH and PP are useful when evaluating acute neuromuscular status in team sports. Previous literature has demonstrated that reduced CMJ performance follows a bimodal response to intense, repeated SSC actions (11,13,16,19,28), which may require 2-8 days of recovery before CMJ performance returns to baseline. The initial reduction in CMJ performance (i.e., within 1 to 2 hours after a match) is a result of fatiguing metabolic factors, and the secondary reduction (i.e., between 1 to 2 days) is caused by structural and/or mechanical changes of muscles (i.e., delayed onset of muscle soreness, muscle damage, and neuromuscular fatigue). In our case, the decline in CMJ JH and PP may have also been caused by structural and mechanical changes in muscle. For example, de Hoyo et al. (11) reported that the significant reduction in CMJ JH corresponded with the increased CK concentration at 24 hours post-match in elite youth soccer players. It seems that repeated actions such as sprints, jumps, and changes of directions that occur during soccer match-play negatively affect the neuromuscular status, ultimately causing decreased CMJ JH and PP. Therefore, based on our findings and evidence from previous literature, it is likely advantageous to assess acute neuromuscular status by measuring CMJ JH and PP.

Our study showed that no significant differences were seen in CMJ kinetic variables between Pre and Post38. Although a 38 hours interval may be sufficient recovery prior to engaging subsequent match play among collegiate female soccer players, the decreases were trivial to small in JH, RSI, CI, PP, RPP, and CAP at Post38 than Pre by 1 to 5%. Dissimilar to this study, several studies have suggested that 72 hours between matches may be required to maximize neuromuscular performance and minimize the risk of injuries in soccer (1,5,26). Based on our findings and previous literature, the interval between 38 and 72 hours may be ideal to be allocated between matches. When collegiate soccer players repeatedly complete two matches with a 38 hours interval, the neuromuscular performance decrements would be evident.

Significant changes in PF were not observed between Pre, Post12, and Post38. However, PP, EI, and CI were significantly lower at Post12 compared to Pre. A few studies (13,16) have indicated that the velocity component of jumping (i.e., peak velocity) may contribute more substantially to changes in CMJ PP than the force component of jumping (i.e., PF) because of the physical demands in soccer. The findings partially agree with the evidence from previous literature that PF is not sensitive to acute neuromuscular status in response to an acute dose of high TLs from soccer match-play due to extended time to reach PF (6,11,22,34). Additionally, the nature of soccer requires that players perform repeated high-velocity muscular contractions while running, sprinting, changes of directions, jumping, and kicking. Thus, the velocity component in CMJ may be sensitive to the changes in neuromuscular performance in soccer. However, care should be taken when sports scientists analyze and interpret CMJ performance. This study would suggest that EI and CI, average force capacity in eccentric and concentric phases, would contribute to the decrements in PP. Interestingly, current evidence also shows that average force production may be sensitive to acute neuromuscular fatigue compared to PF (6,13). Based on our findings and the evidence from previous literature (6,13), the velocity component does not necessarily contribute to the changes in CMJ PP, and average force component may be associated with acute changes in neuromuscular performance.

PPC, MPC, EB, and OR significantly decreased from Pre to Post12 while significant increases in MS, LA, and OS were observed from Pre to Post 12. All the subscales returned to Pre values at Post38. Current literature (9,23,24,29,30,36) indicates that the efficacy of subjective recovery and stress measures may be high when measured in response to the acute change in TLs. Specifically, similar to previous literature (9,23,36), SRSS may be a useful monitoring tool to quantify acute changes in subjective recovery and stress state in response to a high dose of TLs. Wiewelhove et al. (36) reported that four days of high-intensity interval training resulted in significant decreases in RS, increases in SS, significantly lower CMJ JH, and significantly elevated creatine kinase concentrations ($p<0.05$). Similar to our findings, Hitzschke et al. (9) found that all SRSS values returned to baseline values three days after six days of high-intensity interval training in well-trained intermittent players. Based on our findings and the evidence from previous literature (9,36), changes in SRSS seem to be sensitive to acute high TLs.

Interestingly, the magnitude of acute changes in CMJ20 PP appears to be influenced by the volume of match-play in collegiate female soccer players. Although the results of this study showed no significant correlations between CMJ20 JH and match-derived TLs, previous studies supported that high TLs are associated with decreased CMJ JH and PP in soccer players (1,7,27,32,35). Rowell et al. (27) demonstrated that high PlayerLoad from match-play (>1000AU) very likely reduced JH from baseline to post 18 hours in elite soccer players. Additionally, Andersson et al. (1) found that significant changes were observed in CMJ JH, CK, and uric acid at 21 hours post-match compared to baseline. Furthermore, A meta-analysis by Hader et al. (7) demonstrated that there was a large negative pooled correlation between sprint distance and CMJ0 PP ($r=-0.52$) at 24 hours post-match. The changes associated with neuromuscular performance occur due to a variety of mechanisms including structural muscle damage and fatigue (1,19). Based on our findings and evidence from previous literature (1,7,27,32,35), it seems that as TL increase, acute neuromuscular performance decrements also increase among collegiate female soccer players.

There are three notable limitations to this study. First, with only 13 Division I female soccer players, this study was underpowered, limiting the ability to detect effects. Second, no measures of hormonal and metabolic response (i.e., creatine kinase) were included to identify what factors contributed to the changes in neuromuscular status. Third, this study included a recovery session at Post13. The recovery session was performed as a part of a routine session in the team of players after soccer match-play. Previous literature (8,15,25) has indicated that active recovery sessions in the water could promote the recovery rate in blood lactate and C-reactive protein. Therefore, the recovery session of this study may facilitate the recovery rate in neuromuscular performance and subjective recovery and stress state at Post38. Future studies should use various biochemical markers to assess the relationship between changes in neuromuscular status and physiological disturbances after match-play in a controlled condition.

In conclusion, TLs associated with match-play caused a significant decrease in JH, RSI, CI, PP, RPP, and CAP in loaded and unloaded CMJs at 12 hours after soccer match-play. CMJ performance decrements also seemed to be larger in CMJ20 compared to CMJ0. All SRSS values were significantly lower at Pre compared to Post12. No significant difference was seen among all CMJ and SRSS variables at Post38 compared to Pre. Additionally, a significantly strong correlation was found between match-derived TLs and the changes in CMJ20 PP from Pre to Post12. The results of this study indicate that CMJ testing, particularly loaded CMJ testing, may be used to monitor and verify neuromuscular fatigue in response to match-play while also measuring SRSS.

PRACTICAL APPLICATION

Based on our findings and evidence from the previous literature, JH and PP from unloaded and loaded CMJ are indicative of neuromuscular status in response to soccer match-play. The decrements of loaded PP may be larger as match-play TLs increase. In a practical setting, measuring both JH and PP may assist sports scientists and strength and conditioning coaches when designing a recovery plan in preparation for a subsequent match-play. This study also demonstrates that SRSS can be a meaningful monitoring tool to evaluate subjective recovery and stress state in female soccer players. Contrary to CMJ measures, SRSS can be performed on a regular basis due to the ease of administration and non-invasive nature, allowing for more frequent assessment of a player's recovery and stress state.

ACKNOWLEDGEMENTS

The authors would like to thank the team's coaches and players for participating in this research.

REFERENCES

1. Andersson, HA, Raastad, T, Nilsson, JE, Paulsen, G, Garthe, I, and Kadi, F. Neuromuscular fatigue and recovery in elite female soccer: effects of active recovery. Med Sci Sports Exerc 40: 372–380, 2008.

2. Chavda, S, Bromley, T, Jarvis, P, Williams, S, Bishop, C, Turner, AN, et al. Force-time characteristics of the countermovement jump: analyzing the curve in excel. Strength Cond J 40: 67–77, 2018.

3. Claudino, JG, Cronin, J, Mezêncio, B, McMaster, DT, McGuigan, M, Tricoli, V, et al. The countermovement jump to monitor neuromuscular status: A meta-analysis. J Sci Med Sport 20: 397–402, 2017.

4. Cormie, P, McGuigan, MR, and Newton, RU. Changes in the eccentric phase contribute to improved stretch-shorten cycle performance after training. Med Sci Sports Exerc 42: 1731–1744, 2010.

5. Dupont, G, Nedelec, M, McCall, A, McCormack, D, Berthoin, S, and Wisløff, U. Effect of 2 soccer matches in a week on physical performance and injury rate. Am J Sports Med 38: 1752–1758, 2010.

6. Gathercole, R, Sporer, B, Stellingwerff, T, and Sleivert, G. Alternative countermovement-jump analysis to quantify acute neuromuscular fatigue. Int J Sports Physiol Perform 10: 84–92, 2015.

7. Hader, K, Rumpf, MC, Hertzog, M, Kilduff, LP, Girard, O, and Silva, JR. Monitoring the athlete match response: can external load variables predict post-match acute and residual fatigue in soccer? a systematic review with meta-analysis. Sports Medicine - Open 5: 48, 2019.

8. Hinzpeter, J, Zamorano, Á, Cuzmar, D, Lopez, M, and Burboa, J. Effect of active versus passive recovery on performance during intrameet swimming competition. Sports Health 6: 119–121, 2014.

9. Hitzschke, B, Wiewelhove, T, Raeder, C, Ferrauti, A, Meyer, T, Pfeiffer, M, et al. Evaluation of psychological measures for the assessment of recovery and stress during a shock-microcycle in strength and high-intensity interval training. Performance Enhancement & Health 5: 147–157, 2017.

10. Hopkins, WG, Marshall, SW, Batterham, AM, and Hanin, J. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc 41: 3–13, 2009.

11. de Hoyo, M, Cohen, DD, Sañudo, B, Carrasco, L, Álvarez-Mesa, A, Del Ojo, JJ, et al. Influence of football match time-motion parameters on recovery time course of muscle damage and jump ability. J Sports Sci 34: 1363–1370, 2016.

12. Kellmann, M and Kölling, S. Recovery and stress in sport: A manual for testing and assessment. Abingdon, UK: Routledge, 2019.

13. Kennedy, RA and Drake, D. The effect of acute fatigue on countermovement jump performance in rugby union players during preseason. J Sports Med Phys Fitness 57: 1261–1266, 2017.

14. Kölling, S, Hitzschke, B, Holst, T, Ferrauti, A, Meyer, T, Pfeiffer, M, et al. Validity of the acute recovery and stress scale: training monitoring of the german junior national field hockey team. Int J Sports Sci Coach 10: 529–542, 2015.

15. Lum, D, Landers, G, and Peeling, P. Effects of a recovery swim on subsequent running performance. Int J Sports Med 31: 26–30, 2010.

16. McLellan, CP, Lovell, DI, and Gass, GC. Markers of postmatch fatigue in professional Rugby League players. J Strength Cond Res 25: 1030–1039, 2011.

17. Nässi, A, Ferrauti, A, Meyer, T, Pfeiffer, M, and Kellmann, M. Development of two short measures for recovery and stress in sport. Eur J Sport Sci 17: 894–903, 2017.

18. Nedelec, M, McCall, A, Carling, C, Legall, F, Berthoin, S, and Dupont, G. The influence of soccer playing actions on the recovery kinetics after a soccer match. J Strength Cond Res 28: 1517–1523, 2014.

19. Nicol, C, Avela, J, and Komi, PV. The stretch-shortening cycle: a model to study naturally occurring neuromuscular fatigue. Sports Med 36: 977–999, 2006.

20. Nicolella, DP, Torres-Ronda, L, Saylor, KJ, and Schelling, X. Validity and reliability of an accelerometer-based player tracking device. PLoS ONE 13: 1–13, 2018.

21. Nikolaidis, PT, Clemente, FM, van der Linden, CMI, Rosemann, T, and Knechtle, B. Validity and reliability of 10-Hz global positioning system to assess in-line movement and change of direction. Front Physiol 9: 1–7, 2018.

22. Oliver, J, Armstrong, N, and Williams, C. Changes in jump performance and muscle activity following soccer-specific exercise. J Sports Sci 26: 141–148, 2008.

23. Pelka, M, Schneider, P, and Kellmann, M. Development of pre- and post-match morning recovery-stress states during in-season weeks in elite youth football. Science and Medicine in Football 2: 127–132, 2018.

24. Raeder, C, Wiewelhove, T, Simola, RÁDP, Kellmann, M, Meyer, T, Pfeiffer, M, et al. Assessment of fatigue and recovery in male and female athletes after 6 days of intensified strength training. J Strength Cond Res 30: 3412–3427, 2016.

25. Reilly, T, Dowzer, CN, and Cable, NT. The physiology of deep-water running. J Sports Sci 21: 959–972, 2003.

26. Rollo, I, Impellizzeri, FM, Zago, M, and Iaia, FM. Effects of 1 versus 2 games a week on physical and subjective scores of subelite soccer players. Int J Sports Physiol Perform 9: 425–431, 2014.

27. Rowell, AE, Aughey, RJ, Hopkins, WG, Stewart, AM, and Cormack, SJ. Identification of sensitive measures of recovery after external load from football match play. Int J Sports Physiol Perform 12: 969–976, 2017.

28. Russell, M, Northeast, J, Atkinson, G, Shearer, DA, Sparkes, W, Cook, CJ, et al. Between-match variability of peak power output and creatine kinase responses to soccer match-play. J Strength Cond Res 29: 2079–2085, 2015.

29. Saw, AE, Halson, SL, and Mujika, I. Monitoring athletes during training camps: observations and translatable strategies from elite road cyclists and swimmers. Sports (Basel) 6: 1–9, 2018.

30. Saw, AE, Main, LC, and Gastin, PB. Monitoring the athlete training response: subjective self-reported measures trump commonly used objective measures: a systematic review. Br J Sports Med 50: 281–291, 2016.

31. Scott, MTU, Scott, TJ, and Kelly, VG. The validity and reliability of global positioning systems in team sport: A brief review. J Strength Cond Res 30: 1470–1490, 2016.

32. Silva, JR, Rumpf, MC, Hertzog, M, Castagna, C, Farooq, A, Girard, O, et al. Acute and residual soccer match-related fatigue: a systematic review and meta-analysis. Sports Med 48: 539–583, 2018.

33. Taylor, K-L, Chapman, DW, Cronin, J, Michael, NJ, and Gill, ND. Fatigue monitoring in high performance sport: A survey of current trends. Journal of Australian Strength and Conditioning 20: 12–23, 2012.

34. Thorlund, JB, Aagaard, P, and Madsen, K. Rapid muscle force capacity changes after soccer match play. Int J Sports Med 30: 273–278, 2009.

35. Thorpe, RT, Strudwick, AJ, Buchheit, M, Atkinson, G, Drust, B, and Gregson, W. The influence of changes in acute training load on daily sensitivity of morning-measured fatigue variables in elite soccer players. Int J Sports Physiol Perform 12: S2107–S2113, 2017.

36. Wiewelhove, T, Raeder, C, Meyer, T, Kellmann, M, Pfeiffer, M, and Ferrauti, A. Effect of repeated active recovery during a high-intensity interval-training shock microcycle on markers of fatigue. Int J Sports Physiol Perform 11: 1060–1066, 2016.

Chapter 5. Summary and Future Investigations

To achieve the purpose of this dissertation, the purposes of individual research projects were to examine 1) to investigate the relationships between match-derived training load (TL), subjective recovery and stress state, and neuromuscular performance at individual and group levels, 2) to investigate the acute effects of a soccer match-play on neuromuscular performance and player's subjective recovery and stress state in Division I collegiate female soccer players, and 3) to identify the relationship between TLs of a match-play and the acute changes in neuromuscular performance.

The results of study I indicated that match-derived TL was significantly correlated with subjective recovery and stress state at individual and group levels. Total distance of a soccer match-play may be strongly related to the changes in subjective recovery and stress state at both individual and group levels. The finding of study I showed that the magnitude of the correlations was stronger between match-derived TL and recovery and stress state at the individual level than the group level. The findings of study I also demonstrated that a heterogeneous relationship between match-derived TLs, CMJ variables, and the ratings of subjective recovery and stress state. Based on our findings, individually monitoring the ratings of subjective recovery and stress state could be useful in response to match-derived TL.

Study II showed that TLs associated with match-play statistically decreased JH, RSI, CI, PP, RPP, and CPA in loaded and unloaded CMJs at 12 hours after a soccer match-play. The rating of subjective recovery and stress state also statistically changed 12 hours after the match-play. However, no significant difference was observed among all CMJ and SRSS variables at Post38 compared to Pre. Additionally, a significantly strong correlation was found between match-derived TLs and the changes in CMJ20 PP from Pre to Post12. The findings of Study II support that the changes in subjective recovery and stress state and neuromuscular performance corresponds to a soccer match-play in Division I female soccer players.

Overall, studies I and II highlight the efficacy of TL measures, subjective recovery and stress questionnaire, and CMJ during a competitive season in Division I female soccer players. The measures could be useful athlete monitoring tools to extensively quantify 1) player's TL of a training session and match and 2) player's physical readiness in NCAA Division I female soccer. Although biochemical, hormonal, and immunological measures may provide additional evidence to assess the physiological response to TL, these measures are limited due to the feasibility and cost. In NCAA Division I female soccer, sports scientists and strength and conditioning coaches should implement the monitoring tools to optimize sports performance during a competitive season.

Although this dissertation demonstrates the benefits of TL measures, subjective recovery and stress questionnaire, and CMJ in NCAA Division I female soccer, future research is needed to quantify long-term athlete monitoring programs in conjunction with biochemical, hormonal, and immunological measures. Future research also should increase the sample size of female soccer players at various competition levels. Large sample sizes from different collegiate soccer teams can ensure the importance of athlete monitoring programs.

APPENDIX A: Short Recovery and Stress Scale Questionnaire

Short Recovery Scale

Below you find a list of expressions that describe different aspects of your current state of recovery. Rate how you feel right now in relation to your highest ever recovery state.

Physical Performance Capability *

e.g. strong, physically capable, energetic, full of power

	0	1	2	3	4	5	6	
Does not fully apply	○	○	○	○	○	○	○	Fully applies

Mental Performance Capability *

e.g. attentive, receptive, concentrated, mentally alert

	0	1	2	3	4	5	6	
Does not fully apply	○	○	○	○	○	○	○	Fully applies

Emotional Balance *

e.g. satisfied, balanced, in a good mood, having everything under control stable, pleased

	0	1	2	3	4	5	6	
Does not fully apply	○	○	○	○	○	○	○	Fully applies

Overal Recovery *

e.g. recovered, rested, muscle relaxation, physically relaxed

	0	1	2	3	4	5	6	
Does not fully apply	○	○	○	○	○	○	○	Fully applies

Short Stress Scale

Below you find a list of expressions that describe different aspects of your current state of stress. Rate how you feel right now in relation to your highest ever stress state.

Muscle Stress *

e.g. muscle exhaustion, muscle fatigue, muscle soreness, muscle stiffness

	0	1	2	3	4	5	6	
Does not fully apply	○	○	○	○	○	○	○	Fully applies

Lack of Activation *

e.g. unmotivated, sluggish, unenthusiastic, lacking energy

	0	1	2	3	4	5	6	
Does not fully apply	○	○	○	○	○	○	○	Fully applies

Negative Emotional State *

e.g. feeling down, stressed, annoyed, short-tempered

	0	1	2	3	4	5	6	
Does not fully apply	○	○	○	○	○	○	○	Fully applies

Overal Stress *

e.g. tired, worn-out, overloaded, physically exhausted

	0	1	2	3	4	5	6	
Does not fully apply	○	○	○	○	○	○	○	Fully applies

APPENDIX B: Rating of Perceived Exertion Questionnaire

RPE

1 - 10 Borg Rating of Perceived Exertion Scale	
0	Rest
1	Really Easy
2	Easy
3	Moderate
4	Sort of Hard
5	Hard
6	
7	Really Hard
8	
9	Really, Really, Hard
10	Maximal: Just like my hardest race

0 1 2 3 4 5 6 7 8 9 10

Submit

VITA

AI ISHIDA

Education:	Ph.D. Sport Physiology and Performance, East Tennessee State university, Johnson City, TN, 2021
	M.S. Exercise and Wellness, Arizona State University, Downtown Phoenix, Arizona, 2018
	B.A. Sport Sciences, Waseda University, Tokorozawa, Saitama, 2016
Professional Experience:	Lead Sports Scientist and Strength and Conditioning Coach, East Tennessee State University Women's Soccer; Johnson City, Tennessee, 2018-2020
	Sport Performance Coach Intern, Fisher Institute; Phoenix, Arizona, December 2017-March 2018
	Sport Performance Coach Intern, Sun Devil Sports Performance; Tempe, Arizona, July 2016-December 2017
Publications:	**Ishida. A**., Bayzler CD., Sayers AL., Mizuguchi S., & Gentles. JA "Acute Effects of Match-Play on Neuromuscular and Subjective Recovery and Stress State in Division I Collegiate Female". (2021). Journal of Strength and Conditioning [ahead of print].
	Ishida. A., Travis. S. K., and Stone. MH.

"Associations of Body Composition, Maximum Strength, Power Characteristics with Sprinting, Jumping, and Intermittent Endurance Performance in Male Intercollegiate Soccer Players". (2021). Journal of Functional Morphology and Kinesiology, 6(1), 76.

Travis. S. K., **Ishida. A**., Taber. CB., Fry. AC., and Stone. MH. "Emphasizing Task-Specific Hypertrophy to Enhance Sequential Strength and Power Performance". (2020). Journal of Functional Morphology and Kinesiology, 5(4), 76.

Ishida. A., Rochau K., Findlay KP., Devero B., Duca M., & Stone MH. "Effects of An Initial Muscle Strength Level on Sports Performance Changes in Collegiate Soccer Players". (2020). Sports (Basel), 8(9), 127.

Ishida A, & Beaumont. J. S. (2020). "Difference in Internal and External Workloads between Non-Injured and Injured Groups in Collegiate Female Soccer Players". International Journal of Kinesiology and Sports Science. 8(2), 26-32.

Honors and Awards: NSCA Foundation Minority Scholarship, 2020