

UNIVERSITY OF WISCONSIN-LA CROSSE

Graduate Studies

THE EFFECTS OF TRAINING LOAD ON INDICATORS OF RECOVERY AND
INJURY OCCURRENCE IN COLLEGIATE WOMEN
VOLLEYBALL PLAYERS

A Manuscript Style Thesis Submitted in Partial Fulfillment of the Requirements for the
Degree of Master of Science in Human Performance

Eric Linnell

College of Science and Health
Human Performance

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THE EFFECTS OF TRAINING LOAD ON INDICATORS OF RECOVERY AND
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VOLLEYBALL PLAYERS

By Eric J. Linnell

We recommend acceptance of this thesis in partial fulfillment of the candidate's requirements for the degree of Master of Science in Human Performance

The candidate has completed the oral defense of the thesis.

Glenn Wright, Ph.D.
Thesis Committee Chairperson

Date

Clayton Camic, Ph.D.
Thesis Committee Member

Date

Scott Doberstein, M.S.
Thesis Committee Member

Date

Thesis Accepted

Steven Simpson, Ph.D.
Graduate Studies Director

Date

ABSTRACT

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The purpose of this study was to determine the physical demands of a volleyball preseason training cycle using various types of training load and the relationship between training loads and injury. Twelve experienced female collegiate volleyball players (19.6 ± 1.2 years) participated in this project. The reactive strength index was used to estimate neuromuscular fatigue. The perceived recovery status scale was used to determine subjective recovery. External load measurements were acquired through the use of player monitoring units including accelerometers worn around chest. Injuries were evaluated and recorded by the athletic training staff. Significant correlations were found between sRPE load and mechanical load ($r = 0.581$), sRPE and total impacts ($r = 0.640$), total impacts and mechanical load ($r = 0.914$), sRPE load and injury ($r = 0.753$), mechanical load and injury ($r = 0.689$), and total impacts and injury ($r = 0.671$). No significant relationships were found between sRPE load or mechanical load with RSI or PRS. No significant relationships were found between injury occurrence and the sum of contacts in impact Zones 3, 4, 5, or the sum of Zones 4, and 5.

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INTRODUCTION

The significance for volleyball athletes to obtain high fitness and skill levels is ever increasing. Coaches are receiving increased pressure to be successful and thus push the physical and psychological limits of the athletes in hopes to stimulate adaptation (Piggott, Newton, & McGuigan, 2009). Unfortunately, training strategies used by coaches are often unmonitored and may stress the athletes too much or too soon, leading to increased incidence of injuries (Anderson, Tripplett-McBride, Foster, Doberstein, & Brice, 2003). From the 2004-2005 season to the 2008-2009 season volleyball practice injury rates jumped from 3.2/1000 hours to 6.5/1000 hours of participation (NCAA Sports Medicine Handbook, 2014). Furthermore, 72.5% of all volleyball injuries between 2009-2014 occurred during practice (NCAA Sports Medicine Handbook, 2014). This is the highest percentage of injuries occurring in practice across all 25 sports surveyed by the National Collegiate Athletic Association (NCAA) during this time frame.

Through the use of athletic monitoring, coaches can obtain data representing the training loads (TL) they impose on the athletes during a training cycle. Two types of TL exist in reference to athletic monitoring; external and internal TL. External TL is defined as the amount of work that is completed during the workout and can be quantified with different methods such as distance accumulation, duration of exercise, or accelerometry. Internal TL is the physiological response that occurs within the body as a consequence of the external load (Impellizzeri, Rampinini, & Marcora, 2005; Lambert & Borresen, 2010). Survey responses such as the session rating of perceived exertion (sRPE) are

inexpensive practical ways to estimate internal TL and have been used for large groups and teams for many years (Foster, 1998; Halson, 2014; Impellizzeri et. al., 2005; Lambert & Borresen, 2010).

Monitoring TL in relation to fatigue can provide information regarding the optimal amount of training and recovery necessary to stimulate adaptation. Two common methods for assessing fatigue and recovery include the objective neuromuscular assessment, reactive strength index (RSI), (Young, 1995) and the subjective perceived recovery status scale (PRS), (Laurent et al., 2011), respectively. If coaches observe progressive decreases of recovery values over time, they should recognize the necessity to change the training plan or injuries are likely to occur.

Current research has examined the relationship between TL and injury occurrence. Anderson et al. (2003) examined the relationship between sRPE load and occurrence of injury in collegiate basketball players and found large significant correlations, which are similar to the results of Gabbett (2004a, 2004b), and Gabbett and Domrow (2007) who investigated these relationships with rugby players. Colby, Dawson, Heasman, Rogalski, & Gabbett (2014) used global positioning systems (GPS) to quantify external TL using distance traveled and velocity and found a significant relationship with injury incidence. This suggests there is a relationship between external TL and injury, however using GPS is not practical for volleyball because of the necessity for a clear view of the sky and distance travelled may not reflect external TL in volleyball. As a result, acceleration based external TL quantification seems much more suitable for indoor sports such as volleyball. Currently, no research exists exploring the relationships between internal and external TL with measures of fatigue and recovery or

injury occurrence in volleyball players. Therefore, the purpose of this study is to determine the physical demands of a volleyball preseason training cycle using various types of TL and the relationship between TLs and injury.

METHODS

Experimental Approach to the Problem

An observational study using multiple means of athlete monitoring was performed to determine the physical demands of a Division III women's volleyball preseason training cycle consisting of 17 training sessions over 12 days (Table 1) and the relationship between TL and injury. Athlete monitoring included the use of accelerometers and sRPE to determine external and internal TL, respectively. Indicators of fatigue included the use of the RSI as a sign of neuromuscular fatigue and the PRS gave an indicator of subjective perception of recovery between training days. The incidence of injury was recorded before, during, and after practice by the sports medicine staff. Training session planning included technical and tactical skill practice and conditioning that were developed entirely by the coaching staff with no intervention from the researchers.

Table 1. Training Days and Number of Training Sessions

Day	1	2	3	4	5	6	7	8	9	10	11	12
# of Training sessions	2	2	2	0	2	2	1	1	0	2	1	2

Subjects

Eleven women Division III collegiate volleyball athletes completed this study (Table 2) during the two weeks prior to starting the competitive season. Players with any previous self-reported chronic injury that prevented full participation at the beginning of

the season were not included in this study. All subjects were recruited from the University of Wisconsin-La Crosse varsity volleyball team. Recruiting of players was conducted at the first team meeting of the preseason. Twelve subjects started the study, but one did not make the final roster. All players were allowed to ask any questions and then provided written informed consent before inclusion to this study. All players were above the age of 18 years. Full Institutional Review Board approval was obtained through the University of Wisconsin-La Crosse to ensure the procedures protected the rights of the players.

Table 2. Player Demographics (n=11, mean $\pm$ SD)

Age (years)	Height (cm)	Mass (kg)	Body Mass Index
19.6 $\pm$ 1.2	169.9 $\pm$ 6.8	65.8 $\pm$ 8.3	22.9

Testing and Procedures

Twenty minutes before the first training session of each day, the subjects reported to the laboratory to determine pre-practice values of the tested variables. Values were not measured on days with no training sessions. Following a standardized warm-up of 200m jog, 10 walking lunges, three maximal tuck jumps and a 5 minute passive recovery, the RSI test was performed.

The RSI test involved players performing a drop jump by stepping off of a 30 cm box with hands on hips on to a contact mat and immediately jumping vertically. The athletes were instructed to jump for maximum height and minimal contact time upon ground contact. The best RSI of three jumps was used for analysis. Upon completion of the drop jump, the subjects reported their PRS. The PRS consists of numbers (0-10)

anchored to the word that describes their subjective recovery following a warm-up (Table 3).

Table 3. Perceived recovery status (PRS) scale

Rating	Description
10	Very well Recovered / Highly energetic
9	
8	Well recovered/Somewhat energetic
7	
6	Moderately recovered
5	Adequately recovered
4	Somewhat recovered
3	
2	Not well recovered / somewhat tired
1	
0	Very poorly recovered / Extremely Tired

The subjects then reported to practice while wearing a physiological monitoring device which includes an accelerometer (Bioharness 3, Zephyr Technology Corp., Annapolis, MD) to determine mechanical load and number of impacts; both which are measures of external TL. Mechanical load is a metric that provides the volume and intensity of movements based on the accumulation of mechanical intensity determined by proprietary software (PSM Training, Zephyr Technology Corps, Annapolis, MD). Mechanical intensity was determined by the highest peak acceleration (g forces) in the x (vertical), y (lateral), or z (sagittal) axis of an internal accelerometer during each 1 second epoch sampled at 100 Hz. The peak acceleration is reported on a 0-10 linear scale between 0.5 (=0) and ≥ 6 g (=10). Impacts are g-force values athletes are exposed to during deceleration. Any deceleration that rises above the lower limit of exposure (2 g) is counted as an impact. Impact zones are represented incrementally by each 2 g meaning

Zone 1 is any impact >2g, Zone 2 >4g, Zone 3 >6g, Zone 4 >8g, and Zone 5 >10g.

Zephyr's impact processor tool automatically analyzes the acceleration/deceleration forces and produces the data set. The device was fixed to a chest strap and worn under the sports bra as recommended by the manufacturer. Subjects were provided the same device and chest strap throughout the study.

Each subject's sRPE was collected approximately 20-30 minutes after each training session to ensure the perceived effort was referred to the whole session rather than the most recent exercise intensity. Subjects were asked, "How hard was your workout?" and responded using the CR-10 scale (Table 4) as modified by Foster (1998). The identified number was then multiplied by the duration (minutes) of the training session to determine sRPE load, which represents a estimation of internal TL. Training session duration began at the start of the team dynamic warm-ups and ended upon completion of the final organized team drill. Subjects were familiarized with the CR-10 scale and its use in training during the previous spring season.

Table 4. Modified CR-10 scale

Rating	Description
0	Rest
1	Very, very easy
2	Moderate
3	
4	Somewhat hard
5	Hard
6	
7	Very hard
8	
9	
10	Maximal

Injury, for the purposes of this study, was defined as one that 1) occurred as a result of participation in an organized intercollegiate volleyball training or competitive

session, 2) required medical attention by the athletic training staff, and 3) resulted in restriction of the players participation or performance for one or more calendar days beyond the date of initial injury (Dick, Agel, & Marshall, 2007). Each evaluated injury was only counted as one injury whether it was seen by the athletic training staff once or multiple times.

Statistical Analysis

When analyzing data, the individual practice data from each subject was recorded. Daily load of each variable (i.e. RPE load, mechanical load, total impacts) for each subject was determined as the sum of load for all practices in one day. From this data, group mean $\pm$ SD were determined for the values of daily sRPE load, daily mechanical load, and daily total impacts. Group daily mean $\pm$ SD were also determined for RSI, and PRS for each day of training during the preseason. There were 7 days that had 2 training sessions, 3 days that had 1 training session, and 2 days when no training sessions were held. A Pearson Product correlation was performed among daily sRPE load, daily mechanical load, daily total impacts, RSI, PRS, and incidence of injury. Hopkins (2002) has ranked the meaningfulness of correlations as r = trivial (0.0), small (0.1), moderate (0.3), strong (0.5), very strong (0.7), nearly perfect (0.9), and perfect (1.0). All data were analyzed using SPSS (v. 22) statistical platform. Statistical significance was determined a priori at the $p < 0.05$ significance level.

RESULTS

Daily Training Loads

Figure 1 represents the range of daily TLs during the preseason practices of this collegiate volleyball team. Session RPE load shows large spikes during days 1, 2, 3, and 10. Mechanical load shows large spikes during days; 1, 2, 3, 6, and 10. Training loads indicate the first few days of the preseason practice were heaviest of the 2 week plan.

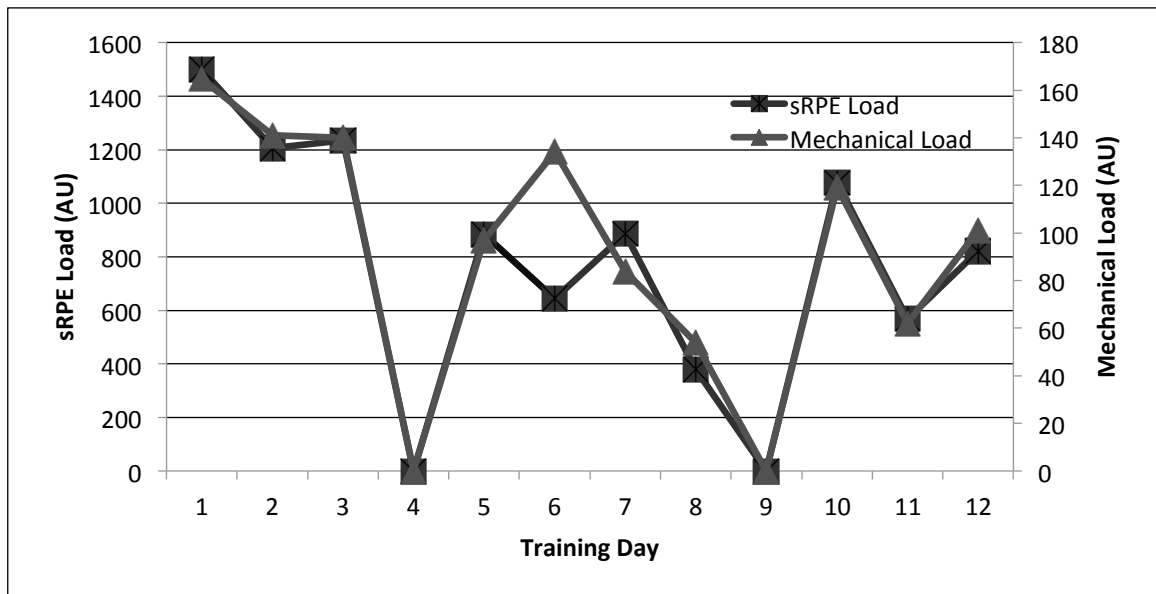


Figure 1. sRPE load and mechanical load

Training Load Relationships

Significant correlations were found between TLs. Strong correlations were found between sRPE load and mechanical load ($r = 0.581$, $p = 0.000$) and between sRPE load and total number of impacts ($r = 0.640$, $p = 0.000$). A nearly perfect correlation ($r = 0.914$, $p = 0.000$) was found between the total number of impacts and mechanical load. No

significant relationships were revealed between sRPE load and RSI or PRS. Likewise, no significant relationships were seen between mechanical load and RSI or PRS.

Relationships to Injury

Figure 2 shows the distinguishable spikes in both sRPE training load and number of injuries. A very strong correlation ($r = 0.753$, $p = 0.005$) was identified.

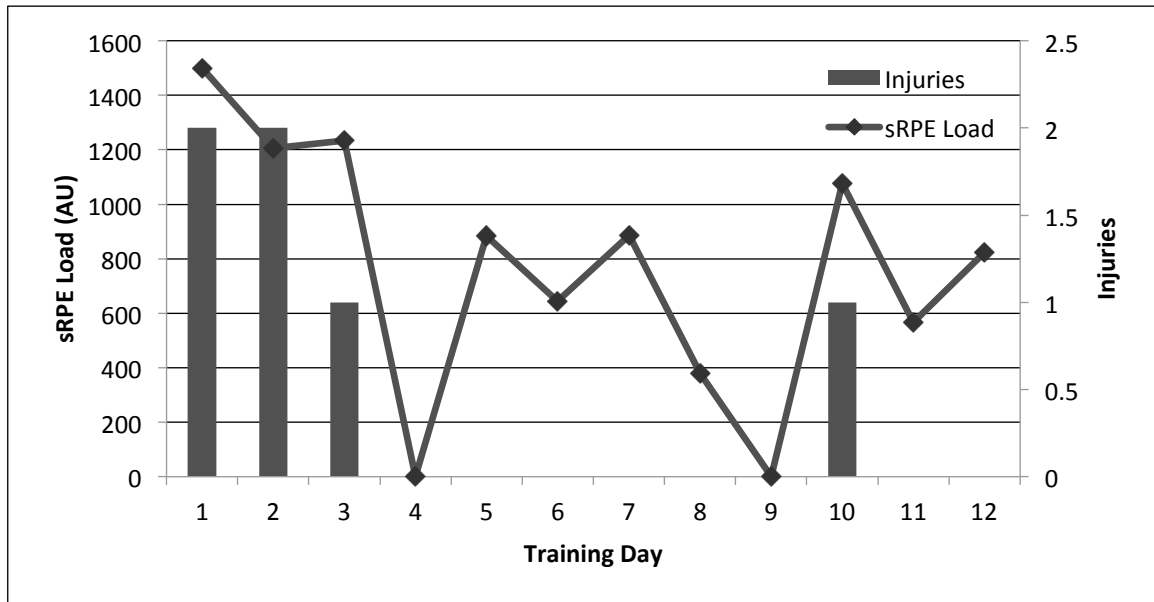


Figure 2. sRPE load and injury

Figure 3 shows the distinguishable spikes in both mechanical load and number of injuries. A strong correlation ($r = 0.689$, $p = 0.013$) was observed.

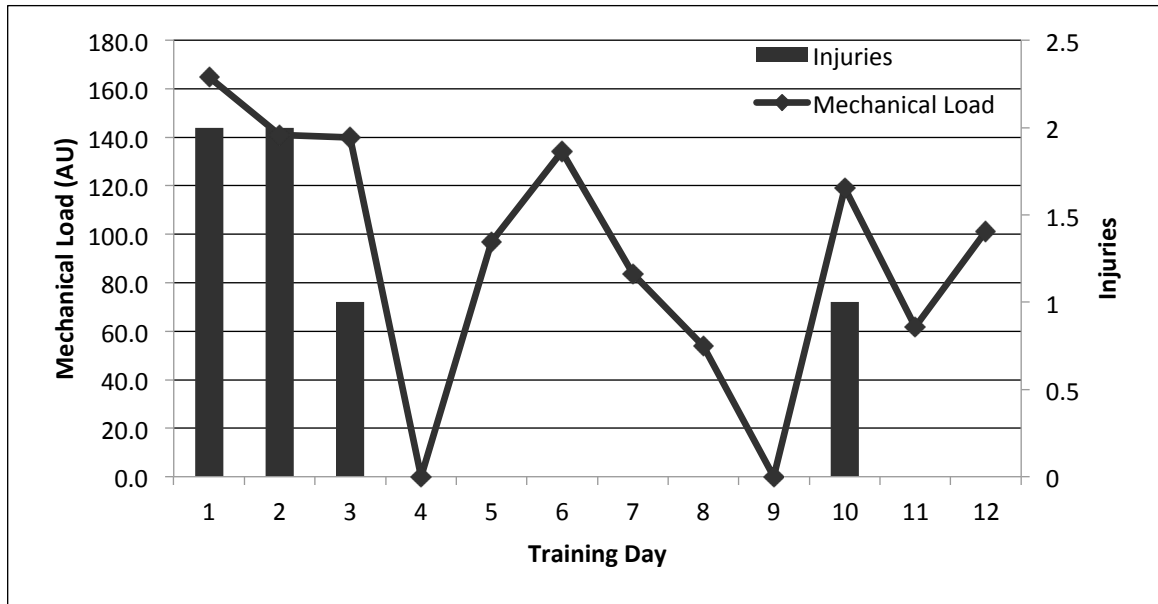


Figure 3. Mechanical load and injury

Figure 4 shows the distinguishable spikes in both total impacts and number of injuries. A strong correlation ($r = 0.671$, $p = 0.017$) was revealed. No significant correlations were found between the sum of contacts in the impact zones 3, 4, 5 or the sum of zones 4, and 5 with injury occurrence.

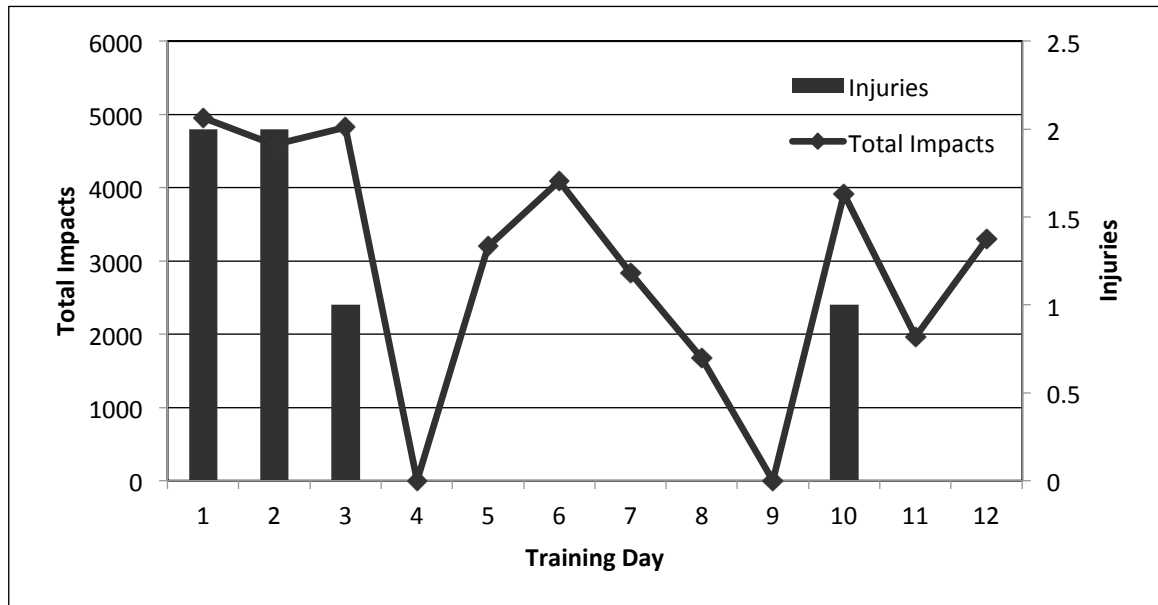


Figure 4. Total impacts and injury

DISCUSSION

The purpose of this study was to determine the physical demands of a volleyball preseason training cycle using various types of TL and the relationship between these TLs and injury. To the author's knowledge, this study is the first of its kind to provide analysis and comparison of internal and external TL for volleyball.

Internal and external TLs are inherently different measures of intensity (Scanlan et al., 2014a) where external TL is stimulus outside the body that triggers the internal TL; however, the internal load is the stimulus for training adaptations (Impellizzeri, et al., 2005). Internal TL in this study was monitored through the use of sRPE load. The mean daily sRPE load found in this study ranged from ~400-1500 arbitrary units (AU). These values are seemingly higher compared to other sports. Alexiou and Coutts (2008) found values ranging from ~200-1000 AU during a 16 week soccer season. With basketball players, Anderson et al. (2003) reported daily sRPE values ~200-900 and Scanlan, Wen, Tucker, Borges and Dalbo (2014b) found values ranging from ~250-700 AU per day, with the highest values occurring during tactical training/game play. Further, Scanlan et al. (2014a) observed a mean of only ~300 AU per day during the preparatory training phase in basketball athletes. On the other hand, Scott, Lockie, Knight, and Janse de Jonge (2013) observed soccer players that reported values of ~100-800 AU over 29 training sessions during the in-season training phase. These sRPE loads of ~100-800 AU are still smaller than the values we observed in the present study. There are 2 primary factors likely causing our sRPE values to be elevated above those reported in other

studies. Seven of the 12 days during the preseason training phase of our study involved 2 training sessions per day. Since our values are reported as daily means, our results are a total value that represents two different training sessions added together for a given day. It is likely that the previously mentioned studies consisted of training plans involving only one training session per day as opposed to days with 2 training sessions observed in the present study. Second, Scott et al. (2013) reported training session durations lasting between 60-90 minutes where as our study monitored training sessions that lasted 120 minutes with some sessions reaching as many as 150 minutes. Because TL is function of intensity multiplied by duration in minutes, increases in TL are likely explained by longer practice durations and multiple practices in one day.

External TL in this study was determined using an accelerometer based metric. Other studies with various sports have also used accelerometer and GPS based metrics to express external TL. Although the different types of monitoring systems using accelerometers calculate TL using different algorithms, proportionally they are similar in that the higher the value, the greater the volume of work performed during activity over the course of a training or competitive session.

Casamichana, Castellano, Calleja-Gonzalez, San Roman, and Castagna (2013) observed external TL derived from accelerometer based loads during training sessions that were strongly related to sRPE load ($r = 0.76$) in Spanish semiprofessional soccer players. Similarly, Scott et al. (2013) found a strong correlation ($r = 0.84$) between accelerometer based load and sRPE load, using Australian professional soccer players. However, Scanlan et al. (2014a) observed only a moderate correlation ($r = 0.49$) between accelerometer based TL and sRPE load in semi-professional Australian basketball

players. The strong relationship between sRPE and mechanical load observed in our study ($r = 0.58$) falls between these other studies.

An explanation for the differences between the studies mentioned and our results for TL may be the result of the sport monitored. Soccer athletes spend a predominant amount of time away from the ball moving up and down the field performing increasingly greater amounts of linear running compared to volleyball. Scott et al. (2013) reported soccer players in their study spent approximately 2.5% of the total duration training in high-speed running and 0.5% in very-high speed running. The remaining duration (97% of the training duration) was spent in low speed activity. This suggests that when a large percentage of low speed activity is combined with greater linear running, a stronger relationship may exist between sRPE and accelerometer based loads. It has also been suggested that unique, intermittent, and lateral movements performed under similar external conditions of mean speed and linear distances may lead to an inflation of sRPE loads (Scanlan et al., 2014a) and therefore, result in a smaller correlation between internal and external TLs. Inflation of sRPE in the range of 13-25% have been observed (Scanlan et al., 2014a) during intermittent and lateral movements in soccer and tennis players when total external load, including duration (min) (Dellal, Keller, Carling, Chaouache, Wong, & Chamari, 2010), distance covered (Greig, McNaughton, & Lovell, 2006), and speed (Williford, Olson, Gauger, Duey, & Blessing, 1998), were controlled in a laboratory setting.

Volleyball training involves intermittent and lateral movements but due to more players per side in a smaller court area, the overall distance of lateral movements of each player are shorter than those repeated during basketball play. Therefore, proportional

differences in sRPE load compared to external TL during volleyball training may not be as great, likely explaining our stronger relationship between sRPE load and accelerometer based load compared to other studies investigating the same relationship in basketball play. Due to the high number of jumps that volleyball athletes must recover from, we also analyzed the relationship between sRPE load and total impacts, another metric of external TL. Impact is a measure of the body decelerating that has a measure of intensity (g force) and volume (number) of impact. The strong relationship between sRPE and total impacts suggests that the athlete's perception of training difficulty (sRPE) may depend on total number of impacts performed during a given training session. The nearly perfect correlation ($r = 0.914$) between mechanical load and total impacts seen in our results suggests total impacts increased proportionately to mechanical load; a measure of acceleration during jumps and changes of direction. With the exception of Day 6, sRPE load and external TL fluctuated proportionally. This may be explained, as Day 6 involved an exhibition match as opposed to a normal training session. In support of this finding, Montgomery, Payne, and Minahan (2010) observed accelerometer based external loads were higher during gameplay compared to training in basketball. Likewise Casamichana, Castellano and Castagna (2012) found higher accelerometer based external loads during friendly matches (which are similar to exhibition matches) compared to small sided games during soccer training. Our results are in agreement with these previous findings suggesting that a competitive aspect of volleyball play elicits lower proportional sRPE loads compared to external TL values seen during volleyball training sessions.

It is evident in our subjects that, as daily sRPE load, mechanical load, and total impacts peaked; a subsequent injury was likely to follow. Although internal TLs during practices are dependent on coaching styles and athlete preparation status, other studies have observed a similar trend of injury following peaks in TL during training cycles. Anderson et al. (2003) reported a strong relationship ($r = 0.68$) between rises in sRPE TL and injury occurrence in basketball players. Likewise, Gabbett and Domrow (2007) found that significant increases of internal TLs during the preseason training cycle increased the odds of injury occurrence. Our results indicate spikes of increased sRPE TL and external TL early in the training phase or following recovery days were also linked to injury as noted on training days 1, 2, 3 and 10. Therefore, our data indicates that, using both external and internal monitoring data, our subjects were not physically prepared for such high increases of TL early in the preseason training cycle. In this case, too high of TL related to maladaptation, or in other words, injury. Our results indicate that monitoring of both internal and external daily TL may assist in determining threshold training TL to reduce the incidence of injury. Since adaptation is a function of internal TL (Impellizzeri, 2005), it is likely; the sRPE load may be a better predictor of injury as the same external load may create different individual sRPE loads in different athletes. It is important to point out that the current study was limited by the amount of injury data collected for individual players during the brief preseason period. As a consequence, the correlation coefficients for injury in this study reflect the relationship between number of injuries from the pooled data rather than the mean of intra-subject correlations, as is commonly performed in the literature.

No significant relationships were found between sRPE load or mechanical load with either the RSI or PRS. This may demonstrate that the athletes were not impacted by physiological or subjective fatigue by the designed training plan according to these two measures and therefore injury may be related to excess load accumulation or lack of progressive loading, as opposed to fatigue measured through the RSI or PRS.

Practical Application

The sRPE method is an inexpensive tool that coaches can employ to monitor training plans. Coaches can also establish team wide and individually based injury thresholds, and through monitoring, use the injury threshold to adjust training plans accordingly in order to prevent injury occurrence while still maximizing training outcomes. Since there is a nearly perfect correlation between mechanical load and total impacts, and both have large relationships to injury, these findings suggest that volleyball coaches may be able to establish a jump count threshold, or utilize a real-time mechanical load and impact recording system, to prevent injuries. Since this is the first study of its kind to investigate this relationship, future studies should look deeper into monitoring total impacts and impact intensity in “real” time.

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APPENDIX A
INFORMED CONSENT

Informed Consent

Title of Study: The Relationship Between Mechanical Load, Internal Load, Impact Forces, and Performance Measures During a Traditional Collegiate Volleyball Season.

Principal Investigator: Eric Linnell, ATC, LAT

elinnell@uwlax.edu

(507) 995-3284

PLEASE READ THE FOLLOWING INFORMATION TO BE SURE YOU ARE INFORMED ABOUT THE RESEARCH STUDY. PLEASE SIGN THE FORM IF YOU AGREE TO PARTICIPATE IN THIS STUDY. BY SIGNING THIS FORM YOU CONFIRM THAT YOU HAVE BEEN INFORMED OF THE PURPOSE OF THIS STUDY, RISKS OF PARTICIPATION, POTENTIAL BENEFITS, AND THAT YOU HAVE MADE YOUR DECISION VOLUNTARILY.

Purpose and Procedure

- The purpose of this study is to examine the mechanical load, internal load, impact force, and their effect on drop jump reactive strength index over the course of a collegiate volleyball season.
- It is the primary aim of this study to determine a relationship between the above listed variables to predict fatigue, injury risk, and optimal performance ability.
- Participants will wear an accelerometer on a chest strap around the torso during all practice sessions during the preseason phase, and during all practices and competitions every other week during the in-season phase.
 - Accelerometers will measure mechanical load and impact force.
- Participants will respond to a rating of perceived exertion (RPE) survey between 15-30 minutes following the final drill of each practice, and 15-30 minutes following the final point of each competition to determine internal load.
- Participants will respond to a perceived recovery scale 15-30 minutes prior to each practice.
- Prior to and following practice, subjects will perform three (3) drop jumps from a 15-45 cm box onto a contact mat that measures ground contact time and vertical jump height to determine the reactive strength index. The height of the box will be 30 cm.

Potential Risks

- Although rare, it is possible participants may fall on the accelerometer resulting in rib contusion.
- The lead researcher has chosen the “side” placement location underneath the non-dominant arm to minimize any risk of falling directly on the accelerometer. Additionally, the Bioharness straps that house the accelerometers are padded to decrease the chance of injury. A certified athletic trainer will be present during all practices and competitions when the accelerometers will be worn. The athletic trainer will be able to provide evaluation and treatment for any adverse outcomes occurring from falling on the accelerometer.
- There is a very small chance injury may occur during the drop jump performances. An athletic trainer will be available to provide evaluation and treatment for any adverse outcomes that occur during drop jump testing.

What happens if I am injured during this study?

- In the unlikely event that any injury or illness occurs as a result of this research, the Board of Regents of the University of Wisconsin System, and the University of Wisconsin-La Crosse, their officers, agents, and employees, do not automatically provide reimbursement for medical care or other compensation. I have been informed that payment for treatment for any injury or illness must be provided by me or my third-party payor, such as my health insurer or Medicare. If any injury or illness occurs in the course of research, or for more information, I will notify the investigator in charge. I have been informed that I am not waiving any rights that I may have for injury resulting from negligence of any person or the institution.
- For information about policies, the conduct of the study, or the rights of the research subjects, please contact the University of Wisconsin-La Crosse Institutional Review Board (IRB) for the Protection of Human Services (608-785-6892; irb@uwlax.edu). The IRB is a group of people who review and research to protect the rights of research participants.

Benefits

- There will be no direct benefits to participants of this study. However, on a greater scale, the data collected from this study may lead to better predictors of fatigue, identify and decrease the risk of injury, and the optimization of training strategies to maximize volleyball performance.

Confidentiality

- Information from this study may be published or presented at professional meetings or conferences. No identifying information will be used during the publication process or at presentations. Your participation in this study will remain confidential.
- All information gathered during this study will be kept on a password secured computer.

If you have questions

- Eric Linnell, ATC (507-995-3284 or elinnell@uwlax.edu) and Glenn Wright, PhD (gwright@uwlax.edu) are available to answer any questions you may have.

I HAVE READ ALL THE ABOVE, ASKED QUESTIONS, RECEIVED ANSWERS CONCERNING MY QUESTIONS, AND I WILLINGLY GIVE MY CONSENT TO PARTICIPATE IN THIS STUDY. UPON SIGNING THIS FORM, I WILL RECEIVE A COPY.

Participant _____ **Date** _____

Researcher _____ **Date** _____

APPENDIX B
REVIEW OF THE LITERATURE

Review of the Literature

The physiological demands of volleyball involve high intensity movements followed by periods of rest or low intensity movements (Filho, Andrade, Nogueira, & Nakamura, 2013). The vast number of jumps and high intensity movements call upon a great need for neuromuscular fitness when competing. Coaches and sports medicine individuals must be tactical in their training loads to provide the optimal physiological stimulus without overstressing the volleyball athlete.

Training load (TL) is defined as the total amount of stress imposed on an athlete in a training session or competition and is related to the amount of stimulus present for inducing physiologic adaptations (Impellizzeri, Rampinini, & Marcora, 2005; Lambert & Borresen, 2010). Due to different ways that TLs can stimulate different physiological adaptations, coaches need to monitor TLs closely to ensure the goal of the training session is met. Furthermore, increasing TLs also have an impact on the incidence of injury (Anderson, Triplett-McBride, Foster, Doberstein, & Brice, 2003) and through monitoring, coaches may be able to avoid preventable injuries. Overall, TL is a function of both internal and external TLs. External TL is defined as the amount of work that is completed during the work out. Internal TL is the physiological response that occurs within the body as a result of the external TL. Physiological adaptations then occur as a response to the internal TL (Impellizzeri et al. 2005).

In order for adaptations to occur, a balance between TL and recovery must exist. Without sufficient recovery, athletes may become chronically fatigued. By monitoring TL and recovery, coaches can gain a better understanding of athlete's response to training

and ideally use that information to periodized appropriate training/rest schedules (Lambert & Borresen, 2009).

Unlike some sports where quantifying TL can be accomplished by distance accumulation or training duration, the acyclic nature of volleyball makes monitoring stresses placed on the athletes difficult. Therefore, the purpose of this paper aims to examine the components involved with quantifying TL for volleyball. More specifically, this paper will inspect the available literature in order to better understand the relationship between internal and external TL and their affiliation with neuromuscular fatigue, recovery, and incidence of injury.

Training Load

Training loads represent the quantification of stresses imposed on athletes and the body's response to those respective stresses during training sessions (Impellizzeri et al. 2005). As athletes aim to maximize performance, modifications of TL are necessary to provide appropriate stimulus and recovery in order for adaptations to occur. To track the changes in overall TL, both internal TL and external TL need to be evaluated. Internal TL involves quantifying the body's physiological response to a physical stimulus where the physical stimulus, such as the amount of work done, is known as external TL (Impellizzeri et. al., 2005; Scott, Lockie, Knight, Clark, De Jong, 2013). It is important to monitor internal and external TLs and examine the relationship between the two as they may reveal different information relating to fatigue (Halsen, 2014) for each athlete.

Traditional methods used by coaches for monitoring external TL may include: quantifying the amount of weight lifted, the distance covered, the acceleration of the body in different planes of movement, the duration of a drill or entire session, and the

number of jumps, etc. With the invention of integrated technology such as accelerometers, global positioning systems (GPS), time motion analysis, and power output measurements (Halsen, 2014; Dellaserra, Gao & Ransdell, 2014) external TL can be quantified much easier than previous times when such monitoring methods were not available. For example, individual cyclic sports, such as running or cycling, can rely on training duration or power output measurements to quantify external TL. However, these methods are difficult to use with team sports due to the intermittent nature of multidirectional movement. Quantifying external TL with integrated technology monitoring devices, more specifically accelerometers, has been successful in team sports such as soccer, rugby, Australian Rules football, netball, and basketball (Dellaserra et. al., 2014; Scott et. al., 2013; Chandler, Pinder, Curran, & Gabbett, 2014; Cormack, Mooney, Morgan, & McGuigan, 2013). Triaxial accelerometers calculate external TL by accumulating accelerations measured in gravitational forces (g) in the vertical (x), lateral (y), or frontal (z) axes. Mechanical intensity is the range in which the peak acceleration value fits in any one second epoch, which can be described as 1/60th minute. Mechanical intensity is then multiplied by duration to provide external TL (OmniSense Analysis User Guide, Zephyr Technology Inc, Annapolis, MD, 2013).

Internal TL is also important to monitor for comprehensive knowledge of the stress placed on an athlete during training. Currently, there are many subjective and objective measures available to quantify internal TL. Objective measures of quantifying internal TL include: heart rate (HR) based measures, blood lactate measures, biochemical assessments, sleep monitoring, and psychomotor speed assessments (Halsen, 2014; Impellizzeri et. al., 2005; Lambert & Borresen, 2010). Quantifying internal TL is very

common in laboratory settings; however, due to cumbersome instruments and the dynamic nature of sports, the methods used in the labs are not always practical to use with athletes in their training and competitive settings. Subjective measures tend to be easier and more practical to use for team sport athletes. Survey responses such as the session rating of perceived exertion (sRPE) are inexpensive practical ways to measure internal TL and have been used for large groups and teams for many years (Halson, 2014; Impellizzeri et. al., 2005; Lambert & Borresen, 2010). The original rating of perceived exertion (RPE) scale by Borg (1982) integrates information from the working muscles, joints, central cardiovascular system, respiratory function, and the central nervous system and configured into one general representation of perceived exertion during an exercise session.

The sRPE developed by Foster (1998) uses a modification of the original CR-10 scale by Borg (1982) to determine global intensity of a training session and multiplies the intensity value by the duration of training in minutes to determine internal TL (referred to as sRPE load in this paper). Participants respond to the question “How hard was your workout?” 15-30 minutes following the completion of the last drill or exercise of their training session. The time delay following a training session is used to ensure the rating provided by the athlete is representative of the entire workout and not influenced by a particularly easy or difficult drill at the end of the session (Foster et al., 2001). The resulting value is represented in arbitrary units (Foster, 1998). The sRPE allows athletes to accurately report their perception of training intensity regardless of detail oriented or globally focused mindsets (Foster et al. 2001). The sRPE load may be more effective for quantifying TL for high intensity sports whereas HR may be less accurate due to the

incompatibility between slow HR response and rapid change in intensity (Foster et. al., 2001; Scanlan, Wen, Tucker, Borges, & Dalbo, 2014; Alexiou & Coutts, 2008).

Alexiou and Coutts (2008) examined the relationship between sRPE and HR measures of internal TL with soccer players during various training stimuli such as: conditioning, matches, speed training, technical training, and resistance training. A small correlation ($r = 0.25-0.52$) was found between sRPE and HR based training impulse (Banister, 1991), as well as sRPE and summated HR zone TL (Edwards, 1993) during resistance training compared to larger correlations in the other phases of training. Due to the high anaerobic demands of resistance training, HR does not increase in a similar fashion as sRPE. This suggests that HR based TL measures are relatively poor for activities that rely primarily on oxygen-independent energy systems rather than oxygen-dependent energy systems (Alexiou & Coutts, 2008). In place of HR based TL measurements, sRPE load has shown promise to be an effective tool for quantifying TL as perceived by athletes (Foster et al., 2001).

Scanlan et al. (2014) investigated the relationship between sRPE internal TL and external TL using triaxial accelerometers with a men's basketball team and found a moderate correlation ($r = 0.49$). On the contrary, Scott et al. (2013) found strong correlations ($r = 0.84$) between the same external and internal TL measures in a men's soccer team. High-intensity movements such as jumps, turns, and physical contacts may be categorized in a lower intensity category despite imposing a high internal TL on the athlete (Scott et al., 2013). Accelerometer values depend highly on vertical accelerations (Scanlan et al. 2014). Basketball training involves a high amount of rotational and horizontal changes of direction and a relatively smaller amount of linear running and

therefore less vertical accelerations (Scanlan et al. 2014) compared to soccer. The smaller playing area, compared to larger open field sports like soccer, and the intermittent, unorthodox movement demands of volleyball are similar to those of basketball. However, volleyball requires more vertical accelerations to perform skills such as blocking, hitting, setting, and serving. It is possible that a stronger correlation compared to basketball will be observed between the sRPE and accelerometer derived external TL due to the increased demand of vertical accelerations. More research is required to examine the relationship between sRPE and accelerometer derived measures of external TL. Athletic monitoring is important to ensure training loads are met to create a proper physiological stimulus as previously mentioned, likewise, TLs should also be monitored to avoid burn out, staleness, or risk of injury.

Training Loads and Injury Risk

Internal and external TL can also be used to examine potential injury risk (Colby, Dawson, Heasman, Rogalski, & Gabbett, 2014) and the incidence of injury (Gabbett, 2004a; Gabbett, 2004b; Gabbett & Jenkins, 2010; Gabbett & Domrow, 2007) over the course of a periodization plan. Injury is defined as one that has occurred as a result of participation in an organized intercollegiate volleyball training session, required medical attention by a team certified athletic trainer or athletic training student, and resulted in restriction of the players participation or performance for 1 or more calendar days beyond the date of initial injury (Dick, Agel, & Marshall, 2007). The sRPE load has been used to evaluate the incidence of injury in basketball (Anderson et al., 2003) and extensively with rugby (Gabbett, 2014; Gabbett, 2004a; Gabbett, 2004b; Gabbett & Jenkins, 2010; Gabbett & Domrow, 2007). These studies all have a common theme; when TL increases,

a subsequent increase in injury incidence is likely to occur as well. Research suggests that dramatic increases of internal TL tend to result in increased injury occurrence (Anderson et al. 2003). These dramatic increases in internal TL most notably occur between the off-season and pre-season training cycles and following holiday breaks (Gabbett 2004a; Gabbett, 2004b; Anderson et al. 2003). Therefore, in order to monitor internal TL for injury prevention, internal TL should be monitored daily and week to week differences should be noted. Observations over the course of three years found that reducing TLs in the pre-season from the first year to the second year resulted in a reduction of injury occurrence (Gabbett, 2004a). By reducing TLs 10.6%-15.7%, there was a 39.8-50.0% reduction in injury (Gabbett, 2004a). Also noteworthy in this study, there was no significant difference between pre-season sRPE TLs for the second and third years and consequently there was no significant difference in the incidence of injury. This further supports the notion that incidence of injury is related to dramatic increases in sRPE TL. Interestingly, common findings between these studies (Gabbett, 2014; Gabbett, 2004; Gabbett & Jenkins, 2010; Gabbett & Domrow, 2007; Gabbett, 2004) are that overexertion was the primary mechanism of injury as soft tissue injuries, such as muscle strains and sprains, were the most commonly occurring injury. Although recovery was not examined in these studies, an increase in TL followed by ensuing injury suggests that athletes require proper recovery for physiological adaptations to occur. It should also be noted that although internal TL was decreased there was no significant decrease in VO₂ max or agility observed in these studies (Gabbett & Domrow, 2007; Gabbett, 2004). This suggests that a threshold may exist where some amount of TL (external or internal) stimulus is required to maintain the physiological adaptations while

preventing soft tissue injuries. Further research is required to examine the influence of TL on injury and the consequence alterations in TL may have on performance related measures.

In order to determine TLs, accelerometers such as Zephyr BioHarness (manufacturer information here) devices have been found to be valid and reliable for laboratory based, steady-state treadmill running protocol (Johnstone, Ford, Hughes, Watson, & Garrett, 2012a; Johnstone, Ford, Hughes, Watson, & Garrett, 2012b). Field based validity and reliability has also been established ($r = 0.92$) when a test-retest protocol was used during incremental jog-run protocol (Johnstone, Ford, Hughes, Watson, & Garrett, 2012c).

Stretch Shortening Cycle and the Reactive Strength Index

Almost all human movements are comprised of eccentric muscle actions followed immediately by a concentric muscle action (Wilson, Elliott, & Wood, 1991). This is known as the stretch-shortening cycle (SSC). Using the SSC effectively can result in improved concentric contraction performance that ultimately can result in increased work, power, or the efficiency of movement (Wilson et al., 1991). The increase in performance is believed to be, at least in part, a result of elastic energy being stored for a short duration during the eccentric action combined with an involuntary increase of neural reflexes to the muscle. Additional theories related to performance increases of SSC include the musculotendinous stiffness, which allows better transmission of force to the concentric contraction (Wilson et al., 1991). Muscle stiffness is defined as the resistance of a muscle to increase in length under an applied load (Ackland, Elliott, & Bloomfield, 2009). Stiffness regulation is related to elastic properties of the

musculotendinous unit and any activation of muscle, therefore excitatory reflex feedback from muscle spindles and inhibitory reflex feedback from Golgi Tendon Organs will affect muscle stiffness (Ackland, et al, 2009). Muscle stiffness can be determined by the ratio of the change in muscle force production over the change in muscle length (Lapier, Burton, Almon, & Cerny, 1995).

As a consequence of rapid changes in length, the excitatory muscle spindle reflex is employed where muscle spindles send a summation of excitatory action potentials on the afferent pathway to the spinal cord (Brooks, Fahey, & Baldwin, 2005; McArdle, Katch, & Katch, 2010). The spinal cord responds by sending an excitatory action potential along the alpha-motor neuron, increasing motor unit recruitment and thus a more forceful muscular contraction. At the same time inhibitory action potentials are sent to motor neurons of the antagonist muscles to reduce recruitment of motor units and decrease force production in the antagonists, which would oppose agonist muscle force production (McArdle et al. 2010).

Golgi-tendon organs respond to changes in tension as opposed to length. They are responsible for inhibitory action to the alpha motor neurons of agonist muscles and facilitate the activation of the antagonist muscles (Brooks et al. 2005; McArdle et al. 2010; Flanagan & Comyns, 2008). When the forces within the musculotendinous unit reach a threshold at which the Golgi-tendon organs deem as harmful to the muscle, they will send excitatory information on the afferent nerves to the central nervous system where the information is received by interneurons. Interneurons then translate this signal to inhibitory information resulting in inhibitory post synaptic potentials (IPSPs) to the alpha motor neuron of the agonist muscle, causing the motor units of the agonist to

require stronger stimuli to be activated (Brooks et al. 2005; McArdle et al. 2010). At the same time as the inhibition of the agonist, a different set of interneurons receive the same afferent signal and translate it into excitatory postsynaptic potentials (EPSPs) which are then sent on the alpha motor neuron to the antagonist muscle, which causes the antagonist to counteract the force production of the agonist (Brooks et al. 2005; McArdle et al. 2010; Flanagan & Comyns, 2008).

Ground contact time can be described as the amortization phase between the eccentric landing and the concentric take off. In order for the muscle spindles to provide assistance in force production, the amortization time must occur quickly, approximately 0.25 seconds or less (Schmidtbleicher, 1992). By increasing amortization time, the elastic mechanisms and reflexive mechanisms of the muscle cannot produce the maximum amount of force (Wilson, 1991). It is well known that increasing amortization time decreases the benefit of the SSC. Amortization time of 1 second reduces SSC benefit approximately 50% and amortization time of 4 seconds or greater completely inhibits all benefit of the SSC (Wilson, 1991).

The reactive strength index (RSI) is a commonly used measure to assess an individual's fast SSC abilities (Young, 1995). A drop jump from a predetermined height is the most common method of assessing an individual's RSI. Reactive strength index is calculated by dividing the maximal height jumped by the contact time with the ground (Flanagan & Comyns, 2008). Reactive strength index is a reliable measure to use for obtaining feedback regarding training intensity, the integrity of the musculoskeletal complex, thus explosive performance ability for strength and conditioning coaches and researchers alike (Flanagan & Comyns, 2008). The use of an electronic jump mat to

assess RSI has been previously validated by Kenny, Caireallain, & Comyns (2008). When monitoring RSI over an extended period of time, researchers can also gather insight into the status of fatigue and outlook on the risk of injury (Hamilton, 2009).

Following fatigue, a change in muscle stiffness is likely to occur due to an increase in proprioceptive inhibition (Toumi, Poumarat, Best, Martin, Fairclough, & Benjamin, 2006). As a consequence of fatigue, muscle spindle stretch reflex sensitivity is decreased and thus decreasing facilitation during the eccentric phase of SSC actions suggesting that decreased SSC performance may result from decreased input from the muscle spindle stretch reflex (Toumi et al., 2006) following fatigue.

It appears that strength and power exercises result in fatigue and post-activation potentiation effects alike (McCann & Flanagan, 2010). Fatigue seemingly decreased faster than the potentiation effects in the previously mentioned study. Therefore, rest intervals following exercises must allow sufficient time for fatigue effects to subside but not long enough for the potentiation effects to subside (McCann & Flanagan, 2010). Furthermore, Evetovich, Conely, and McCawley (2015) mention that 5 minutes of rest was sufficient for fatigue effects to subside in athletic populations but was not sufficient for recreationally trained individuals.

Careful consideration must be taken into account if researchers plan to study RSI after a training session. The complexity and intensity of drills implemented throughout the training session along with rest periods at the end of a training session may complicate the outcome of RSI assessments following a training session. When rest is allowed following a fatiguing protocol, the exercises performed during the fatiguing protocol appear to have a postactivation potentiation effect. Comyns, Harrison, and

Hennessey (2011) observed an increase in drop jump performance when participants were allowed to rest following a fatigue protocol of repeated rebound jumps from 30 cm using a sled device. Initially, Comyns et al. (2011) noted a decrease in drop jump performance, which is in agreement with the findings of Toumi et al. (2006). However, when the participants were allowed 5 minutes of rest, an increase in RSI, vertical jump height, and a decrease in ground contact time were observed compared to the control (Comyns et al., 2006). The increase in jumping ability is believed to be a combined outcome from postactivation potentiation occurring from the SSC exercises and attenuation of acute fatigue brought on by the protocol. The postactivation potentiation causes participants to perform drop jumps with a stiffer muscle-tendon complex (Comyns et al., 2006). Consequently, a stiffer muscle-tendon complex uses the rapid stretch from the eccentric landing to produce increased RSI by means of shorter contact time and increased jump height (Comyns et al., 2006). Although dynamic warm-up exercises improve overall drop jump performance, these factors can be problematic when longitudinal studies collect measurements before and after training sessions and include increased participant population size. Because each individual's training status differs, the long term fatiguing effects from training sessions combined with acute fatiguing effects from postactivation potentiation exercises may yield inconsistent drop jump results. Since individuals respond differently to strength and power exercises (McCann & Flanagan, 2010), researchers must be careful when implementing a generalized dynamic warm-up protocol with large groups of participants or collect RSI measurements following training.

Ortiz et al. (2010) did not find a significant difference in performance when they immediately succeeded a metabolic fatiguing protocol, 30 second Wingate test, with five, 40 cm drop jumps. Additional motor unit recruitment, gluteal and thigh muscle synchronization, and the common drive theory are believed to be the neuromuscular factors responsible for maintaining jump performance following metabolic fatigue (Ortiz et al, 2010). The common drive theory can be described as co-activation of agonist and antagonist musculature responsible for jumping and is a central nervous system reflex used to protect against potential damage (Rodacki, Fowler, & Bennett, 2002). To that end, the agonist muscles are more easily excited and able to produce high rate of force development where the antagonist is down regulated and therefore has less inhibitory effect on the agonist. Typically many coaches implement high intensity sprinting exercises at the end of a training session in attempt to improve anaerobic capacity. The previous findings from Ortiz et al. (2010) suggest that these sprinting exercises at the end of the training session should not change the outcome of the RSI test.

Utilizing the SSC to its fullest ability is highly important for volleyball. Volleyball athletes must be able to jump in order to kill or block the ball and move quickly in lateral directions to get into proper position to dig or pass a ball. When the neuromuscular system becomes fatigued, the SSC ability suffers as a consequence. Increased time on the ground, decreased jump height, or a combination of both are detrimental to performance especially that of volleyball.

Recovery

The use of the overload principle in training is highly important for athletes to improve and advance as a competitor. Without overload, athletes will fail to reach

appropriate physiological stimulus to generate adaptation. Conversely, if coaches and athletes are not careful, excessive overload can lead to overreaching or overtraining (Sikorski et al., 2013). Tissue breakdown, which occurs during training stimuli, is likely occurring at a higher rate than tissue repair during periods of overreaching and overtraining (Smith, 2004) and as a result impairment of athletic performance will likely take place (Bishop, Jones, & Woods, 2008). It is possible overreaching may be caused by under-recovering, as opposed to too much training (Bishop et al. 2008). Therefore, sufficient recovery is mandatory for athletes to maximize training adaptations and prevent overreaching (Bishop et al. 2008; Sikorski et al. 2013; Laurent et al., 2011).

Currently there is a vast variety of research examining training strategies, however there is a severe lack of research investigating recovery. Bishop et al. (2008) states that recovery is one of the least understood and most under researched constituents of the exercise-adaptation cycle. Presently, the majority of tools and methods we have to measure recovery are time consuming, invasive, and expensive including: salivary immunoendocrine assays, blood markers, and measurements taken during sleep, such as HR variance (Bishop et al. 2008; Sikorski et al. 2013; Laurent et al. 2011). Laurent et al. (2011) recognized the paucity of research that exists regarding day-to-day training recovery and developed an inexpensive, noninvasive perceived recovery status scale.

The perceived recovery status (PRS) scale is a 1-10 scalar representation similar to the RPE scale (Laurent et al. 2011). A few differences are noted between the two scales however. The PRS scale includes verbal anchors such as “not at all recovered,” “moderately recovered,” and “very well recovered.” Additionally, the PRS scale is

presented to the participants prior to the start of a training session following a brief warm-up (Laurent et al. 2011). The PRS may be a better predictor of recovery and better tool to prevent overtraining (Laurent et al., 2011; Sikorski et al. 2013) because participants are asked to rate their level of recovery prior to training, as opposed to after training. If a lack of recovery is observed prior to starting a training session, the training plan can be adjusted accordingly, to prevent further fatigue and subsequent overtraining (Laurent et al. 2011).

To date there is a paucity of research that exists involving the use of the PRS scale. The initial study by Laurent et al. (2011) examined perceived recovery and expected performance outcomes of participants performing repeated sprint exercises. Participants were able to effectively predict whether they would have a better performance or worse performance based on their perception of recovery (Laurent et al. 2011). Further, these findings suggest that athletes performing high-intensity intermittent exercise can provide useful knowledge regarding recovery status and expected performance outcomes through the use of the PRS (Laurent et al. 2011). Similar noteworthy findings were reported by Sikorski et al. (2013) involving resistance training exercises and the use of the PRS. As an individual's recovery status decreases performance will likely decrease. Although high-intensity exercises such as repeated sprints and resistance training are not specifically volleyball related, the results suggest this scale could provide valuable insight to volleyball training due to the high-intensity intermittent nature of the sport.

Acceleration based external TL quantification seems much more suitable for indoor sports such as volleyball. Currently no research exists exploring the relationships

between internal and external TL with measures of fatigue and recovery or injury occurrence in volleyball players. Therefore, the purpose of this study is to determine the physical demands of a volleyball preseason training cycle using various types of training load and the relationship between training loads and injury.

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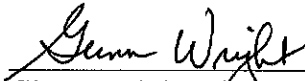
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THE EFFECTS OF TRAINING LOAD ON INDICATORS OF RECOVERY AND
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By Eric J. Linnell

We recommend acceptance of this thesis in partial fulfillment of the candidate's requirements for the degree of Master of Science in Human Performance

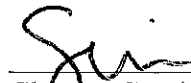
The candidate has completed the oral defense of the thesis.



Glenn Wright, Ph.D.
Thesis Committee Chairperson

June 22, 2015

Date



Clayton Camic, Ph.D.
Thesis Committee Member

6-22-15

Date



Scott Doberstein, M.S.
Thesis Committee Member

6/22/15

Date

Thesis Accepted



Steven Simpson, Ph.D.
Graduate Studies Director

8/24/15

Date