

UNIVERSITY OF WISCONSIN-LA CROSSE

Graduate Studies

FATIGUE AND PERFORMANCE DIFFERENCES BETWEEN INCOMING  
FRESHMEN AND RETURNING DIVISION III COLLEGIATE WOMEN SOCCER  
PLAYERS WHEN COMPLETING A REPEATED SHUTTLE-SPRINT PROTOCOL

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

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By Layne Nowlin

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## ABSTRACT

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Repeated linear and change of direction (COD) ability has received little analysis in collegiate women soccer players. The purpose of this study was to compare differences in performance and rate fatigue between incoming freshmen and returning Division III collegiate women soccer players during a repeated shuttle-sprint (RSS) protocol that included a 10 m linear and 10 m COD component. Each sprint of the RSS test was a modification of the 505-agility test, and subjects completed 10 maximal shuttle sprints on 30-second cycles. Measurements taken were best and average time, and performance decrement for the linear, COD, and total time for each sprint, heart rate and blood lactate during the RSS. Independent t-tests and effect sizes were used to determine differences between groups. No significant differences were identified; however, average linear time showed that there was a moderate effect between groups. All other performance and fatigue variables showed there were trivial to small effects between groups. Total time was more highly correlated to COD time compared to linear time. The results of this study indicate freshmen Division III women soccer players have similar abilities as returning players in repeated linear and COD sprint performance.

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## INTRODUCTION

Soccer is one of the most popular sports for women at the collegiate level (NCAA, 2011). Soccer requires athletes to have high aerobic and anaerobic fitness levels, the ability to jump, sprint, change direction, and to complete sport-specific skills (Aziz, Mukherjee, Chia & Teh, 2007; Little & Williams, 2005; Tang et al., 2018). The ability to repeatedly get to the ball faster than the opponent and to sustain this ability throughout the duration of a soccer match is an important performance criterion. This critical performance criterion relies heavily on repeated sprint ability (RSA). Repeated sprint ability is defined as a series of short sprints (<10 seconds) separated by short recovery periods (<60 seconds) (Iaia et al., 2017). In soccer, players are often required to repeatedly produce maximal or near maximal sprints of short duration (1-7 seconds) with brief recovery periods (Bangsbo, Norregaard & Thorso, 1991; Withers, Maricic, Wasilewski & Kelly, 1982). Therefore, the ability to repeat multiple sprints at high speed is important for soccer physical performance (Wragg, Maxwell & Doust, 2000).

One essential characteristic for soccer players is change of direction (COD) speed, which is the ability to change direction as quickly and efficiently as possible. Change of direction speed is the underlying physical component of agility, and incorporates an individual's movement technique, acceleration and deceleration capacities, leg strength and power, and anthropometry (Sheppard & Young, 2006). One commonly used test to measure COD ability is the 505-agility test. The 505-agility test can isolate COD ability for each leg, and has been used to assess COD ability in soccer players (Lockie et al.,

2016). Bloomfield, Polman, O'Donoghue & McNaughton (2007) found that during a typical soccer match, soccer players perform directional changes 90-100 times at 90-180° angles. Therefore, in order to help make soccer training more specific, directional changes have been introduced in some RSA tests and during repeated sprint training sessions (Buchheit, Bishop, Haydar, Nakamura & Ahmaidi, 2010; Dal Pupo, Detanico, Carminatti & Santos, 2012; Impellizzeri et al., 2008).

The importance of RSA in team sports is well accepted, but there is no consensus on how to measure it. This is because RSA constitutes a physiologically and biomechanically complex performance challenge. One way that has been used to quantify fatigue during RSA is by calculating the performance decrement (Gabbett, 2010). A lower performance decrement has been shown to indicate that athletes are better able to maintain their maximal efforts during repeated sprints (Lockie et al., 2018). In addition, measuring aerobic capacity is a common element in the performance ability of soccer players and has been related to RSA (Bishop & Edge, 2006; Hamilton et al., 1991; Tomlin & Wagner, 2002). The 1200 m shuttle endurance test, which can reliably assess aerobic capacity, takes roughly 5-6 minutes to complete and includes 29 directional changes, accelerations, and decelerations at 180° angles. These characteristics of the 1200 m shuttle endurance test make it an ideal endurance test for soccer athletes (Brew & Kelly, 2014).

Higher skilled soccer players have been shown to have better RSA performance compared to lesser skilled soccer players (Gabbett, 2010; Rampini et al. 2009). However, there is little research on the differences between repeated linear and COD sprints in freshmen and upper class Division III (DIII) collegiate soccer athletes. Therefore, the

purpose of this study was to compare the performance and rate of fatigue between freshmen and returning DIII collegiate women soccer players during a repeated shuttle-sprint protocol that included a 10 m linear component and a 10 m COD component.

## **METHODS**

### **Experimental Approach to the Problem**

A cross-sectional study design was used for this project to compare the rate of fatigue between freshmen and returners, DIII collegiate women soccer players. The two groups were assessed for RSA and aerobic fitness using two different COD protocols. Subjects reported to the indoor facility on three different occasions within the same 7-day period immediately prior to the start of preseason training camp. On two of the visits to the training facility, subjects performed a repeated shuttle-sprint (RSS) test that included a 10 m linear and 10 m COD component. The first visit was a familiarization trial for the RSS test, during the second visit subjects performed a 1200 m shuttle test to assess aerobic fitness, and the third visit was the RSS experimental trial. Intensity of the RSS protocol was indicated by heart rate response and change in blood lactate measurements taken before and after the experimental RSS protocol.

### **Subjects**

Eighteen DIII collegiate women's soccer players (freshmen, n=9; returners, n=9) from the same team were recruited for this study. The subjects' characteristics for each group were as follows (mean  $\pm$  SD) [(Age: freshmen  $18.6 \pm 0.9$  years; returners  $20.4 \pm 0.9$  years) (Height: freshmen  $168.4 \pm 4.9$  centimeters; returners  $165.3 \pm 4.8$  centimeters) (Body Mass: freshmen  $65.02 \pm 5.79$  kg; returners  $66.3 \pm 5.74$  kg)]. The exercise protocols and all possible risks and benefits associated with participation in the study were explained to each subject. Each subject provided written informed consent prior to

participating in the study. The Institutional Review Board of the University of Wisconsin - La Crosse granted approval for the study's procedures.

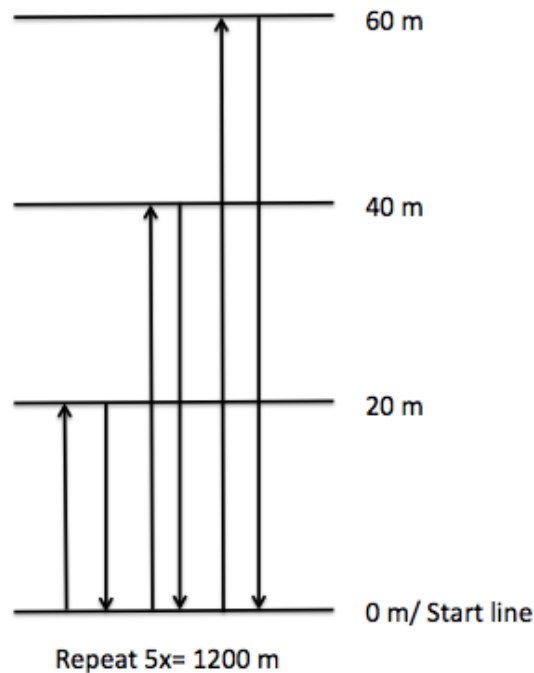
### **Procedures**

Before each assessment below, subjects completed the standardized warm up they were accustomed to, as it was similar to their summer workout warm up. The warm up was performed on an indoor synthetic surface and consisted of dynamic stretches in all planes of movement along with multidirectional short accelerations. A perceived recovery status (PRS) questionnaire (Laurent et al., 2011) was used to evaluate the perceived level of recovery of the athletes before completing each of the following tests (the 1200 m shuttle and the RSS protocol). After completion of the warm up, the athletes ranked their PRS on a scale of 0-10 with 0 not being recovered at all, 5 being moderately recovered, and 10 being well recovered (Laurent et al., 2011).

#### **1200 m Shuttle Test**

The 1200 m shuttle run test (figure 1) consisted of a continuous 20 m, 40 m, and 60 m straight shuttle run (i.e. 20 m and back, 40 m and back, 60 m and back) repeated five times. Subjects performed this test as a conditioning drill on several occasions throughout the summer training program to prepare for the season. Subjects completed the test in two groups of nine with each group having a mixture of freshmen and returners. The 1200 m shuttle test was timed using a stopwatch and subjects were informed of time elapsed regularly during the entire test. The subjects' completion time was recorded to the nearest second, and was later converted to a mean velocity score. Each subject was required to touch each line with their foot, and their foot was closely monitored throughout each shuttle by a member of the research team. Subjects

were told to run at a fast steady pace to complete the test as fast as possible. Strong Verbal encouragement was given for each subject.



**Figure 1: 1200 m shuttle run test**

The 1200 m shuttle test was used to calculate maximal aerobic speed (MAS) through a rough estimation of  $VO_2$  based on the average velocity run during the 1200 m shuttle test. Using the equation by Berthon et al. (1997) ( $VO_2 \text{ max} = 3.23 * \text{MAS} + 0.123$ ), the 1200 m shuttle times were converted to a rough estimation of  $VO_2$  and, assuming maximal effort,  $VO_2 \text{ max}$ .

### **Repeat Shuttle-Sprint Protocol**

The RSS protocol consisted of ten maximal shuttle sprints, occurring every 30 seconds, with the subjects using the same turning foot for every repetition. Each sprint of the RSS protocol was a modification of the 505-agility test (Draper & Lancaster, 1985). An interval timer app (Seconds Interval Timer, Runloop, Ltd., Version 3.16) on an iPad, plugged into a speaker was used to inform the subjects when to start each sprint. Timing

gates (TC timing system: Brower Timing, Draper, UT) were placed at the start line and 10 m from the start line (Figure 2).

Subjects started each shuttle sprint in a staggered 2-point stance with their choice of foot in front, 0.6 m behind the start line to avoid triggering the timing system. The timing system started when the subjects first made contact/disrupted the beam of the timing gate at the starting line. Subjects sprinted as fast as possible through the timing gate at the starting line. Subjects sprinted as fast as possible through the timing gate at the 10 m line to the turning line at 15 m, planted their foot while they turned 180°, and then sprinted 5 meters back through the timing gate. After completing one repetition of the shuttle sprint, the athletes decelerated back to the start line where they passively recovered before the next sprint. Subjects were instructed to complete all sprints as fast as possible, and strong verbal encouragement was provided to each subject during all sprints. The 10 m linear and the 10 m COD portion of the shuttle sprint were recorded separately to the nearest 0.01 second. Total time of each shuttle sprint was also recorded. Performance decrement (%) for the 10 sprints was calculated separately for the linear, COD, and total time components using the formula: Performance decrement =  $100 - (\text{ideal time} / \text{total time} \times 100)$  (Glaister, Stone, Stewart, Hughes & Moir, 2004).

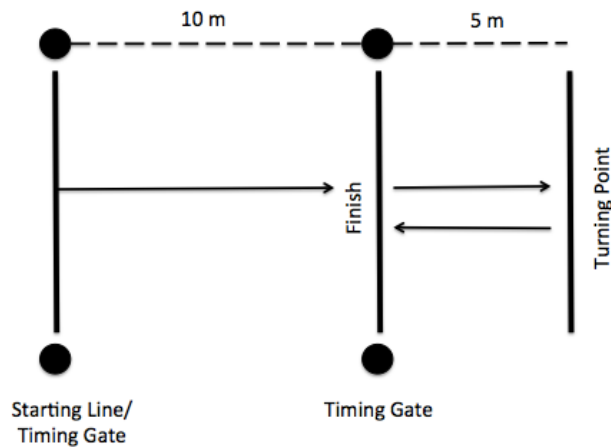


Figure 2: Repeated Shuttle-Sprint

## **Blood Lactate Measurement**

Immediately before, and five minutes following the last sprint of the RSS test, a fingertip blood sample (0.6  $\mu$ l) was collected to determine blood lactate accumulation during the RSS test (Lactate Plus, Nova Biomedical, Waltham, MA).

## **Heart Rate**

Heart rate (RSA) was recorded continuously throughout the entire duration of the RSS testing session using a HR monitor (Polar Electro, Inc., Bethpage, NY) affixed to the subject by a chest strap. Peak percent heart rate max (% HR max) and average % HR max were used for analysis. The equation  $220 - \text{age}$  was used to predict HR max within the proprietary software of the heart rate monitor.

## **Statistical Analysis**

Data are presented as mean  $\pm$  SD and 95% confidence intervals. Independent t-tests were used to determine intergroup differences between performance data. The Shapiro-Wilk Test of Normality was performed before analyzing the data to determine that the data was normally distributed. The effect size (ES) was calculated for all performance data using the Cohen's  $d$  equation:  $(M_2 - M_1) / \sqrt{((SD_1^2 + SD_2^2) / 2)}$ , and classified using the following criteria for 'recreationally trained' subjects:  $<0.35$  (trivial), 0.35-0.80 (small), 0.80-1.50 (moderate) and  $>1.5$  (large) (Rhea, 2004). Pearson's product-moment correlation ( $r$ ) was calculated to determine the relationships between performance variables using the following criteria: 0.00-0.30 (negligible), 0.30-0.50 (low), 0.50-0.70 (moderate), 0.70-0.90 (high) and 0.9-1.0 (very high) (Mukaka, 2012). The alpha level of significance was set as 0.05. Data was analyzed with software

(Statistical Package for Social Sciences Version 26; International Business Machines, Armonk, United States of America).

## RESULTS

### Repeat Shuttle-Sprint Performance Outcomes

Prior to the RSS protocol, recovery from current training indicated by PRS, was not significantly different between the groups (freshmen,  $7.06 \pm 1.19$ , CI= 6.28 to 7.84; returners,  $7.44 \pm 0.88$ , CI= 6.87 to 8.01,  $p= .44$ , ES= 0.37). Qualitatively, PRS values between 7 and 8 have previously been classified by Laurent et al. (2011) as approaching “well recovered- somewhat energetic”, indicating both groups were recovered similarly from any recent training.

Performance times as well as performance decrement of the freshmen and returners for the different portions of each sprint (Linear, COD, Total time) of the RSS protocol are presented in Table I. For best times, differences between groups in linear and COD portions, as well as total time of the shuttle sprint were not significantly different. The small and trivial effects for best times between groups for each portion of the RSS protocol also indicate that any differences were inconsequential.

For average times, differences between groups were not found to be significant for linear, COD, or total time. A moderate effect was identified for average linear time indicating an advantage in average linear speed throughout the 10 shuttle sprints of the RSS protocol for the freshmen vs. the returners was likely practically relevant.

Performance decrement scores were not significantly different between groups for linear, COD, or total time of the RSS protocol. The small and trivial effects in

performance decrement between groups for each portion of the RSS protocol also indicate that any differences were irrelevant.

### **Physiological Responses During the Repeat Shuttle-Sprint Protocol**

Peak % HR max during the RSS protocol was similar between freshmen and returners (freshmen,  $90.0 \pm 3.7\%$ , CI= 87.6 to 92.4%; returners,  $90.0 \pm 4.2\%$ , CI= 87.3 to 92.7%,  $p= .91$ , ES= 0.06). In addition, average % HR max over the entire shuttle-sprint protocol was also similar between groups (freshmen,  $85.0 \pm 4.6\%$ , CI= 82.0 to 88.0%; returners,  $83 \pm 4.8\%$ , CI= 79.9 to 86.1%,  $p= .632$ , ES= 0.26).

Blood lactate levels following the RSS protocol were not different between freshmen ( $6.5 \pm 2.72$  mmol/L, CI= 4.72 to 8.28 mmol/L) and returners ( $8.1 \pm 2.37$  mmol/L, CI= 6.55 to 9.65 mmol/L) ( $p= .20$ ) (ES= 0.62).

### **Performance Outcome of 1200 m Shuttle Endurance Test**

Prior to the 1200 m shuttle endurance test, there was no significant difference in recovery status between groups indicated by PRS (freshmen,  $7.1 \pm .9$ , 6.51 to 7.69; returners  $6.4 \pm 1.4$ , CI= 6.25 to 6.55,  $p= .22$ , ES= 0.59). Interpretation of the PRS rating between 6 and 7 indicate both groups were “moderately recovered” before performing the 1200 m shuttle endurance test (Laurent, 2011).

No difference in performance of the 1200 m shuttle endurance test was observed between groups (returners,  $348.0 \pm 17.9$  sec; CI= 335.6 to 360.4 sec) (freshmen,  $352.0 \pm 46.9$  sec; CI= 321.36 to 382.64 sec) ( $p= .82$ ) (ES= 0.11).

It was estimated that freshmen had a maximal  $\text{VO}_2$  of  $\sim 42.2$  ml/kg/min, and the returners had a maximal  $\text{VO}_2$  of  $\sim 40.3$  based on the average velocity run during the 1200 m shuttle test.

### **Relationships Between Variables**

The best total time was highly related to best COD time ( $r = .88, p < 0.01$ ) and moderately related to best linear time ( $r = .67, p < .01$ ). In addition, the relationship between the best linear time and the best COD time was low ( $r = .32, p < 0.01$ ).

Average total time of each shuttle sprint was found to have a high relationship with the time of average COD ( $r = .82, p < 0.01$ ) and the average linear ( $r = .79, p < 0.01$ ) portion of each shuttle sprint.

Total time performance decrement was found to have significant relationships with the COD performance decrement ( $r = .66, p < .01$ , Moderate), and 1200 m shuttle ( $r = .33, p < .01$ , Low).

Table 1. Performance variable outcomes between freshmen and returning soccer players during the repeated shuttle sprint test (mean  $\pm$  SD; 95% confidence intervals).

Variable	Freshmen	Returners	p-value	ES	ES Strength
Linear Best (s)	2.01 $\pm$ 0.09 (1.95 to 2.07)	2.07 $\pm$ 0.06 (2.03 to 2.11)	.13	0.78	Small
COD Best (s)	2.62 $\pm$ 0.08 (2.57 to 2.67)	2.64 $\pm$ 0.05 (2.58 to 2.79)	.71	0.23	Trivial
TT Best (s)	4.68 $\pm$ 0.13 (4.59 to 4.77)	4.74 $\pm$ 0.13 (4.65 to 4.82)	.39	0.45	Small
Linear Ave. (s)	2.06 $\pm$ 0.09 (2.00 to 2.12)	2.13 $\pm$ 0.05 (2.10 to 2.16)	.08	0.95	Moderate
COD Ave. (s)	2.70 $\pm$ 0.08 (2.64 to 2.76)	2.70 $\pm$ 0.09 (2.64 to 2.76)	.98	0.00	Trivial
TT Ave. (s)	4.77 $\pm$ 0.14 (4.68 $\pm$ 4.86)	4.74 $\pm$ 0.13 (4.74 to 4.91)	.39	0.45	Small
Linear %Dec	2.75 $\pm$ 1.30 (1.90 to 3.60)	3.00 $\pm$ 1.13 (2.26 to 3.74)	.67	0.21	Trivial
COD %Dec	2.98 $\pm$ 0.68 (2.54 to 3.42)	2.46 $\pm$ 0.88 (1.88 to 3.04)	.18	0.66	Small
TT %Dec	1.74 $\pm$ 0.70 (1.28 to 2.20)	1.94 $\pm$ 0.56 (1.58 to 2.30)	.50	0.32	Trivial

Change of direction (COD), total time (TT), average (Ave.), performance decrement (%Dec), seconds (s), effect size (ES)

## **DISCUSSION**

The goal of this study was to compare the performance and rate of fatigue between freshmen and returning DIII collegiate women soccer players during a RSS protocol (10 x 20 m shuttle-sprint departing every 30 seconds) where each shuttle-sprint included a 10 m linear and 10 m COD component. We hypothesized that freshmen and returning soccer players would have similar linear sprinting performances, but the returning soccer players would have faster COD sprint performances. We also hypothesized that fatigue would be greater in freshmen during the RSS protocol, especially during the COD portion of the sprint.

The athletes rated their perceived recovery before completing the 1200 m shuttle and the RSS protocol, and PRS was similar between groups for both tests, indicating adequate recovery for optimal performance. Laurent et al. (2011) found that 76% of subjects that rated PRS to be >5 performed better than a previous repeat 30 m sprint protocol and 86% of those that reported a PRS of <5 performed worse. Both groups in our study rated PRS between 7 and 8 for the RSS and between 6 and 7 for the 1200 m shuttle, indicating that impaired recovery status was likely not a factor of performance outcomes between groups during the RSS or 1200 m shuttle protocols.

### **Performance Outcomes Between Groups**

The results of our study indicate there were no significant differences in RSS performance outcomes between freshmen and returning women's soccer players of the team studied. However, it is also important to consider effect size in sport science

research as effect size is a way of assessing practical relevance when quantifying the difference between two groups, independent of sample size (Frohlich, Emrich, Pieter & Stark, 2009). The only practically relevant performance outcome observed to be different between groups was the moderate effect for average linear sprint time during the RSS. This finding indicated freshmen maintained faster running velocity during the linear 10 m portion of the RSS protocol than returners, which challenges our original hypothesis.

Other studies comparing soccer players of different NCAA Divisional levels and different experience levels have found equivocal results comparing 10 m linear sprint performance (Lockie et al., 2016; Lockie, Dawes & Jones, 2018; Risso et al., 2017). Similar to our findings, Lockie, Dawes & Jones (2018) found no significant difference and a trivial effect in best 10 m linear sprint between Division I and Division II collegiate women soccer players. Risso et al. (2017) also found there were no significant differences and a trivial effect in best 10 m linear sprint times between Division I collegiate women starters vs. nonstarters. In contrast to our study, Lockie et al. (2016) found that there were no significant differences and a moderate effect in best 10 m linear sprint times between incoming freshmen and returning Division I collegiate male soccer players favoring the returning players for faster best 10 m linear sprint time, whereas our results indicated that there was little practical relevance between groups.

The best 10 m linear sprint times in our study were slower compared to other studies using women team-sport athletes. In our study, the freshmen and returners best linear 10 m sprint times were 2.01 and 2.07 seconds, respectively. McFarland, Dawes, Elder & Lockie (2016) found that the 10 m linear best sprint time in Division II collegiate women soccer players was 1.92 seconds. Similarly, Lockie, Dawes & Jones (2018) found

that Division I collegiate women soccer players had a 10 m linear best sprint time of 1.91 seconds, and Division II collegiate women soccer players had a 10 m linear best sprint time of 1.89 seconds. Lockie et al. (2015) used a mixture of nine collegiate women team sport athletes, and found the best 10 m linear sprint time to be 1.98 seconds. In addition, Jones et al. (2016) found that elite women rugby back position players had a best 10 m linear sprint time of 1.87 seconds. Risso et al. (2017) found that Division I collegiate women soccer player starters had a best 10 m linear sprint time of 1.98 seconds, and nonstarters had a best 10 m linear sprint time of 1.99 seconds. Plausibly, a reason why our best linear sprint times were slower compared to the other studies may be because other studies used higher level (Division I and II) or more experienced athletes. The literature is sparse in studies using DIII collegiate women's soccer players and as a result, this study contributes 10 m linear sprint times between freshman and returning players from which other future studies may compare.

Other studies have also found COD sprint performance to be similar between soccer players different experience levels when comparing best COD sprint ability between groups (Lockie et al., 2016; Lockie, Dawes & Jones, 2018). Similar to our study, Lockie et al. (2016) found no significant difference and a small effect between freshmen and returning Division I collegiate male soccer players when completing a 10 m COD sprint. In contrast to our study, Lockie, Dawes & Jones (2018) found a moderate effect in best 10 m COD sprint between Division I and Division II collegiate women soccer players. The observation that there were no differences between best 10 m COD sprint times in our study may be because both groups were equally skilled at being able to

change direction from prior training and soccer playing experience, or could be due to a lack of training for COD in the returners, making them less skilled as the freshmen.

The best 505 COD sprint times in our study were similar to some studies and dissimilar to other studies. In the 505-agility test, after a 10 m acceleration, the athlete sprints forward 5 m and then pivots 180° and sprints another 5 m (Draper & Lancaster, 1985). In our study, the freshmen and returners best 505 COD times were 2.62 and 2.64 seconds, respectively. Our results were similar to 505 COD times of Lockie et al. (2015) who used a variety of nine collegiate women team sport athletes and found that the best 505 COD trial for the left leg was 2.62 seconds and 2.63 seconds for the right leg. Lockie, Dawes & Jones (2018) also found the best 505 COD sprint time to be 2.60 seconds in Division II collegiate women soccer players. Jones et al. (2016) found that the elite women rugby back players had a best 505 COD time of ~2.58 – 2.59 seconds. However, our results were slower compared to Division I collegiate women soccer players who recorded a best 505 COD time of 2.40 seconds. It appears that DIII soccer players have similar abilities for COD speed to Division II women soccer players, but slower than Division I women's soccer players.

Our results indicate that there was only a low relationship between best linear time and best 505 COD time, indicating that each portion requires different skills. Thus, having a fast linear speed will not necessarily mean a fast COD speed and this has been found by others (Draper and Lancaster, 1985; Brughelli, Cronin, Levin & Chaouachi, 2008; Sheppard & Young, 2006; Wisloff, Castagna, Helgerud, Jones, & Hoff, 2004) suggesting that short (<10 m) linear and COD sprint tests should not be used interchangeably to test running speed.

Our results also showed that best total time was highly related to best COD time and moderately related to best linear time. Average total time had a high relationship with average COD time and average linear time. Total time performance decrement had a moderate relationship with COD performance decrement. These results suggest that total time is more highly dependent on COD speed. Therefore, coaches should place a greater emphasis on training COD speed.

We assessed the average shuttle-sprint times for 10 sprints with 30 seconds between starts of each sprints. To our knowledge, no studies have compared average 10 m linear, 505 COD, or 20 m shuttle times of repeated sprints. As a result, we suggest these findings for freshmen and returning women's soccer players be set as normative values for DIII soccer players until further studies of this nature are performed.

### **Differences in Linear and COD Fatigue Between Groups**

Before the start of the study, we hypothesized that both groups would exhibit similar fatigue during the linear portion of the RSS protocol, but freshmen would exhibit a greater rate of fatigue during the 505 COD sprints compared to the returning soccer players. We speculated that freshmen would be less familiar with the mechanical skills related to the 180° COD and as a result, be less efficient with the energy necessary for the demands of the shuttle.

No significant differences were found in performance decrement between the groups for total time of each repetition, the linear portion, or the COD portion of the RSS protocol. Total time, linear, and COD performance decrement each showed a small effect indicating that both groups showed similar levels of fatigue. In comparison to the results of this study, Buchheit, Bishop, Haydar, Nakamura & Ahmaidi (2010) found a similar

performance decrement (2.61%) after a mixture of team sport athletes completed a RSS protocol (6 x [2 x 12.5 down-back]) on 25-second cycles.

The rough estimation of  $\text{VO}_2$  max (freshmen,  $\sim 42.2$  ml/kg/min; returners,  $\sim 40.3$  ml/kg/min) based on the average velocity run during the 1200 m shuttle test is likely an underestimation of MAS (average velocity) because the equation used does not take into account directional changes. Over the duration of the 1200 m shuttle test, the athletes had to change direction a total of 29 times. Changing direction requires the athletes to decelerate and reaccelerate which increases the overall time to complete the 1200 m shuttle. Studies using elite teenage male soccer players and college age male Australian Rules Football players have found a weak relationship between  $\text{VO}_2$  max and repeated sprint (RS) performance if  $\text{VO}_2$  max is greater than 46 ml/kg/min (Alizadeh, Hovanloo & Safania, 2010; Aziz, Mukherjee, Chia & The, 2007; Da Silva, Guglielmo & Bishop, 2010; Wadley & Rassignol, 1998). In contrast, Alizadeh, Hovanloo & Safania (2010) found that there was strong relationship between  $\text{VO}_2$  max and RS performance in teenage soccer players who had a  $\text{VO}_2$  max of  $\sim 37$  ml/kg/min ( $r = 0.86$ ). Since there was no difference in performance between 1200 m shuttle test between groups in our study, and the estimates of  $\text{VO}_2$  max of each group was likely in the mid-40's ml/kg/min we speculate that the lack of difference in the performance decrement for total time may be related to similar levels of aerobic capacity between groups. Da Silva, Guglielmo & Bishop (2010) have also noted that few studies have shown that  $\text{VO}_2$  max is related to RSA when sprints less than 40 m (or 6 seconds) have been used. Therefore, our protocol of repeated 20 m shuttles (with total time being less than 5 seconds) may not have been conducive to having a great reliance on  $\text{VO}_2$  max.

Heart rate was used as a measurement of exercise intensity. Our results showed that freshmen and returners had similar peak HR (90% estimated max HR for both groups) and similar average HR (85% vs. 83% estimated max HR, respectively) when completing the RSS protocol. Rampinini et al. (2011) found that over the course of a soccer match, mean HRs ranged from 82.5%- 88% of maximum HR and that peak HRs ranged from 95.1%- 96.3% of maximum. Rampinini's study indicates that the RSS used in our study was similar to the intensity of a soccer match. Buchheit et al. (2010) found that after team sport athletes completed a 6 x 25 m linear sprint test and a 6 x 25 m shuttle (12.5 down-back) sprint test that their maximum HR was 94% of their % HR max. Similarly, Little & Williams (2007) found that after % HR max to be 87% in professional men soccer players completed 15 x 40 m linear sprints with a 1:6 work to rest ratio that their maximum HR was 87% of their % HR max. Our % HR max were slightly higher than Little & Williams (2007), likely because this study used higher-level athletes, and ran further distances. In contrast, our % HR max were slightly lower compared to Buchheit et al. (2010).

Blood lactate levels are an indicator of anaerobic energy contribution (Lonbro et al., 2019) and as a result were used as an indicator of relative exercise intensity. The post blood lactate levels found following the RSS protocol in our study (6-8 mmol/L) were found to not be different between groups; however, they were lower compared to other studies of RS running in team sport athletes (Alemdaroglu et al., 2018; Buchheit et al., 2010; Dal Pupo, Detanico, Carminatti & Santos, 2013; Morcillo et al., 2015). For example, Buchheit et al. (2010) had 13 men and women complete 6 x 25 m linear sprints and 6 x 25 m shuttle (12.5 m down-back) sprints on a 25 second cycle and noted blood

lactate levels, measured three minutes after the last sprint, were 9.3 mmol/L for the linear sprints, and 10.0 mmol/L for the shuttle. Similarly, Dal Pupo et al. (2013) used the same protocol as Buchheit et al. (2010) except the subjects were all men, rest periods between sprints was 10 seconds, and blood lactate levels were measured seven minutes after the last sprint. The authors found blood lactate levels were 11.15 mmol/L after the linear sprints, and 12.23 mmol/L after the shuttle sprints. Kantanista et al. (2019) found that blood lactate levels tend to be higher in men compared to women when sprinting. Therefore, the post blood lactate found in our study may be lower compared to other studies due to the types of subjects used (men vs. women).

### **Limitations**

There are a few limitations with our study that should be mentioned. The greatest limitation is the use of the shuttle sprint protocol that has not been tested for reliability. We recommend that future studies assess the reliability of a 20- yard shuttle-sprint of this manner. Another limitation includes the use of a sample size. Based off of independent t-tests using GPower 3.1, our study would have needed 128 people (64 in each group) in order to have potentially increased the statistical power to 0.8. However, having a total of 64 athletes from each group was not possible because most collegiate soccer teams do not carry that many athletes on their rosters, especially as regards to freshmen.

Another obstacle of this study was that data collection was performed a week before the start of preseason, which may have caused a lack of motivation from the subjects due to the potential risk of injury during the repeat sprint protocol. Thus, this might have affected their sprinting time as a result of decreased effort. Therefore, we recommend future research include a “maximal” single shuttle-sprint during

familiarization training to use as a reference sprint to help determine if the subjects were giving 100% effort or pacing during the test. However, testing should be performed as close as possible to the start of preseason as athletes should be in their best fitness, which was our rationale for testing the week prior to preseason.

Another limitation is that a single sprint containing a linear and COD component was measured in this study. There could potentially be a different response by freshmen and returning soccer players if separate repeated linear and COD sprint tests were used, similar to other studies (Buchheit et al., 2010; Morcillo et al., 2015; Wong, Chan & Smith, 2012).

Lastly, HR was not measured during the 1200 m shuttle test, and it may have been useful to have that reference between HR during the 1200 m shuttle test and the RSS test. Related, there was also a malfunction with the HR monitors for four of the subjects (3 freshmen and 1 returner). Therefore, the HR data for those subjects was excluded from the results, and may have lowered the statistical power for HR results.

In summary, there were no significant differences in performance outcomes of the RSS test between groups. We hypothesized that there would be a difference in COD ability and performance decrement between groups, but our findings do not support our hypothesis. Similarities across most of the performance variables may have been due to the graduation of 11 seniors at the end of the previous season (lack of playing experience of returners), but also the similarity of training program of the subjects in the months prior to testing. Therefore, the subjects in both groups may have entered the study with similar fitness levels. The greatest difference between groups was in linear speed and may have been due to the freshmen group having inherent physical ability to run fast.

Both groups showed similar rates of fatigue during the linear and COD sprint portion of the repeated-shuttle test. To our knowledge, this is the first study to compare the rate of fatigue in freshmen and returning DIII collegiate women soccer players using a novel repeated 20-yard shuttle sprint ability test.

### **Practical Applications**

The current study introduces a novel shuttle-sprint test that can assess linear and COD sprint ability separately in one test, reducing the number of visits to the testing facility and testing time taken from training opportunities. The data from this study provide a reference of a 10 m linear sprint and a 10 m 180° COD sprint for total time of a repeated shuttle sprint for DIII collegiate women soccer players. The data also provides a reference for linear, COD and total time performance decrement scores specific to DIII collegiate women soccer players. Soccer, along with strength and conditioning coaches should work on and emphasize correct 180° COD mechanics. Having improved COD mechanics will increase the athlete's COD speed, and may help to delay the onset of fatigue.

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APPENDIX A

LITERATURE REVIEW

## **Introduction**

Soccer is a sport that consists of intermittent high-intensity movements during match play where repetitive sprints, that include rapid accelerations, decelerations and directional changes, are common (Tang et al., 2018; Little & Williams, 2007). Aerobic endurance is important for soccer match performance because it helps the athletes to perform multiple high intensity efforts (Aziz, Mukherjee, Chia & Teh, 2007; Aziz, Chia & Teh, 2000; Bangsbo, Norregaard & Thorso, 1991). However, the crucial moments in a soccer match depend on the performance of anaerobic activities such as sprinting and jumping (Jullien et al., 2008; Little & Williams, 2005).

During a soccer match, women soccer players cover a total distance of 8.6-11.3 km at an average of 85-87% of maximum heart rate (HR) (Andersson, Randers, Heiner-Moller, Krstrup & Mohr, 2010; Krstrup, Mohr, Ellingsgaard & Bangsbo, 2005; Mohr, Krstrup & Bangsbo, 2003). A typical soccer match consists of about 250 brief intense anaerobic actions, per player, with repeated sprints occurring about 39 times, and sprinting occurring every 90-120 seconds with the sprints lasting 2-4 seconds (Bradley, Mascio, Peart, Olsen & Sheldon, 2010; Bangsbo, Mohr & Krstrup, 2006; Stolen, Chamari, Castagna & Wisloff, 2005; Mohr, Krstrup & Bangsbo, 2003). Intense actions include an average of 111 on ball activities, jumping, and changes of direction (COD) 90-100 times at 90-180° angles (Bloomfield, Polman, O'Donoghue & McNaughton, 2007). The number of times that a soccer player accelerates, decelerates, and changes direction contributes to the neural and metabolic fatigue over the course of a match (Russell et al., 2016).

Linear and COD repeated sprints of the same distance, can differ for the time it takes to complete each sprint, as well as have different effects on the neuromuscular and metabolic demands. Recovery duration, length of the sprint, and the number of directional changes can have various effects on HR, power output (PO), and blood lactate (BLa) concentrations (Tang et al., 2018; Padulo et al. 2010; Little & Williams, 2007; Glaister, Stone, Stewart, Hughes & Moir, 2005).

Studies have shown that highly skilled soccer players have better repeated sprint ability (RSA) performance compared to lesser skilled soccer players (Gabbett, 2010; Rampini et al., 2009). However, there is very little research on the differences between repeated linear and COD sprints in freshmen and upper-class Division III collegiate soccer athletes. An athlete's ability to perform repeated sprints and directional changes is regarded by soccer coaches as a predictor of superior performance, as well as being important indicators of an athlete's overall fitness level (Glaister, 2005; Spencer, Bishop, Dawson & Goodman, 2005; Young, McDowell & Scarlett, 2001). Therefore, the purpose this review is to compare neuromuscular and metabolic demands between RSA with and without COD, and to see if playing experience may play a role in fatigue resistance.

### **Neuromuscular Fatigue**

One consequence that comes with intermittent high intensity exercise with short recovery periods is the onset of fatigue. Neuromuscular fatigue has been defined as an exercise induced reduction in the ability to produce maximum force or power within a muscle or muscle group (Taylor, Amann, Duchateau, Meeusen & Rice, 2016). Fatigue can be classified as neural when the origin is proximal to or at the neuromuscular

junction and muscular when the origin is distal to the neuromuscular junction (Gandevia, 2001).

Neural fatigue results when there is a decrease in central or voluntary drive (motivation) to the motor unit. During exercise, mechanical and metabolic stimuli cause an increase in the discharge rate of groups III and IV muscle afferents that are located within the muscle (Amann, 2012). The groups III and IV muscle afferents are responsible for “activating” the ventilatory and cardiovascular reflex responses, which are controlled by the medulla, during exercise (Craig, 1995). The neural feedback from groups III and IV muscle afferents is essential during high intensity exercise because a lack of muscle blood flow and oxygen delivery will contribute to the level of fatigue in skeletal muscle (Amann, 2012). The III and IV muscle afferents are also responsible for facilitating central fatigue by providing inhibitory feedback to the regulation of neural motor drive and voluntary muscle activation during exercise (Gandevia, 2001). A decrease in voluntary drive will cause a decrease in motor unit recruitment and rate coding, which will then cause a decrease in force production.

Muscular fatigue is multifactorial and can be caused by impaired excitation-contraction (EC) coupling, metabolic factors, and muscle damage. Metabolic fatigue in the muscle occurs when the muscle is using adenosine triphosphate (ATP) at a faster rate than it is producing it, causing a decrease in force production (Gaitanos, Williams, Boobis & Brooks, 1993). Impairment in EC coupling may be caused by a failure of the coupling mechanism between muscle action potentials and the release of calcium due to the action potentials not being able to properly propagate along the surface membrane

and the t-tubular system (Jones, 1996). There are two types of fatigue that can cause EC coupling failure, high frequency fatigue (HFF) and low frequency fatigue (LFF).

High frequency fatigue is characterized by having a loss of force at high frequencies of stimulation around 50 Hz or higher (Jones, 1996; Jones & Bigland-Ritchie, 1986). The high rates of stimulation lead to an increase in the accumulation of potassium ( $K^+$ ) in the extracellular fluid surrounding the muscle fiber. The increase in  $K^+$  will slow the action potentials from propagating along the sarcolemma, and can block the conduction along the t-tubules. This obstruction along the t-tubules will slow repolarization, causing there to be a decrease in calcium ( $Ca^{++}$ ) release, and therefore a decrease force production (Jones, 1996; Westerblad, Lee, Lamb, Bolsover & Allen, 1990). Jones (1996) suggests the recovery of HFF only takes a few minutes, and occurs when the frequency of stimulation is reduced.

Low frequency fatigue is characterized by a loss of force at lower stimulatory rates around 20-30 Hz, compared to forces produced at the same stimulatory rates prior to fatigue conditions (Jones, 1996; Edwards, Young, Hosking & Jones, 1997). Evidence indicates that LFF is likely due to a reduction in  $Ca^{++}$  release at the lower frequencies, but is not necessarily caused by low frequency stimulation (Jones, 1996). Another characteristic of LFF includes the feeling of having “heavy legs”. The recovery of LFF is slow, and can take several hours or days to fully recover (Jones, 1996).

The direct causes of LFF still remain unknown, but muscle damage may play a role. This is supported through the observation that LFF is more pronounced following exercise, that has strong eccentric force production involvement (Jones, Newham & Torgan, 1989; Newham, Mills, Quigley & Edwards, 1983), such as rapid deceleration

from a sprint. It is also possible that muscle damage is not a cause of LFF, but may be present and have similar recovery times as LFF with different mechanisms related to decreases in force production (Jones, 1996).

Rapid deceleration during sprinting includes strong eccentric muscle actions that may cause muscle damage (Howatson, Hortobagyi & Someren, 2007), where symptoms such as delayed onset muscle soreness (DOMS) can last for several days after the exercise or workout is performed (Howatson, Hortobagyi & Someren, 2007; Nosaka & Newton, 2002). Howatson & Milak (2009) and Keane, Salicki, Goodall, Thomas & Howatson (2015), studied the extent of muscle damage caused by rapid decelerations from a repeated sprint protocol. They asked twenty collegiate men's (Howatson & Milak, 2009) and women's (Keane et al., 2015) team sport athletes to complete 15 x 30 m sprints where they needed to stop within a 10 m deceleration zone. The protocols were the same between the studies except for the rest periods. Each sprint was separated by 60 (Howatson & Malik, 2009) or 65 (Keane et al., 2015) seconds of rest, and muscle soreness was measured immediately before, 24, 48, and 72 hours posttest. Muscle damage was assessed by measuring maximum isometric force (MVC), creatine kinase activity, and muscle soreness. In the days following the repeated sprints and rapid decelerations, there was a decrease in MVC, and increases in creatine kinase levels and muscle soreness, demonstrating that repeated sprints with rapid decelerations can induce muscle damage.

### **Single Short Sprint (<10 sec) Fatigability**

Metabolic fatigue during single short sprints (<10 seconds) typically develops within the first 5-7 seconds (Hirvonen, Rehunen, Rusko & Harkonen, 1987). During short

high intensity exercise, ATP resynthesis is primarily produced from anaerobic sources through the breakdown of phosphocreatine (PCr) and anaerobic glycolysis (Hirvonen et al., 1987). Phosphocreatine rapidly transfers a phosphate group to adenosine diphosphate (ADP) to generate ATP, but PCr is often severely depleted within 10 seconds of intense exercise (Dawson et al., 1997), and can take approximately 3-5 minutes to fully recover after performing a single maximal sprint (Dawson, Fitzsimons & Ward, 1993).

Hirvonen et al. (1987) studied the metabolism of a 100 m sprint. The authors had seven top-level sprinters sprint distances of 40, 60, 80, and 100 m. During the 100 m sprint (approx. 11 seconds), about 88% of the PCr used in muscle work was depleted in about 5.5 seconds. After about ~50 m (5.5 seconds) of the 100 m sprints, PCr levels were lower and glycolysis became the main energy source. The rate of lactate accumulation was similar across all running distances, suggesting that glycolytic energy production is increasing at a constant rate during maximal exercise lasting up to 11 seconds. Phosphocreatine is the main energy source at the beginning of a 100 m sprint, but is severely reduced around 50 m, which relates to a decrease in running speed due to ATP being utilized at a faster rate than it is being made. Therefore, if the recovery time between sprints is not sufficient, sprint performance will decrease.

### **Repeated Sprint Fatigability**

Repeated sprint ability is defined as the ability to maintain repeated short sprint (<10 seconds) performance separated by short recovery periods (<60 seconds) (Iaia et al., 2017). Fatigue during repeated sprints, indicated by a drop off in sprint power or speed, typically develops after the first one or two sprints due to a severe depletion of PCr (Mendez-Villanueva, Edge, Suriano, Hamer & Bishop, 2012; Dawson et al., 1997;

Gaitanos et al., 1993), and an increased or decreased accumulation of muscle and blood metabolites (ATP, inosine monophosphate, pH, inorganic phosphate, lactate, and glycogen). As the number of sprints with short recovery time increases, PCr is rapidly depleted due to insufficient recovery time, and the active muscles will depend on the lactic energy system and/or an increased contribution of aerobic metabolism to help resynthesize ATP (Bogdanis, Nevill, Lakomy & Nevill, 1995).

Maintaining muscle PCr levels plays an important role in the ability to maintain repeated sprint performance, where a high rate of ATP utilization and resynthesis is required. Since recovery times during RSA usually do not exceed 60 seconds, the ATP/PCr stores may only be partially restored before the next sprint (Dawson et al., 1997; Bogdanis, Nevill, Boobis & Lakomy, 1996), resulting in a decrease in performance during multiple sprints. The recovery of PO and the resynthesis of PCr follow similar timelines, suggesting that as PCr levels decrease so does PO. Significant correlations have been found between PCr resynthesis and PO during the first 10 seconds of a 30 second sprint ( $r=0.84$ ) (Bogdanis et al., 1996). In addition, PCr resynthesis has also been shown to correlate with the recovery of repeated sprint performance during after subjects completed 10 x 6 second sprints with 30 seconds of recovery and then after a 6 minute rest period completed 5 more 6 second sprints ( $r=0.67$ ) (Mendez-Villanueva et al., 2012).

Interestingly, fast twitch fibers that dominate power production during repeated sprints have been shown to show greater PCr depletion levels compared to slow twitch fibers (Karatzafiri, Haan, Mechelen & Sargeant, 2001). Therefore, it can be concluded that some of the neuromuscular fatigue during repeated sprint exercise may be partly due

to metabolic fatigue, specifically the depletion of PCr in the fast twitch motor units of active muscle.

Rapid resynthesis of PCr, which is linked to oxidative metabolism, can delay muscular fatigue and increase the capacity to repeat high intensity sprints (Thebault, Leger & Passelergue, 2011). As fatigue increases with sprint repetitions, aerobic energy sources during recovery periods become more important for resynthesizing PCr stores (Bangsbo, Krustup, Gonzalez- Alonso & Saltin, 2001; Bogdanis et al., 1996; Gaintanos et al., 1993). Studies have found that individuals with a higher maximal oxygen consumption ( $\text{VO}_2 \text{ max}$ ) and maximal aerobic speed (MAS) will have greater aerobic contributions to RSA and an increased time to fatigue. This suggests that increasing aerobic fitness may increase the ability to resist fatigue during repeated sprints (Bishop & Edge, 2006; Hamilton et al., 1991; Tomlin & Wagner, 2002). However, there are controversial findings on the relationship between aerobic capacity and RSA. Studies have found that if  $\text{VO}_2 \text{ max}$  is greater than 46 ml/kg/min then there is a weak relationship between  $\text{VO}_2 \text{ max}$  and RSA in elite teenage male soccer players and college age male Australian Rules Football players (Alizadeh, Hovanloo & Safania, 2010; Aziz, Mukherjee, Chia & Teh, 2007; Da Silva, Guglielmo & Bishop, 2010; Wadley & Rassignol, 1998). Alizadeh, Hovanloo & Safania (2010) found a strong relationship between  $\text{VO}_2 \text{ max}$  and repeated sprint performance in teenage soccer players who had a  $\text{VO}_2 \text{ max}$  of 37 ml/kg/min. It seems that aerobic fitness levels played the largest role when subjects had lower fitness levels (Table 1). Studies that did not see strong relationships between RSA and  $\text{VO}_2 \text{ max}$  used subjects with higher aerobic fitness levels (Table 1). Therefore, it can be hypothesized that  $\text{VO}_2 \text{ max}$  is a good indicator of RSA

performance when the subjects have a low VO<sub>2</sub> max, but may not be as good of an indicator when subjects are highly trained.

Table 1: Female training status and VO<sub>2</sub> max classification (Decroix, De Pauw, Foster & Meeusen, 2016)

<b>Female Training Status</b>	<b>VO<sub>2</sub> max (ml/kg/min)</b>
Sedentary or Untrained	<37 ml/kg/min
Recreationally trained	37-48 ml/kg/min
Trained and Competitively Trained	48-52 ml/kg/min
Highly Trained, Endurance Trained	52-58 ml/kg/min
Professional Cyclists	>58 ml/kg/min

Anaerobic glycolysis involves the breakdown of glucose, mainly in the form of muscle glycogen to ATP and lactate (Glaister, 2005). In contrast to PCr, glycogen availability is unlikely a major limiting factor in maintaining ATP stores during multiple sprint work (Glaister 2005; Krstrup et al., 2006). This is because multiple sprint work tends to lead to glycolytic inhibition (Gaitanos et al., 1993). In support of this, Krstrup et al. (2006) found that the decrease in repeated sprints performance after intense exercise periods in the first and second halves of a soccer match were not correlated to total muscle glycogen levels ( $r^2 = 0.02$ , and  $0.01$ ,  $p > 0.05$ ).

A high utilization of glycogen in the muscle leads to a production of lactate in the muscle that diffuses to the blood ( $\text{Glycogen} + 3 \text{ ADP} + 3 \text{ Pi} \rightarrow 3 \text{ ATP} + 2 \text{ lactate} + 2 \text{ H}^+$ ) (Glaister, 2005). Gaitanos et al. (1993) found that after performing 10 x 6 second sprints with 30 seconds recovery BLa levels were 12.6 mmol/L in eight male education students. Another study utilizing teenage boy soccer players found BLa levels to be 10.5 mmol/L after performing 12 x 20 m with 20 seconds of recovery (Meckel, Mechnal & Eliakim, 2009). Buchheit, Bishop, Haydar, Nakamura & Ahmaidi (2010) had 13 team sport athletes complete 6 x 25 m linear sprints, and found post BLa concentrations to be 9.3

mmol/L. The studies above show that BLa concentrations are elevated after performing repeated sprints. While BLa concentrations are elevated after performing repeated sprints, Krustup et al. (2006) found there was no significant relationship between muscle lactate and a reduction in sprint performance ( $r^2 = 0.13-0.14$ ). This is in agreement with other studies (Bangsbo, Grahman, Kiens & Saltin, 1992; Krustup et al, 2003; Mohr et al, 2004), and suggests that accumulation of muscle lactate is not the cause of fatigue during intense exercise. However, increases in muscle lactate concentrations have been associated with increases in hydrogen ion ( $H^+$ ) concentrations (Glaister, 2005). Increases in  $H^+$  concentrations have been shown to cause fatigue, and can cause glycolytic inhibition (Metzger & Fitts, 1987; Sahlin, 1992). Therefore, BLa levels can be useful when used as an indicator for exercise intensity, and can roughly define the anaerobic metabolism contribution during a given exercise bout (Lønbro et al. 2019).

Inorganic phosphate ( $P_i$ ) is one metabolite that has been known to cause fatigue through interfering with EC coupling and HFF. The concentration of  $P_i$  can increase during high intensity exercise due to the breakdown of PCr and the splitting of ATP (Westerblad, Allen & Lännergren, 2002). Inorganic phosphate can interfere with muscle function by inhibiting  $Ca^{++}$  release from the sarcoplasmic reticulum (SR). Calcium release from the SR controls the actin and myosin cross-bridge interactions (Glaister, 2005). Therefore, a reduction in  $Ca^{++}$  release will decrease the number of active cross-bridge binding sites and thus decreases force production (Allen & Trajanovska, 2012; Glaister, 2005).

Lanza et al. (2006) examined the relationship between  $P_i$  and force production in response to 6 x 12 second anterior tibialis contractions that were separated by 12 seconds

of rest. It was found that as the concentration of Pi increased, force production decreased. Therefore, it could be hypothesized that as Pi concentration increases, so does muscular fatigue.

### **Recovery Duration**

Recovery duration between sprints can have a considerable effect on performance and physiological responses during repeated sprint protocols. The further the accumulation or depletion of blood metabolites, the longer it takes for them to return to resting levels. For example, after performing repeated sprints, it has been reported that PCr and ATP may take 4-7 minutes of recovery in order to return back to resting levels (Dawson et al. 1997; Mendez-Villanueva et al., 2012), and pH and H<sup>+</sup> concentrations can take up to 60 minutes to recover (Mendez-Villanueva et al., 2012; Sahlin, Harris, Nyling & Hultman, 1976). Buchheit et al. (2010) found that after 13 team sport athletes completed 6 x 25 m linear and shuttle sprints departing every 25 seconds that the linear performance decrement was 3.18% and the shuttle performance decrement was 2.61%. Further, Lockie et al. (2018) had 19 Division I collegiate women soccer players complete 6 x 20 m sprints every 15 seconds and found the performance decrement to be 8.37%. Therefore, the recovery duration between sprints can produce differences in fatigue and consequently, performance.

The recovery period between sprints can have an effect on maximal HR and recovery. Studies have found that after performing heavy or intense exercise HR can remain elevated above resting value for up to 60 minutes (Brown, Li, Chitwood, Anderson & Boatwright, 1993; Carter, Watenpaugh, Wasmund, Wasmund, & Smith, 1999; Takahashi, Okada, Hayano, Tamura & Miyamoto, 2000). Buchheit et al. (2010)

found that after completing 6 x 25 m linear and shuttle sprints departing every 25 seconds that % HR max was 93.9% of overall max HR. In addition, Gabbett (2010) had 19 elite women's soccer players perform 6 x 20 maximal linear sprints on a 15 second cycle. He found that the average heart rate was ~182 bpm. Further, Nakamura et al. (2009) had 13 elite handball players complete 6 x 15 m shuttle sprints (approx. ~5 seconds) that departed every 20 seconds, and found that peak HR was 180 bpm. Heart rates during repeated sprint protocols have been found to be similar to HRs found during a soccer match. For example, Rampinini et al. (2011) found that over the course of a soccer match mean HRs ranged from 82.5%-88% (164-177 bpm) of maximum HR and that peak HRs ranged from 95.1%- 96.3% (190-192 bpm) of maximum HR. Similarly, Krustup et al. (2006) found that mean HR ranged from 156-157 bpm and that peak HR ranged from 181-187 bpm during a soccer match. This suggests that the recovery duration between the above repeated sprint protocols are similar to the recovery periods seen during a soccer match.

### **Change of Direction (shuttle) Sprint Demands**

During a soccer game, players often have to repeatedly change the direction of their sprints because they have to react to the ball and other players on the field. For this review, a shuttle or COD sprint is characterized by having at least one 180° directional change, and requires the athlete to quickly decelerate and then re-accelerate in order to be successful on the field (Attene et al., 2015; Dalen, Jorgen, Gertjan, Havard & Ulrik, 2016). For example, Buchheit et al. (2010) had 13 team sport athletes perform 6 x 25 m linear sprints and 6 x 25 m (12.5 m down-back) shuttle sprints. It was found that the best

linear sprint time was ~1.2 seconds faster compared to the best shuttle sprint time. This ~1 second time difference represents the time it takes to complete one COD.

One way to measure COD ability is by performing the 505-agility test (Draper & Lancaster, 1985; Stewart, Turner & Miller, 2014). The 505-agility test is a COD speed test that typically involves a 10 m sprint past a timing gate, a further 5 m sprint to a turning line where one leg needs to reach and plant at this line, before the athlete completes a 180° cut and sprints back through the timing gate. The time taken to complete the test is recorded in the 5 m up-and-back COD (Lockie et al., 2017). The 505 test has been shown to have a reliability and validity of ICC= 0.88 (Stewart, Turner & Miller, 2014). Division I collegiate women soccer players were able to complete the 505 agility test in 2.4 seconds (Lockie, Dawes, & Jones, 2018). Therefore, this test duration may reduce the influence of metabolic limitations that may be present in other COD agility tests (i.e. pro-agility or 3-cone drill), which can take anywhere from ~4-8 seconds to complete (Siere, Battaglini, Mikalik, Shields, & Tomasini, 2008). The 505-agility test can also examine the COD ability for each leg, which can be beneficial for athletes/coaches because it will show if there is an imbalance between the two legs (Lockie et al. 2014; Lockie, Callaghan & Jeffriess, 2013; Nimphius, McGuigan & Newton, 2010).

Common methods used to evaluate the COD ability using the 505-agility test are: 1) time taken to complete the test and 2) the change of direction deficit (CODD). Change of direction deficit is defined as the added time that one directional change requires compared with a linear sprint of an equivalent distance and may provide a more accurate representation of COD speed compared to total time (Nimphius, Callaghan,

Spiteri & Lockie, 2016). Therefore, the larger the COD deficit, the less effective the directional change or the athlete has a lower ability to change direction relative to their physical capability for linear speed (Nimphius et al., 2016).

Leg strength qualities have been found to be a determinant factor of COD speed performance among soccer players (Lehance, Binet, Bury & Crosier, 2009). Soccer players often use their dominant leg (DL) to manipulate the ball (i.e. kicking or passing), and use their non- dominant leg (NDL) to support the body and provide stability. The greater use of the DL in mobility tasks may lead to muscle imbalances or strength differences in hip abductors, hip adductors, and knee flexors and extensors between the DL and NDL (Fousekis et al., 2010; Lehance et al., 2009). Rouissi et al. (2016) found that soccer players had a faster COD time when they performed the directional change with their DL compared to their NDL, and hip abductors, knee flexors and extensors of the DL were stronger than the NDL with no difference for the hip adductors. The results of these studies suggest that if muscle imbalances are present, coaches should work on reducing the imbalances in the NDL in order to increase COD performance in all directions in soccer players.

Alemdaroglu et al. (2018) investigated BLa responses in four different RSA protocols of a total of 240 m; 6 x 40 m shuttle (20 m down and back), 6 x 40 m linear sprints, 8 x 30 m shuttle (15 m down and back) sprints, and 8 x 30 m linear sprints with 25 seconds of recovery between sprints in all protocols. They found that the 6 x 40 m shuttle protocol had the highest BLa values, but there were no significant differences found in terms of BLa response for the four different RSA protocols. This is in agreement with Padulo et al. (2014), Buchheit et al. (2010), and Dal Pupo, Detanico, Carminatti &

Santos (2013) who also found no significant differences in BLa values between linear and COD repeated sprints of similar distances.

### **Ways to Monitor Recovery**

Recovery from exercise includes an integration of physiological, psychological and emotional responses (Coutts, Slattery & Wallace, 2007; Kentta & Hassmen, 1998). Efficient recovery is necessary for initiating subsequent bouts of training (Bishop, Jones & Woods, 2008; Lane & Wagner, 2004). The perceived recovery status (PRS) scale has been developed to allow coaches to estimate their athlete's recovery relative to a subsequent exercise performance (Laurent et al., 2011). The PRS scale is similar to the rating of perceived exertion (RPE) scale except the different verbal descriptors of the PRS scale measures recovery and the RPE scale measures exertion. When using the PRS scale, an athlete after completing a warm-up, will rank their PRS on a scale of 0-10 with 0 being not at all recovered, 5 being moderately recovered, and 10 being very well recovered. A PRS score recorded following warm-up was shown that subjects were able to determine whether their recovery was appropriate to permit an improved or decreased performance from previous training session. Of those subjects that rated the PRS > 5, 77% of them improved their performance from the previous workout. For those that rated PRS < 5, 86% decreased their performance of the previous workout (Laurent et al., 2011). In summary, subjects were able to perceive a lack of recovery that resulted in changes in performance, with greater consistency shown for more extreme values (i.e. PRS score further from 5). Therefore, individual PRS scale ratings allows coaches to effectively estimate, before initiating exercise, whether or not the athlete's recovery will permit an increase or decrease in performance. The observation that PRS rating

effectively predicted individualized performance suggests that performance may mediate perceptually based recovery estimations (Laurent et al., 2011).

### **Experienced vs. Inexperienced Athletes**

Highly skilled or experienced soccer players may have better RSA performance (Rampinini et al., 2009) and COD ability (Gabbett, 2010) compared to lesser skilled or inexperienced soccer players. Wong, Chan & Smith (2012) found no significant differences between professional and collegiate soccer players in RSA (6 x 20 m sprints with 25 seconds recovery) and repeated COD (6 x 20 m with four 100° COD at every 4 m with 25 seconds recovery) for fastest time, average time, and total time. Similarly, Lockie et al. (2016) compared the differences between a 30 m linear sprint, a 505 agility test, and a 6 x 30 m RSA test with 20 seconds of recovery between incoming Division 1 freshmen to returning Division 1 collegiate men soccer players. They found no significant differences between the two groups in the 505 agility test or the RSA test. The experienced athletes had a higher aerobic fitness levels compared to the incoming freshmen, but the difference was not significant (Lockie et al., 2016). The authors of this study suggest that returning Division 1 soccer players do not have a great advantage over incoming freshmen Division 1 soccer players. Another study by Lockie, Dawes & Jones (2018) examined the difference in best 505 and 10 m sprint time between Division 1 and Division II collegiate women soccer players. It was found that the Division 1 soccer players were significantly faster in the 505 sprint, but there were no significant differences in the 10 m linear sprint times between groups. The authors of this study suggest that Division II athletes should attempt to improve their lower body power to positively influence COD speed, and the ability to complete challenging 180° directional

changes. To our knowledge there are no similar studies comparing linear or COD sprint ability or RSA for Division III women's soccer players.

### **Conclusion**

In conclusion, sprint performance decreases over a repeated short sprint protocol. Performing repeated COD sprints causes there to be different responses compared to linear sprints of the same distance because of the rapid accelerations and decelerations that are required to change direction. However, the metabolic differences and other fatigue related variables have mostly been shown to not differ between repeated linear and COD sprints. This could be caused by the number of CODs not being high enough to elicit significant changes between the different variables. Having a higher aerobic fitness may increase the ability to resist fatigue during RSA. However, this finding is controversial and may only be true in individuals who have a  $\text{VO}_2$  max less than 46 ml/kg/min.

There is very little research that has studied the difference of repeated linear and COD ability between freshmen and returning soccer players. The few studies that have compared the difference used either Division I or professional athletes, and found there to be no significant differences between the groups. Therefore, future research should focus on the different athletic abilities between incoming freshmen and returning athletes of lower athletic divisions such as Division II, Division III, or NAIA level athletes.

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APPENDIX B

PERCEIVED RECOVERY STATUS SCALE

10	Very well recovered/Highly energetic	Expect Improved Performance
9		
8	Well recovered/ Somewhat energetic	
7		
6	Moderately recovered	Expect Similar Performance
5	Adequately recovered	
4	Somewhat recovered	
3		
2	Not well recovered/Somewhat tired	Expect Declined Performance
1		
0	Very poorly recovered/Extremely tired	
Perceived Recovery Status Scale		