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THE ROLE OF PRACTICE LENGTH IN THE MAINTENANCE OF POWER
PRODUCTION IN COLLEGIATE GYMNASTS

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THE ROLE OF PRACTICE LENGTH IN THE MAINTENANCE OF POWER
PRODUCTION IN COLLEGIATE GYMNASTS

The length of practice: Implications for power training of college gymnasts

By Kasey Crawford

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

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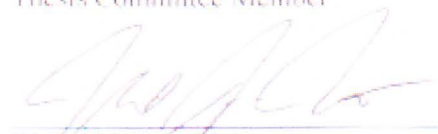
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ABSTRACT

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The purpose of this study was to observe the effect the length of practice had on power production. Twelve Division III collegiate women gymnasts volunteered for this investigation. During each testing session, gymnasts performed three different power tests: a four consecutive jump test (4JT), a loaded squat jump (SJ), and a loaded shoulder throw (TH). Fatigue conditions were measured by the length of practice session performed prior to power testing: following a warm-up (PRE), following half of a practice (PostHalf), and after a full practice (PostFull). In the SJ, peak power (PP) increased following the Half practice, which lead to a significant difference in SJ PP between the Half and Full workout. Peak force (PF) decreased in the TH following the Half practice. The changes in ground contact time (GCT) lead to a significant difference between the Half and Full practice. Motivation, Rating of Perceived Exertion (RPE), phase of menstrual cycle, and sleep were all found to have no significant correlations with the results. Overall, power training following similar amounts of practice may not hamper trained gymnasts, and strength coaches may want to consider doing power training after a light practice.

TABLE OF CONTENTS

| | PAGE |
|---|------|
| LIST OF TABLES..... | v |
| LIST OF FIGURES..... | vi |
| INTRODUCTION..... | 1 |
| METHODS..... | 4 |
| Experimental Approach to the Problem..... | 4 |
| Subjects..... | 3 |
| Procedures..... | 5 |
| Statistical Analysis..... | 9 |
| RESULTS..... | 10 |
| DISCUSSION..... | 17 |
| REFERENCES..... | 24 |
| APPENDICES..... | 28 |
| Appendix A: Written Informed Consent..... | 28 |
| Appendix B: Review of Literature..... | 32 |

LIST OF TABLES

| TABLE | PAGE |
|--|------|
| 1. Squat Jump Peak Force and Peak Velocity..... | 11 |
| 2. Shoulder Throw Peak Force and Peak Velocity..... | 13 |
| 3. 4-Jump Reactive Strength Index and Jump Height..... | 15 |

LIST OF FIGURES

| FIGURE | PAGE |
|---|------|
| 1. Squat Jump Peak Power..... | 10 |
| 2. Shoulder Throw Peak Power..... | 12 |
| 3. 4-Jump Peak Ground Contact Time..... | 14 |

INTRODUCTION

The sport of gymnastics involves four unique events: vault, uneven bars, balance beam, and floor exercise. Force, power, and rate of force development (RFD) are critical aspects of these four events and can be crucial to a gymnast's success. Training in gymnastics consists of a variety of things: conditioning, stretching, strength, plyometrics, and of course, time on the equipment. To meet all these training demands, practices can last up to 3 hours, leading to mental and physical fatigue. The overall volume of a gymnast's workout can produce an overtraining effect that relates to decreases in strength, power, and speed (Kraemer et al., 1995; Hennessy & Watson, 1994; Hakkinen et al., 2002).

Gymnasts specifically use a combination of eccentric and concentric actions that form a natural type of muscle function called the stretch-shortening cycle (SSC). According to Komi & Paavo (2000) and Sargeant & Dolan (1987), recovery from SSC fatigue involves a dramatic decline in performance immediately after exercise (a decrease in short-term power output), and that recovery after fatigue takes the longest in power athletes (Hakkinen & Myllyla, 1990). In general, fatigue has been found to increase the ground contact time of a drop jump, decrease dynamic balance, agility and quickness, reduce peak force, power, and RFD in both squat and countermovement jumps, and thus, decrease performance (Zemkova & Hamar, 2009; McLellan, Lovell, & Gass, 2011; Thorlund, Michalsik, & Aagaard, 2008; Hoffman et al., 2002). Fatigue also interferes with movement patterns, especially during high power technique-oriented activities that

utilize the SSC, such as Olympic weightlifting (Barker, Poe, & Midgett, 1990) and gymnastics. Athletes should be well rested when learning new skills, because fatigue will impede the athlete's ability to master motor skills (Jeffreys, 2007). Historically, neuromuscular fatigue has been studied by using isometric, concentric, or eccentric movements (Gandevia, 2001). However, recent evidence suggests that exercises involving the SSC provide a more specific examination of neuromuscular fatigue (Komi, 2000; Nicol, Avela, & Komi, 2006). Neuromuscular fatigue reduces activation, which could result from either a reduced motor drive by the central nervous system (central fatigue) or from failure of peripheral electrical transmission (peripheral fatigue) (Bigland-Ritchie, Johansson, Lippold, & Woods, 1983).

The purpose of training in the weight room is to develop maximal strength and power. In order to do this, optimal loads and movement velocities must be used in training to see optimal adaptations of the nervous system (Kraemer & Nindl, 1998). For maximum benefit, power training should be performed in a low-fatigue state (Newton & Kraemer, 1994). If the scheduling of training sessions, in a manner that reduces strength-training quality is not taken into account, the acute fatigue hypothesis suggests fatigue may be responsible for causing impaired strength (Leveritt, Abernethy, Barry, & Logan, 1999) and power development.

Therefore, the purpose of the present study was to determine the effect that fatigue, produced by manipulating the length of a gymnastics practice, has on power production. The results may determine the efficacy of the common practice of performing power training following a team practice. We hypothesize that a significant

decrement in power performance will be observed following practice with the greatest decrement seen following the longer (Full) practice.

METHODS

Experimental Approach to the Problem

A counterbalanced, within-subject design was used. Gymnasts were assessed on their ability to produce force and power output on three different neuromuscular tests at three different stages of a practice session, following a warm-up (PRE), following half of a practice (PostHalf), and after a full practice (PostFull). Both practice lengths (Half and Full) included uneven bars. Peak power (PP), peak force (PF), and peak velocity (PV) were measured during the squat jump (SJ) and shoulder throw (TH), while ground contact time (GCT), jump height (JH), and reactive strength index (RSI) were measured during four continuous plyometric jumps (4J). Each subject performed the tests in random order, however they were tested in the same order for both days of testing. The study was performed during the middle of the gymnast's season (January 2011). The gymnast's perceived exertion during practice (session-RPE, s-RPE), motivation, sleep, and menstrual cycle were all monitored and assessed for the influence on testing results.

Subjects

Twelve Division III women collegiate gymnasts volunteered for this investigation (20 ± 2 yrs, 157 ± 10 cm, 56 ± 11 kg). Ten of these gymnasts were members of the Division III National Collegiate Gymnastics Association (NCGA) National Champion gymnastics team the previous year. Subjects were familiarized with the equipment and testing protocol three times, one week apart, before testing. Five of the subjects participated in

pilot testing three additional times before familiarization. Subjects were familiarized with determining their RPE during practice sessions for a few weeks prior to testing. The university's Institutional Review Board approved the study, and all subjects provided written informed consent.

Procedures

The gymnasts were studied on the first active day of 2 consecutive microcycles to account for similar practice session objectives. Each testing day, subjects performed their sport specific five-minute warm-up followed by three power tests (PRE; SJ, TH, & 4J). Following the warm-up, subjects reported to the laboratory for testing. Fifteen minutes following the warm-up and prior to testing they were asked for their s-RPE from a modified 0-10 Borg scale to determine training load (TL; s-RPE x length of warm-up in minutes) of the warm-up (Foster et al., 2001; Singh et al., 2007). Subjects were also asked the first day of their current menstrual cycle, the amount of sleep they received the night before (in hours), and a series of written questions to determine their level of motivation using the Intrinsic Motivation Inventory (IMI) (McAuley, Duncan, & Tammen, 1989). Following power testing, subjects participated in either half of a practice (Half, two 30 minute rotations, including bars), or a full practice (Full, two 45 minute rotations including bars and one other 30 minute rotation) and then, repeated the power testing within 15 minutes of completion of their workout. The s-RPE and the IMI questions were asked again prior to testing at the post testing session. All practice and testing occurred from 2-6pm as recommended by Teo, McGuigan, & Newton (2011) to take advantage of optimal circadian rhythms.

Four Consecutive Jump Test. The 4J consisted of four consecutive maximal ankle jumps (body weight only) performed on a contact mat (Just Jump System; Probotics, Huntsville, AL) to assess average ground contact time (GCT), average jump height (JH), and average reactive strength index (RSI) over the four jumps. The RSI is determined by the ratio between average jump height (cm) and average floor ground contact time (sec) of the four jumps. The subjects performed three sets of the 4J with at least 90 seconds of rest between each set. Subjects were instructed to stand on the contact mat; feet hip width apart and hands on their hips. They were then asked to choose a self-selected depth of knee flexion (McLellan et al., 2011), and simply, jump as high as they could with as little time as possible on the ground, exerting maximal effort on every jump. The set with the highest RSI of the three attempts was used for analyses. The Intraclass Correlation Coefficient (ICC) for GCT, RSI, and JH of the four-continuous jump series showed an ICC of $r=0.844$.

Shoulder Throw and Squat Jump. The shoulder throw (TH) and squat jump (SJ) tests were both administered using the Plyometric Power System (PPS; Lismore, Australia) to assess PF, PP, and PV of the upper and lower body, respectively. The PPS is a modified Smith machine that allows movement of the bar in only the vertical plane and can be set to slow or stop the decent of the bar for safety purposes. Subjects performed three SJs and three THs. All kinetic data (PP, PF, PV) was determined by the Myotest Pro accelerometer system (Myotest, Inc., Royal Oak, MI, USA) that was placed on the bar of the PPS within 5 cm from the subjects' right hand. The Myotest data (collected at 500 HZ) was downloaded to a laptop computer using the proprietary software for later analysis.

One week prior to the experimental trials the strength and conditioning staff re-tested 1RM for squat and shoulder press. Squat testing used a free weight bar and shoulder press was tested on the PPS. The TH was performed using 50% of 1RM reported by strength and conditioning staff (Dalziel et al., 2002). The bar was held at the level of the clavicles with the hands shoulder width apart, elbows fully flexed, and shoulders in slight flexion. Subjects kneeled on a mat placed on the floor to prevent them from performing a counter-movement. They were instructed to make sure they do not move their hips when they threw the bar. Bar movement occurred from the concentric action of the muscles controlling flexion at the shoulder and extension at the elbow joints. An audio signal came from the Myotest when the bar was motionless for a count of two seconds. At the sound, the subjects threw the bar as high, hard, and fast as they could. A two-minute recovery period was maintained between attempts. The repetition with the highest PP of three attempts was used for analyses of PP, PF, and PV. ICC for PP and PF of the shoulder throw were $r > 0.848$ with $r = 0.555$ for PV.

During the SJ, subjects started with the bar of the PPS across the top of the shoulders in a standing position, with feet shoulder width apart and loaded at 40% of their 1RM free weight squat reported by the strength and conditioning staff. When the bar was motionless for two seconds after removing from the racked position, the Myotest gave a beep signal to lower the bar to a self-selected half squat position ($\sim 135^\circ$ at the knee), hold that position for approximately two seconds until the Myotest beeped again, and then explosively jump as high as possible. No countermovement was allowed and the bar could not leave their shoulders during the jump. The repetition with the highest PP of three attempts was used for analyses of PP, PF, and PV. A two-minute recovery was

ensured between attempts. The ICC for PF, PP, and PV of the squat jump were all $r > 0.920$.

STATISTICAL ANALYSIS

All data are expressed as mean \pm SD. Separate paired samples t-tests were employed to determine the differences between Pre- and Post-practice for the Half and Full workouts for each variable tested. Separate paired samples t-test were also used to compare the change in each variable between the Half and Full practice. The criterion level for statistical significance was set at $p \leq 0.05$. Repeated measures ANOVA was employed to determine differences in TL, motivation, and between Δ Half and Δ Full. Repeat measures ANOVA was also employed to determine difference in day of menstrual cycle and sleep between Half and Full practice days. A Pearson Correlation Coefficient was utilized to determine the relationship between change of motivation, TL, and the changes in performance variables from Pre to Post practice. Effect size (Cohen's d) and magnitudes were determined and interpreted for highly trained athletes as recommended by Rhea (2004). All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS for Windows, version 19.0; SPSS, Inc., Chicago, IL).

RESULTS

Significant differences associated with length of practices were identified in all three power tests. In the SJ, PP increased ($p=0.02$; $ES=-0.11$, trivial) following the Half practice, while PP remained unchanged following the Full practice ($p=0.10$; $ES=0.19$, trivial). The change in PP from Pre to PostHalf was significantly different ($p<0.05$) from the change in PP between Pre and PostFull for SJ (Δ Half, 33.3 ± 38.4 ; Δ Full, -30 ± 184.8 , $p=0.01$; $ES=0.57$, moderate) (Figure 1).

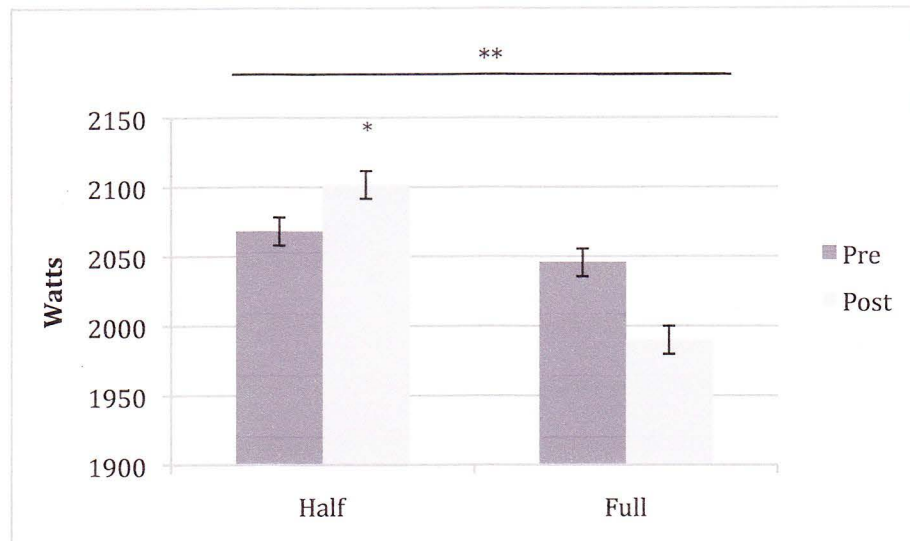


Figure 1. Squat Jump (SJ) Peak Power (PP)
*Post-Half workout significantly different than Pre-Half workout;
** Δ between pre and post for the Full and Half workout is significantly different; $n=12$; Pre, after warm-up; Post, after workout; Half, 2 events including bars; Full; 3 events including bars

Squat jump force and velocity of the squat jump following different length practices can be seen in Table 1. No significant differences were identified in PF or PV of the SJ following the Half (PostHalf) or Full (PostFull) practice. The change in

PF from Pre to PostHalf was not significantly different from the change in PF between Pre and PostFull for SJ. The change in PV from Pre to PostHalf was not significantly different from the change in PV between Pre and PostFull for SJ.

Table 1. Squat Jump Peak Force and Peak Velocity

| Peak Force | | | | | | | |
|---------------|-------------------|-------------------|------|--------------------|----------------|------|------|
| | Pre | Post | p | ES | Δ PF | p | ES |
| Half | 1425.8 (159.6) | 1427.5 (141.3) | 0.90 | -0.01 (trivial) | 1.7 (41.4) | 0.56 | 0.21 |
| Full | 1410.8 (139.4) | 1401.7 (122.5) | 0.63 | 0.19 (trivial) | -9.2 (60.6) | | |
| Peak Velocity | | | | | | | |
| | Pre | Post | p | ES | Δ PV | p | ES |
| Half | 174.5 (14.0) | 175.9 (15.1) | 0.59 | -0.28 (small) | 1.4 (8.5) | 0.11 | 0.55 |
| Full | 173.9 (16.6) | 169.6 (18.4) | 0.26 | 0.32 (small) | -4.3 (12.1) | | |

All data is mean (SD); n = 12; Pre, after warm-up; Post, after workout; Half, 2 events including bars; Full, 3 events including bars; Δ , difference between pre and post for Half and Full workout; ES, effect size

Figure 2 shows the PP results of the TH. There was no significant difference in PP of the TH in the Half (p=0.085. ES=0.59; moderate) or Full practice (p=0.425; ES=0.14; trivial) (Figure 2). The change in PP from Pre to PostHalf was significantly different from the change in PP between Pre and PostFull for TH (Δ Half, -20.3 ± 37.1 ; Δ Full, -5.8 ± 24.0 ; p=0.293; ES=-0.47; small).

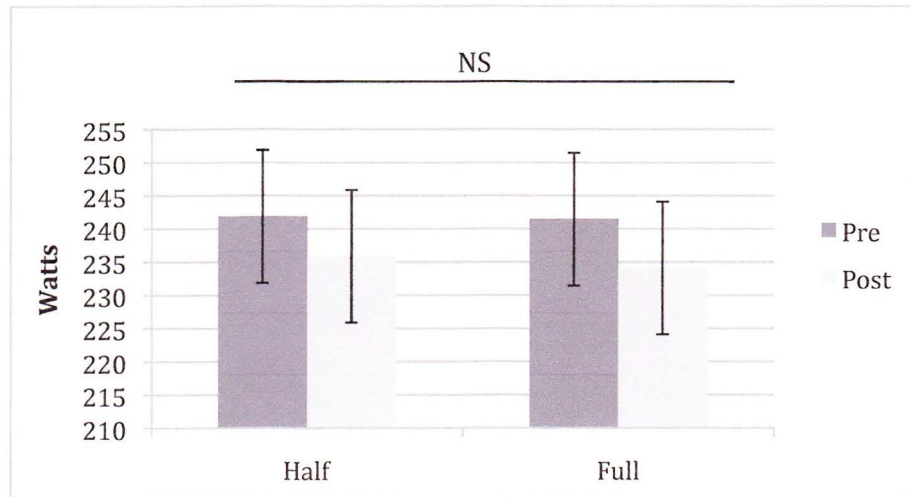


Figure 2. Shoulder Throw (TH) Peak Power (PP)
 NS; change between pre and post for the Full and Half workout not significant; n=12; Pre, after warm-up; Post, after workout; Half, 2 events including bars; Full; 3 events including bars

Peak force and peak velocity of the shoulder throw power test following different length practices can be seen in Table 2. In the TH, PF decreased significantly after the Half workout, but no significant differences were found in PF of the TH in the Full workout. No significant differences were found in PV of the TH in the Half practice or Full practice. The change in PF from Pre to PostHalf was not significantly different from the change in PF from Pre to PostFull for TH. The change in PV from Pre to PostHalf was not significantly different from the change in PV from Pre to PostFull for TH.

Table 2. Shoulder Throw Peak Force and Peak Velocity

| Peak Force | | | | | | | |
|---------------|-----------------|-----------------|-------|--------------------|-----------------|-------|---------------------|
| | Pre | Post | p | ES | Δ PF | p | ES |
| Half | 273.3 (44.5) | 233.3 (26.3) | 0.03* | 1.1 (large) | -39.9 (56.1) | 0.125 | -0.58 (moderate) |
| Full | 254.2 (26.5) | 242.8 (27.7) | 0.37 | 0.51 (moderate) | -11.3 (41.7) | | |
| Peak Velocity | | | | | | | |
| | Pre | Post | p | ES | Δ PV | p | ES |
| Half | 129.1 (12.6) | 129.7 (12.8) | 0.58 | 0.07 (trivial) | 0.58 (3.5) | 0.1 | 0.67 (moderate) |
| Full | 129.1 (14.8) | 125.7 (12.3) | 0.18 | 0.21 (small) | -3.4 (8.3) | | |

All data is mean (SD); *Peak force post workout is significantly different than peak force pre workout in the Half practice; n = 12; Pre, after warm-up; Post, after workout; Half; 2 events including bars; Full, 3 events including bars; Δ , difference between pre and post for Half and Full workout; ES, effect size

In the 4J, no significant difference was observed between Pre and Post practice in GCT for the Half practice (p=0.09; ES=0.41, small) or Full practice (p=0.17; ES=-0.45, small) (Figure 3). The change in GCT from Pre to PostHalf was not significantly different from the change in GCT between Pre and PostFull for 4J (Δ Half, -0.007 ± 0.012 ; Δ Full, 0.007 ± 0.016 ; p=0.04; ES=-0.96, moderate) (Figure 3).

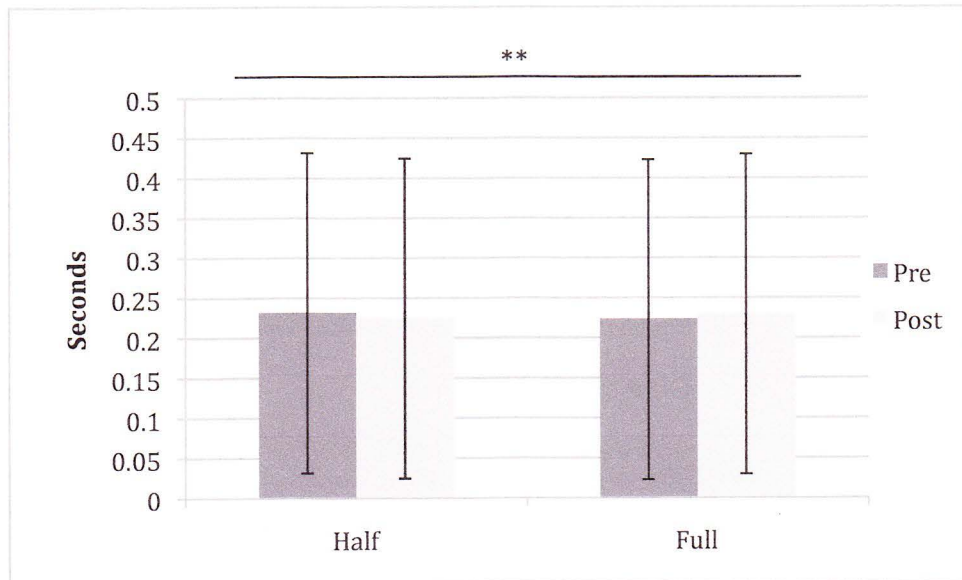


Figure 3. 4-Jump (4J) Peak Ground Contact Time (PGCT)
 **Change between pre and post for Full and Half workout significantly different; n = 12; Half, 2 events including bars; Full; 3 events including bars

Table 3 presents the JH and the RSI of the 4J following different length practices.

No significant differences were identified in JH or RSI of the 4J in the Half or Full practice. The change in JH from Pre to PostHalf was not significantly different from the change in JH between pre and PostFull for 4JT. The change in RSI from Pre to PostHalf was not significantly different from the change in RSI between Pre and PostFull for 4JT. Although statistical significance was observed, the moderate effect size questions the practical significance of this difference.

Table 3. 4-Jump Peak Jump Height and Peak Reactive Strength Index

| Peak Jump Height | | | | | | | |
|------------------------------|-----------------|-----------------|------|--------------------|----------------|-------|---------------------|
| | Pre | Post | p | ES | Δ JH | p | ES |
| Half | 39.8 (2.2) | 39.9 (2.9) | 0.87 | -0.04 (trivial) | 0.15 (3.14) | 0.202 | -0.58 (moderate) |
| Full | 40.4 (1.9) | 41.7 (4.0) | 0.33 | -0.44 (small) | 1.24 (4.2) | | |
| Peak Reactive Strength Index | | | | | | | |
| | Pre | Post | p | ES | Δ RSI | p | ES |
| Half | 175.6 (20.8) | 177.3 (17.2) | 0.73 | -0.09 (trivial) | 1.65 (16.0) | 0.711 | 0.67 (moderate) |
| Full | 182.5 (15.4) | 182.2 (20.0) | 0.97 | 0.02 (trivial) | 0.3 (20.5) | | |

All data is mean (SD); n=12; Pre, after warm-up; Post, after workout; Half, 2 events including bars; Full, 3 events including bars; Δ , difference between pre and post for Full and Half workout; ES, effect size; reactive strength index, jump height (cm)/contact time (s)

The TL was found to be similar between the two pre-practice sessions (PreHalf, 2.7 ± 1.1 ; PreFull, 3.0 ± 0.9 ; $p=1.00$; $ES=0.27$). The s-RPE was significantly different between PreHalf and PostHalf (4.4 ± 1.3 ; $p=0.01$; $ES=1.55$) and different between PreFull and PostFull (7.1 ± 1.4 ; $p<0.001$; $ES=4$). The s-RPE for PostFull was also identified to be significantly higher than for PostHalf ($p=0.01$; $ES=2.08$). Menstrual cycle was found to be similar between the Half and Full practice sessions (MenstrualHalf, 8.42 ± 8.07 ; MenstrualFull 13.08 ± 8.63 ; $p=0.205$; $ES=0.577$; moderate). The hours of sleep received the night before testing was found to be similar between the Half and Full practice session (SleepHalf, 8.71 ± 0.81 ; SleepFull 8.67 ± 1.17 ; $p=0.889$; $ES=-0.049$; small).

Pearson correlation coefficients suggest that the relationships between the change in motivation scores and changes between Pre and Post practice for the performance variables (PP, PF, and PV for SJ and TH; 4JT variables of GCT, JH, and RSI) were all

considered low correlation ($r=-0.135-0.285$). Relationships between the change in TL and the performance variables of the SJ, TH, and 4JT were also considered low to moderate correlation ($r=-0.201-0.451$).

DISCUSSION

The present study examined the effect the length of practice had on power production. The main findings of the study were that lower body PP, indicated by results of the SJ, showed a small but significant increase after a Half practice, while no significant signs of neuromuscular fatigue occurred following the Full practice. In addition, upper body PF significantly decreased following a Half practice but no decrements in PP, PF, or PV were observed after a Full practice.

It is also possible that acute fatigue affects neuromuscular performance differently in athletes of different sports. There were no significant differences between pre- and post-match force and power measures in NCAA Division III soccer players (Hoffman et al., 2003), elite soccer players (Thorlund et al., 2009), or Australian football players (Cormack, Newton, McGuigan, 2008). Hoffman et al. (2003) had collegiate soccer players perform a squat jump and countermovement jump to measure their power performance before and after a match and found no difference in power performance following the game, possibly due to the team winning a landslide victory game (5-0). The authors observed the athletes were highly motivated during testing due to winning their game, which may be similar to our study as our athletes showed a high level of motivation according to the IMI survey (McAuley et al., 1989). Cormack et al. (2008) studied 22 elite Australian football players to determine power performance before and after a match by testing a single countermovement jump and five repeated countermovement jumps. Similar to our study, mean power, relative mean power, and

relative mean force of the single countermovement jump remained unchanged after the match. Thorlund et al., (2009) found that elite soccer players were able to maintain peak rate of force development (PRFD), PF, and PP after a match. As well, maximal jumping power, jump height, and jumping strategy remained unaltered pre- vs. post-match; similar to our study. It seemed this was most likely due to the high-level training status of the subjects (elite soccer players) or possibly the low statistical power of the results with only nine subjects (Thorlund et al., 2009). Our study was similar to this in that we were using similarly trained athletes (National Champion collegiate gymnasts). Thorlund used a warm-up similar to the one used in our study before testing, and a countermovement jump was used to measure power performance. The results of these studies seem to indicate that chronic training of the neuromuscular system may help prevent fatigue in jump tests.

A major difference between these studies (Thorlund et al., 2009, Hoffman et al., 2003, Cormack et al. 2008) and our study was that they all used a non-loaded CMJ to measure power performance while we used a loaded SJ. Cormack et al. (2008) suggested that a countermovement jump (CMJ) may lack the sensitivity to detect neuromuscular fatigue from a single game. A CMJ can increase variability within each test, while static jumps produce more stable scores from each subject, as they are instructed how far they can squat down and when to jump as high as they can; taking as much variability out of the test as possible (Cormack et al. 2008). We used a static start for the jump squat and shoulder throw because the static starts emphasize the use of the contractile properties of the muscle more than a counter movement would as the static start would decrease the involvement of the elastic properties of the muscle.

Recent research (Hartman, Ryan, Cramer, & Bembien, 2011, Hoffman et al., 2003, Thorlund et al., 2008, 2009; Cormack et al., 2008) may explain how our subjects were able to maintain PF, PP, and JH in the lower body movements following the various length practice sessions. Hartman et al. (2011) examined the ability to maximally activate motor units after a fatiguing activity of the plantar flexors at 40% maximal voluntary contraction (MVC). They found that while trained and untrained subjects both had significant fatigue following this activity, the untrained subjects showed a significant decrease in the ability to activate motor units; whereas, the trained subjects did not see a significant decrease in activation. Therefore, it may be that athletes with strength training experience may have a greater ability to activate motor units than untrained individuals when fatigued. This notion is supported by Behm et al., (1998) who found that resistant trained subjects experienced less fatigue (MVC decreased 32% in trained subjects, compared to a 45% decrease in untrained subjects) when performing an isometric, intermittent, sub-maximal fatigue protocol. Considering previous research suggests that long-term chronic resistance training may attenuate the decrease in neuromuscular performance; it may be that in our study, the Full practice length was not long enough or intense enough to produce significant fatigue in our trained subjects. It is likely that the resistance-training background of our gymnasts may have helped delay the onset of neuromuscular fatigue.

Contrary to the results of our study, trained athletes in some studies have shown decrements in power due to neuromuscular fatigue (Zemkova & Hamar, 2009; McLellan et al., 2011; Thorlund et al., 2008; Hoffman et al., 2002). However, the assessment of neuromuscular fatigue by strength or power tests following competition in these sports

may have been complicated by some confounding problems besides just simple fatigue. The decreases in power production in athletes following competition in rugby (McLellan et al., 2011) or American football (Hoffman et al., 2002) may be related to the blunt force trauma and minor injuries that take place in these collision sports. Zemkova & Hamar (2009) produced the only study that showed decrements in a non-collision sport: soccer. Fatigued developed after the soccer match showed an increased in GCT during a drop jump.

Our study did find that lower body power increased after the Half practice. It is possible that after a relatively short practice, a potentiating effect may occur. Post-activation potentiation (PAP) is a type of potentiation that causes an increase in muscle twitch and low-frequency tetanic force after a “conditioning” contractile activity (Sale, 2002). PAP can serve to improve performance, and people with a higher percentage of Type II fibers within a muscle exhibit greater PAP. When potentiation occurs, activities like jumping, kicking, and throwing can improve (Sale, 2002). It seems that gymnastics, a sport filled with many conditioning activities that involve recruitment of Type II fibers, could cause a form of potentiation after a brief practice. It is also possible that the five-minute warm-up we implemented before PRE testing was not long or intense enough for the athletes to produce their maximal power. Had the PRE results been higher, there may have been less of an increase in power after the Half and more of a significant decrease in power after the Full.

Our results also showed that a significant decrease in PF occurred in the TH following the Half practice, but not in the Full practice. This was surprising since the Full practice had more repetitions and movements of the upper body than the Half

practice. In addition, the fatigue was not reflected in changes in PV or PP following the half practice. Therefore, we have no explanation why the PF decreased during the Half, but not the Full practice length for the TH. Correlations between PF and motivation, RPE, sleep, and menstrual cycle were found to be insignificant ($r = -0.013 - 0.108$). Therefore none of these variables seem to explain the decrease in PF during the Half practice but not the Full practice.

A concern when using women as subjects, when investigating strength-power performance, is the effect the menstrual cycle may have. We found no correlations between menstrual cycle and the performance results. There was also no significant difference ($p=0.205$) in menstrual cycle day between Half and Full practice test days. Research indicates that little difference in strength/power performance exists between the phases of the menstrual cycle (Friden, Hirschberg, & Saartok, 2003; Lebrun, McKenzie, & Prior, 1995; Gur, Akova, & Kucukoglu, 1999; Gur, 1997). In addition, Sarwar et al. (1996) found that women who take oral contraceptives may display even smaller differences in strength/power production during the different phases of the menstrual cycle. In our study, eight of our 12 subjects were using oral contraceptives. Therefore, we interpret our power performance data assuming menstrual cycle had little, if any, effect on our results and possibly, may have had a positive influence of maintaining strength/power performance. Menstrual cycle was found to be similar between the Half and Full practice sessions. These findings indicated that there was no significant change in menstrual cycle stage between practice sessions.

The session rating of perceived exertion (s-RPE) method was used to quantify the TL of the gymnastics training from the perspective of each individual gymnast. The TL

method has been found to be applicable to a wide variety of exercise, especially high-intensity exercise and sports with technical skill (Foster et al., 2001; Minganti et al., 2010). Our gymnasts gave an s-RPE for the work accomplished following the warm-up (PRE) and the different practice lengths (PostHalf, PostFull). The TL is the product of s-RPE and length (minutes) of activity. In general, the warm up lasted approximately five minutes in length. The Half practice lasted approximately 90 minutes and the Full practice lasted approximately 150 minutes. While s-RPE rating following the Full practice was higher than the Half practice, the greatest change in internal load was due to the duration of practice. Despite athletes rating their training differently, it has been found that UW-La Crosse gymnasts seem to be consistent in their own pattern of rating their practice (Foster et al., 2001), and no meaningful correlations were found among the power performance results and the s-RPE ($r = -0.264-0.451$). The TL was found to be similar between the two pre-practice sessions. These findings indicate that the gymnasts rated the exertion of the warm up was similar for both practice sessions, both practice lengths produced a greater TL than the warm up activity, and a greater TL was realized following the Full practice than following the Half practice.

Motivation is a key ingredient to improvements in strength and power. Achieving optimal athletic performance is more likely to occur when an athlete is mentally motivated to reach a goal or task. It seems that psychological factors (high-positive and non-stressful felt arousal) can play a prime role in the enhancement of strength performance (Perkins & Wilson, 2001), and athletes who are highly motivated, may be able to overcome their fatigue. The results of the IMI questionnaire indicated each subject believed they gave their maximal effort during testing (McAuley, Duncan, &

Tammen, 1989). No correlations were found between the results and motivation ($r = -0.302$ - 0.285) after reviewing the scores of the IMI.

Lastly, sleep was also monitored. We found no correlations between sleep and the results. There was also no significant difference ($p=0.889$) in sleep between Half and Full practice test days. The hours of sleep received the night before testing was found to be similar between the Half and Full practice session. These findings indicate that the hours of sleep received the night before were not different between both practice sessions. No gymnasts received less than seven hours of sleep the night before they were tested, concluding that sleep most likely had no effect on the results.

In conclusion, our results indicate that significant increases in lower body power following the Half practice may actually benefit power training following practice. This could have been due to a potentiating effect from the shorter practice. There were no signs of neuromuscular fatigue in lower body power production following the Full practice, most likely due to the training status of the gymnasts. The significant decrease in PF in the TH following the Half practice and not the Full practice is hard to explain as both practices had the same volume of upper body involvement. Motivation, sleep, S-RPE, and menstrual cycle all seem to have no effect on the results of the study.

Overall, power training following similar amounts of practice may not hamper trained gymnasts. Sport coaches should consider power training following shorter practice durations if training for power follows practice sessions.

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APPENDIX A
INFORMED CONSENT

Informed Consent

Protocol Title: The Role of Practice Length in the Maintenance of Power Production in Collegiate Gymnasts

Principal Investigator: Kasey Crawford
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Purpose and Procedure

- The purpose of this study is to determine the effect the length of practice has on power output of college gymnasts.
- The procedure will involve three different strength/power performance tests (a four consecutive countermovement jump test, a half-squat jump, and a shoulder throw) to determine the effects of neuromuscular fatigue on strength training. Each testing day, subjects will perform a sport specific warm-up followed by the three power tests. Then, subjects will practice on 2 events and repeat the three power tests. On a separate day, subjects will be tested following the sport-specific warm-up and then again after a full gymnastics practice which includes practice on 3 events. The designated warm-up is a 10-minute U.S. National Team warm-up integrated by USA Gymnastics. When practicing 2 or 3 events, one of those events must include the uneven bars, so the subjects are receiving an upper and lower body workout. Before testing, the gymnasts will be asked to answer four questions that monitor their rating of perceived exertion on the modified 0-10 Borg scale (Foster et al., 2001), their level of motivation based on the Intrinsic Motivational Inventory (McAuley et al. 1989), the first day of their current menstrual cycle, and the amount of sleep they received the night before (in hours).
- The total time requirement of each gymnast is, at the most, two hours over a three-week period (60 minutes per testing session in the lab). Testing will take place at the Human Performance Lab at Mitchell Hall at the University of Wisconsin-La Crosse.

Potential Risks

- I may experience inconvenience in my gymnastics practice or less practice time for two days.
- I may experience some muscle soreness due to the power testing.
- The risk of serious or life-threatening complications for a healthy individual like me is near zero.

Rights & Confidentiality

- My participation is voluntary. I can withdraw without consequences at any time.
- The results of this study may be published in scientific literature or presented at professional meetings using grouped data only. All information will be kept confidential through the use of number codes (Example: you may be Subject #1). My data will not be linked with personally identifiable information.

Possible Benefits

- I and other athletes may benefit by understanding how my performance during a strength training session is affected following practice.

Questions regarding study procedures may be directed to Kasey Crawford (952-201-6013), the principal investigator, or the study advisor, Dr. Glenn Wright, Exercise and Sport Science Department, UW-L (608-785-8689). Questions regarding the protection of human subjects may be addressed to the UW-La Crosse Institutional Review Board for the Protection of Human Subjects, (608- 785-8124 or irb@uwlax.edu).

Participant _____ Date _____

Researcher _____ Date _____

APPENDIX B
REVIEW OF LITERATURE

REVIEW OF LITERATURE

The sport of gymnastics involves four unique events: vault, uneven bars, balance beam, and floor exercise. Training consists of a variety of things: body conditioning, stretching, plyometrics, time on the equipment, and strength. Force and power are critical aspects of these four events and can be crucial to a gymnast's success. The best indicator for vaulting talent is a gymnast's squat jump power and average power during the last five jumps in a continuous bent-leg jump series (Bradshaw & Rossignol, 2004). It is also logical that these predictors may also relate to floor tumbling ability (Bradshaw & Rossignol, 2004). Rate of force development (RFD) is of great importance for fast movements, such as sprinting, tumbling, and "explosive" muscle strength used in gymnastics as well (Thorlund, Michalsik, & Aagaard, 2008). Thus, the ability to generate explosive muscle force (i.e. exerting a high RFD) within fractions of a second is an important determinant of performance in artistic gymnastics (Thorlund, Aagard, & Madsen, 2009).

Central fatigue and peripheral fatigue are two different types of fatigue athletes experience during training or competition. Central fatigue designates a decrease in voluntary activation of the muscle (i.e. a decrease in the number and discharge rates of the motor units recruited during muscle force generation) (Boyas & Guevel, 2011) and may refer to an activity-induced inability to fully activate a muscle voluntarily (Nordlund, Thorstensson, & Cresswell, 2004). When the athlete experiences central fatigue, their motivation to perform is an important variable in determining the

performance outcome. When fatigue decreases the motivation to perform, activation of the motor units is reduced.

Peripheral fatigue is associated with an impairment of the mechanisms from excitation of the muscle to force production, and may be induced by a perturbation of the calcium ion movements, an accumulation of phosphate, and/or a decrease of the adenosine triphosphate stores within the muscle cell (Boyas & Guevel, 2011). Therefore, peripheral fatigue arises when the athlete is motivated to participate further, but the motor units are fatigued. Performing a strength training workout, following a sport practice and in a state of fatigue, will likely inhibit the ability to use optimal loads at optimal velocities that stimulate adaptations to increase strength and power during strength training. Following a review of the literature, it seems this has not been extensively studied.

Because gymnasts train intensely, they are fatigued often. Neuromuscular fatigue has been described in humans as any exercise-induced reduction in the maximal voluntary force or power produced by a muscle or muscle group (Bigland-Ritchie & Woods, 1984; Gandevia, 2001) and is determined by the type of muscle contraction, the intensity of exercise, and the duration of the exercise (Enoka, 2002). Recent evidence indicates that both short and long duration exercises lead to deterioration in neuromuscular performance (Komi, 2000; Zemkova & Hamar, 2009; McLellan, Lvell, & Gass, 2010; Thorlund et al., 2008; Hoffman, et al., 2002). The combination of both eccentric and concentric actions forms a natural type of muscle function called the stretch-shortening cycle or SSC (Norman & Komi, 1979; Komi, 1984). Recent evidence

suggests the incorporation of movements involving the SSC provides a more specific model to study neuromuscular fatigue (Komi, 2000; Nicol, Avela, & Komi, 2006).

The SSC is used repeatedly in the sport of gymnastics, therefore leading to various levels of fatigue during practice and competition. Recovery from SSC fatigue is a delayed process involving a dramatic decline in performance immediately after exercise (Komi, 2000). Komi (2000) found that a decline in performance was due to a reduced tolerance to impact, loss of elastic energy potential, and increased work during the concentric phase of a contraction. It was also found that exercise with a large eccentric component (on physically active subjects) produces a decrease in short-term power output than does concentric work of a considerably higher metabolic cost (Sargeant & Dolan, 1987). This suggests that when athletes train during intense practice sessions that include a large amount of eccentric work, fatigue is likely and can have a negative impact on any kind of explosive movements they do in the gym or in the weight room. However, the training status of subjects may lead to discrepancies in power decrements. Marathon runners have been the subject of study for Komi (2000), where the volume of contractions in running is much greater than in gymnastics. Gymnasts may not train intense enough or long enough to see the same fatigue in which Komi found.

Bigland-Ritche (1983) observed a decrease in force and EMG activity in untrained subjects after holding a maximal isometric voluntary contraction for 60 seconds. The decline in EMG was attributed to a progressive reduction in neural drive from the central nervous system. Similar decrements in neural drive were found by Racinais et al. (2007) who used non-athlete subjects performing a repeated sprint protocol. After the subjects performed 10 x 6-second maximal sprints with 30 seconds of

recovery, significant decrements in peak power were observed in physically fit men, with the peak power of the last sprint 11% lower than the first sprint. Despite the active recovery period after each repeated-sprint, significant decreases in maximal voluntary contraction, peak twitch force production, RMS (root mean square)/M-wave ratio, and an associated significant decrement in the percentage of voluntary activation estimated by the twitch-interpolation methods occurred. Racinais et al. (2007) suggests that there was a possible decrement in neural drive to the muscle. A variety of mechanisms could cause the decrease in neural drive, such as a physiological incapacity of the motor cortex to generation an appropriate command, a physiological failure in motoneuron pool excitability, and/or in both the conscious and unconscious will of the subject to reduce the exercise intensity (level of motivation or arousal) (Gandevia, 2001; Racinais et al., 2007). Therefore, it seems fatigue may have a negative effect on power and may stem from mechanisms related to central fatigue, especially in untrained subjects.

Neuromuscular fatigue has been demonstrated to have negative effects on sport performance in team sport athletes (Zemkova & Hamar, 2009; McLellan, Lovell, & Gass, 2010; Thorlund et al., 2008; Hoffman, Nusse, & Kang, 2003). Fatigue developed during a soccer match has been shown to increase ground contact time (amortization phase) during a drop jump and increase the reaction time during an agility test, with more pronounced influence on the concentric phase of the stretch-shortening cycle (Zemkova & Hamar, 2009). As a consequence of longer ground contact time during the drop jump, loss of dynamic balance and agility was observed to the altered sensory feedback of the periphery to the central nervous system (CNS) and decreases in performance resulted (Zemkova & Hamar, 2009). Injuries, such as ankle sprains and tearing of knee ligaments,

occur mostly at the end of intense workouts or games (when the athletes are fatigued), which raises the possibility that muscular fatigue not only reduces athletes' power and quickness, but also place these athletes at a greater risk of injury (Zemkova & Hamar, 2009).

Other team sports have also seen neuromuscular fatigue produce negative effects on power performance. McLellan et al. (2010) showed significant decreases in peak rate of force development and peak power in a countermovement jump in professional rugby players for up to 24 hours post-match. McLellan found that the running volume, sprinting profiles, tackling and wresting, and heavy blunt force trauma placed on rugby players is intense enough to cause decrements in power performance. Similarly, following a handball match, elite men handball players were found to have a drastic reduction in their performance for maximum jump height, maximum voluntary contraction for the quadriceps and hamstrings, total concentric work, and force development for the quadriceps and hamstrings (Thorlund et al., 2008). Football players have also demonstrated significant decreases in peak force and power in both squat and countermovement jumps after the second quarter of a football game (Hoffman et al., 2002), indicating the presence of neuromuscular fatigue. Tidow (1995) has also observed the effect of intra-workout fatigue has on power performance. When testing 50 subjects doing 10 bench press repetitions (progressing 10% each day, from 30% 1RM to 70% 1RM, over 5 consecutive days) there was a slowing-down of the barbell velocity by more than 10% during the sixth repetition, while in the tenth repetition the velocity decreased by approximately 27%. Considering a 5% decrease in velocity of a shot put reduces the

distance of the shot put from 22 meters to 20 meters, reductions in 10 and 27% velocity are unacceptable from a speed-strength point of view (Tidow, 1995).

Decrements in power performance of individual sports, such as cycling, have also been observed. Hautier et al. (2002) observed an 11% drop off in power output in the last sprint compared to the first sprint in a brief, maximal intermittent cycling protocol (15 maximal five-second sprints with 25 seconds of rest between each sprint) after nine weeks of four days of strength training per week preceded by seven weeks of no training. Because both of these studies used short-duration sprints (five to six-second sprints), it may be observed that with longer duration training sessions (such as a three hour gymnastics practice), more significant decrements in power may be observed. As well, the training status of these subjects may have also affected the results, as non-sprint trained subjects were used.

The degree of force developed by the muscle during training is a critical factor in producing optimal strength development (Atha, 1981). When maximal strength and power development are desired, optimal loads and movement velocities must be used in training to see optimal adaptations of the nervous system (Kraemer & Nindl, 1998; Leveritt, Abernethy, Barry, & Logan, 1999). Performing high-level movements in a fatigued state may interfere with learning or stabilizing proper technique and result in diminished adaptations for maximum strength and power, as well (Barker, Poe, & Midgett, 1990). Fatigue has been found to reduce muscular force, decrease the isometric RFD (Thorstensson & Karlsson, 1976; Viitasalo & Komi, 1978) and interfere with movement patterns, especially during high power technique-oriented activities that utilize the SSC, such as Olympic weightlifting (Barker, Poe, & Midgett, 1990) and gymnastics.

Thus, the acute fatigue hypothesis suggests that the scheduling of training sessions in a manner such that strength training quality is reduced because of residual fatigue from a previous training session may be responsible for causing impaired strength development (Leveritt, et al., 1999).

Training to improve power production increases the ability of the neural system to activate the muscles and develop the skill to coordinate the movement for greatest effectiveness (Newton & Kraemer, 1994). Newton & Kraemer (1994) suggest that when scheduling training sessions, it is important not to pre-fatigue the athlete prior to power training. For maximum benefit, power training should be performed in a low-fatigue state to receive optimal benefit. A problem exists in that it is common for in-season athletes to perform strength training after sport practice. However, it appears possible that strength training and other types of training done concurrently may interfere with the development of strength by impairing the ability of the neuromuscular system to make adaptations in the organization of efficient motor unit recruitment patterns normally associated with strength training alone (Leveritt et al., 1999).

When specific sport training is intense or long in duration, fatigue will likely have a negative effect on the development of strength and/or power (Zemkova & Hamar, 2009; Atha 1981). Therefore, it is likely that after an intense practice, fatigued athletes are less able to produce the optimal force and power in the fatigued muscles necessary to stimulate adaptations in the neuromuscular system in the weight room.

Training Status and Fatigue

It is possible that acute fatigue affects neuromuscular performance differently in different types of athletes. Hakkinen (1986) and Hakkinen & Myllyla (1990) found that

when strength-trained men maintained a 60% isometric contraction by extending both legs for as long as possible, a slight change in maximal neural activation of the muscles occurred, while a decrease in maximal force also took place. An acute significant decrease in force production and relaxation characteristics for all types of athletes (endurance, strength, power) occurred, but when a short resting period (three minutes) was offered, neuromuscular performance only partially recovered, and the recovery tended to take the longest in power athletes. This partial recovery, however, could have been attributed to the subjects not being able to fully restore PCr with a three-minute recovery. Had the subjects received more recovery time (such as five minutes), neuromuscular performance may have fully recovered. Unfortunately, EMG activity was not measured, so whether the fatigue was due to central or peripheral conditions was unknown.

Recent studies have also showed that there were no significant differences between pre- and post-match force and power measures in NCAA Division III football players (Hoffman et al., 2003), NCAA Division III soccer players (Hoffman et al., 2002), elite soccer players (Thorlund et al., 2009), or Australian football players (Cormack, Newton, McGuigan, 2008). Thorlund et al. (2009) found that elite soccer players were able to maintain peak rate of force development (PRFD), peak force (PF), and peak power (PP) performing a countermovement jump after a match. According to Thorlund (2009), it seemed this was most likely due to the high-level training status of the subjects (elite soccer players). As well, the study consisted of a low statistical power (nine players), which also could have played a role in showing no significance. Hoffman et al. (2003) found no difference in power performance until 24 hours after soccer match in

Division III soccer players (starters or non-starters). However, this may have been due to their landslide victory (5-0), allowing the starters sufficient recovery time immediately after the game, or that the athletes appeared to be highly motivated during testing (given they won the last game of their season), and may have had elevated catecholamine concentrations during testing (Hoffman et al., 2003). This, however, is just a speculation of the cause, as data did not exist to make these claims.

Hoffman et al. 2002 found similar results in Division III football players, as power and force levels decreased only during the first quarter, reached lowest values by half time, and returned to baseline by the end of the game. Hoffman believed this occurred because the game was a lower intensity game, as they won in a landslide victory. The observed power decrease 24 hours after the game most likely occurred because of muscle damage that is usually not evident until 24 to 48 hours following exercise. Cormack et al. (2008) showed no difference in power performances after a game, suggesting that a countermovement jump (CMJ) may lack the sensitivity to detect neuromuscular fatigue from a single game. A CMJ can increase variability within each test, while static jumps produce more stable scores from each subject, as they are instructed how far they can squat down and when to jump as high as they can; taking as much variability out of the test as possible (Cormack et al. 2008).

Recent research indicates that those with moderate to long term strength training experience may have a greater ability to activate motor units than untrained individuals when fatigued (Hartman, Ryan, Cramer, & Bembem, 2011; Hoffman et al. 2003; Thorlund et al. 2008; Thorlund et al. 2009; Cormack et al. 2008). Hartman et al. (2011) examined resistance trained and untrained subjects performing isometric maximal

voluntary contractions (MVC's) before and immediately after unilateral dynamic isotonic contractions performed at 40% of MVC until volitional exhaustion, using the interpolated twitch technique (ITT) to determine the level of muscle activation, central activation ratio (CAR), and surface EMG. It was determined that despite a similar number of repetitions completed at the same relative load, as well as similar reductions in MVC torque post-exercise, the untrained men experienced nearly twice the decline in % voluntary activation than the resistance-trained men (Hartman et al. 2011). Both groups had decreases in muscle activation, but only the untrained group experienced a decrease in surface EMG activity. This suggests that long-term, chronic resistance training may help delay the onset of neuromuscular fatigue, specifically central fatigue, produced during dynamic isotonic exercise (Hartman et al., 2011).

When subjects performed an isometric, intermittent, sub-maximal, fatigue protocol of the plantar flexor muscles, Behm et al. (1998) found that resistant trained subjects experienced less fatigue (MVC decreased 32% in trained subjects, compared to a 45% decrease in untrained subjects) and there was a greater depression of peak twitch amplitude, EMG, and M-wave amplitude of untrained subjects. It seems critical for researchers to consider prior resistance-training histories of volunteers when performing human performance research involving muscular fatigue (Hartman et al., 2011). When testing the athletes, resistance-training histories of the subjects will be taken into consideration.

Potentiation

It is possible that after a workout, an increase in power can occur. In contrast to fatigue, post-activation potentiation (PAP) serves to improve performance (Sale, 2002).

PAP is an increase in muscle twitch and low-frequency titanic force after a “conditioning” contractile activity (Sale, 2002). A notable feature of PAP is that it is greater in fast, Type II muscle fibers, and people with a higher percentage of Type II fibers within a muscle, exhibit greater PAP (Sale, 2002). PAP can increase rate of force development (RFD), even at very high stimulation frequencies where force is not increased by PAP. Thus, PAP would shift the load (force-velocity) relation upward and rightward. When this happens, activities like jumping, kicking, and throwing might be improved if the muscles are in a state of PAP (Sale, 2002). It seems that a gymnastics practice, a sport filled with many conditioning activities that involve recruitment of Type II fibers, could cause a form of potentiation after practice.

Why Static vs. Counter Movement Lifts

To fully test the effect fatigue had on power and strength in the weight room, we used tests that used both SSC and non-SSC to measure neuromuscular fatigue. Subjects were tested on a static jump squat, static shoulder throw, and plyometric jumps, to determine the effect of a gymnastics practice on force and power production during strength training. We used a static start for the jump squat and shoulder throw because the static starts emphasize the use of the contractile properties of the muscle more than a counter movement would as the static start would decrease the involvement of the elastic properties of the muscle. We also implemented a 4-jump test as a SSC task, as recent evidence suggests the SSC provides a more specific model to study neuromuscular fatigue (Komi, 2000; Nicol, Avela, & Komi, 2006). Since much of the lower body muscle recruitment uses more plantar flexor involvement compared contribution of the

hip and knee flexors, this multiple-jump test may be more specific to fatigue seen in gymnasts.

Load for Squat Jump and Shoulder Throw

Load for Shoulder Throw. Limited research exists for the optimal load (% of 1RM) for upper body power. Dalziel, et al., (2002), found PP to be significantly greater in a shoulder throw compared with a shoulder press at both 30% and 40% 1RM, and optimal power was shown to be the greatest at 40% for the shoulder throw. The greater PP in the shoulder throw may be due to greater maximum acceleration or a shorter deceleration phase of the bar motion. Therefore, the shoulder throw is a more appropriate choice of shoulder exercises to assess PP compared with the shoulder press.

Other research to determine optimal load for upper-body PP found that the concentric-only bench throw had the highest peak power at 20-30% 1RM using resistant-trained subjects (Newton, 1997). However, Baker, Nance, & Moore (2001a) found that the greatest adaptations to power training were found using approximately 55 of 1RM in a bench throw. It is likely that those with strength and power training experience may benefit more from heavier loads than those with less training experience (Baker et al. 2001a). When % of 1RM is low, velocity contributes to more of the power production, and when % of 1RM is high, strength appears to contribute to more of the power production (Baker et al. 2001a). In addition, Tidow (1995) found that an optimal load to produce strength and power improvements is 10% above optimal power. Because one purpose of this study is to determine the effects of fatigue on strength training, we chose to use a load that would emphasize the force component rather than the velocity component of the power equation (power = force x velocity).

After pilot work experimenting with 40-50% 1RM of the shoulder press, we decided to use 50% 1RM for the shoulder throw, since this was a little heavier than optimal power for upper-body tests, the subjects were well-trained, and the subjects could still throw the bar in the air in a ballistic manner.

Load for Squat Jump The load for all subjects was based on percentage of their 1RM of the back squat. For jump squats, Dugan (2004) found that % of 1RM can range between 20-70% 1RM depending on whether body weight is included in calculations. Baker et al. (2001) found that using 55-59% of 1RM utilized the maximal power output in jump squats, but that loads in the range of 47-63% of 1RM were often similarly effective in maximizing power output for strength and power-trained athletes. On the contrary, Cormie, McCauley, Triplett, & McBride (2007), and Cormie, McBride, & McCauley (2008), found that the optimal power for jump squats in untrained subjects was 0%. When % of 1RM is low, velocity contributes to more of the power production, and when % of 1RM is high, strength appears to contribute to more of the power production (Baker, Nance, & Moore, 2001b). Because we are interested in applying our results of this study to training in the weight room, we want to use a % of the 1RM during testing that will emphasize the force contribution to the power equation more than the velocity.

Due to the range of findings (0% - 63% 1RM) and other pilot work, we decided to go with 40% 1RM for the squat jump, as we wanted to keep the % 1RM consistent with the optimal power for resistance-trained subjects and have a little heavier % 1RM to remain on the strength-side of the strength-power spectrum.

Monitoring Internal Load of Practice Session

The ability to monitor the exertion due to training was critical in this study. High-

intensity exercise, such as gymnastics, is particularly difficult to quantify. Thus, the session rating of perceived exertion (s-RPE) method was used to quantify the internal training load (TL) of the gymnastics practice from the perspective of each individual gymnast. The s-RPE method has been shown to be highly consistent with heart rate in training for basketball and cycling (Foster et al 2001). The s-RPE method was also found to be applicable to a wide variety of exercise, especially high-intensity exercise and sports with technical skill (Foster et al. 2001, Minganti et al., 2010). Session-RPE has been used with athletes in a variety of sports, such as soccer (Hill-Haas, Dawson, Coutts, & Roswell, 2009; Impellizzeri, Rampinin, Coutts, Sassi & Marcora, 2004), cycling (Foster, et al., 2001), and even teamgym (Minganti, et al., 2010), which is a new and emerging closed-skill sport, which includes tumbling, trampette, and floor programs (similar to gymnastics). Session-RPE, reported during teamgym practice sessions, had a high correlation with the heart rate method, taking into account physiological and psychological factors (Minganti et al., 2010). Session-RPE has also been used to monitor the TL during resistance training (Day, 2004).

At least 15 minutes after practice, subjects will rate their perceived exertion based on a modified CR-10 RPE scale (Foster et al., 2001) by answering the following question: “How was your workout?” The subjects will indicate a number on a piece of paper, privately. Numbers from 0 to 10 on the scale are used to rate the intensity of the entire workout session. A rating of 0 is associated with rest, and the highest rating, 10, refers to maximal effort. The use of the s-RPE is different from the more standard approach of asking subjects to rate how difficult they perceived a particular exercise or set to be. The aim of the s-RPE is to provide a global TL for the entire workout session

(Foster, et al., 2001).

The subjects in our study will give their s-RPE at least 15 minutes after practice, because Singh, Foster, Tod, & McGuigan (2007) found significant differences between the average s-RPE values at 5 and 10 minutes post-exercise compared with 30 minutes post-exercise. All other s-RPE values (15-25 minutes) had no significant difference compared with the 30-minute mark (Singh, et al., 2007). Studies suggest that most athletes can use s-RPE fairly well with only minimal instruction, primarily by focusing on the verbal anchors associated with the RPE scale (Foster, et al., 2001). Despite athletes rating training differently, it has been found that these athletes seem to be very consistent in their own pattern of using the s-RPE method (Foster, et al., 2001).

For this study, we will not use EMG to measure neuromuscular fatigue, however, s-RPE has been found to represent neuromuscular fatigue or effort (Rhea et al., 2002; Singh et al., 2007). Rating of perceived exertion was developed to take into consideration the various signals coming from the working muscles and joints, central cardiovascular function, and the central nervous system (CNS) (Borg, 1982). It has been demonstrated that when performing multiple sets of the same load during resistance training (similar to performing multiple sets in the gym), s-RPE increases, indicating s-RPE may be related to metabolic accumulation, representing neuromuscular fatigue or effort (Rhea et al., 2002; Singh, et al., 2007).

Menstrual Cycle and Muscle Strength/Power

A concern when using women as subjects, when investigating strength-power performance, is the effect the menstrual cycle may have. When investigating muscle strength and muscle endurance in women during three well-determined phases of the

menstrual cycle: early follicular phase (cycle day 1-13, low levels of Estradiol and progesterone), ovulation phase (cycle day 13-16; moderate to high levels of Estradiol, but low progesterone levels), and mid-luteal phase (cycle day 16-28; high levels of both progesterone and Estradiol), muscle strength and muscle endurance were not affected by the phase of their cycle (Friden, Hirschberg, & Saartok, 2003). The study was hormonally validated by blood samples and was repeated in two consecutive menstrual cycles (Friden, et al., 2003). Lebrun, McKenzie, & Prior (1995) measured isokinetic muscle strength of knee flexion and extension during the early follicular phase (cycle day 3–8) and the luteal phase (4–9 days after ovulation), and found no significant variation in performance between these phases as well. Other recent studies (Gur, Akova, & Kucukoglu, 1999; Gur, 1997) could not detect any differences in either concentric or eccentric isokinetic muscle strength in the knee flexors and extensors during the menstrual cycle when hormonally validated, as well.

Other studies have found that the phase of the menstrual cycle may have some effect on force production. Davies, Elford, & Jamieson (1991) reported an increase in explosive muscle strength doing simple muscle tests (a handgrip test and standing long jump) during the early follicular phase (cycle day 1-4, low levels of estradiol), compared to the late follicular phase (cycle day 12-14, high levels of estradiol) and the luteal phase (cycle day 19-21, high levels of Estrogen and progesterone). Sarwar, Niclos, & Rutherford (1996) studied two groups of ten young, healthy, relatively sedentary women through two complete cycles; one on an oral contraceptive pill and one not. The subjects were tested on their maximum voluntary isometric strength of the quadriceps, percutaneous electrical stimulation on the quadriceps to measure contraction and

relaxation time, a measure of fatigability in the quadriceps (the percentage of force lost over 3 minutes), and a measure of handgrip strength using a hand dynamometer (Sarwar et al., 1996). The results indicated that women taking oral contraceptives increased isometric strength of the quadriceps during the ovulation phase (cycle day 12-18), compared with the other phases in women who were not taking an oral contraceptive pill. The increase in isometric strength was accompanied by a significant slowing of relaxation time and increase in fatigability. Women who were on oral contraceptives had no changes in strength, relaxation, or fatigability (Sarwar et al., 1996).

There is speculation that estradiol and progesterone inhibit skeletal muscle performance (strength and power), whereas low levels of these sex steroids during the early follicular phase may enhance muscle strength (Davies et al., 1991). Unfortunately, no hormonal analyses was performed by Davies et al. (1991) and Sarwar et al. (1996) to confirm the role of hormones in these findings. The results of these studies suggest that the phase of the menstrual cycle may have little bearing on strength/power performance, and women who take oral contraceptives may display even smaller differences in strength/power production during the different phases of the menstrual cycle.

The Effects of Motivational level

Motivation is a key ingredient to improvements in strength and power. Achieving optimal athletic performance is more likely to occur when an athlete is mentally motivated to reach a goal or task. High arousal can either motivate an athlete to perform well through encouraging, positive arousal or decrease the performance outcome of an athlete (by over-arousal) (Perkins & Wilson, 2001). According to reversal theory, both the level of arousal and the current motivational state of the individual determines

emotion (Perkins & Wilson 2001). In a sporting context for example, reversal theory would predict that a highly aroused athlete preparing to perform while in the telic state (e.g., when the individual is focused on “I must win,” or “I must not foul”) would tend to feel anxious rather than excited (Perkins & Wilson, 2001). Alternatively, the reversal theory would also predict that a highly aroused athlete in the paratelic state (e.g., when anticipating the kinesthetic sensation or thrill of a coordinated and powerful throw or sprint) would tend to experience positive excitement rather than anxiety (Perkins & Wilson, 2001).

In a review of other studies involving the sports of rugby, squash, and gymnastics, Kerr reports that relatively high levels of positive and non-stressful felt arousal were a feature of successful performance (1997). Subjects have also been found to show the greatest handgrip strength performance following the paratelic state, supporting that high positive arousal (measured by heart rate, breaths per minute, skin conductance level, and finger pulse amplitude) can enhance performance (Perkins & Wilson, 2001). It seems that psychological (manipulation of telic/paratelic motivational state) rather than physiological factors (increases in HR, SNS), play a prime role in the enhancement of strength performance (Perkins & Wilson, 2001). Due to this, we may find that athletes, who are highly motivated, may be able to overcome their fatigue.

In contrast, Brody, Hatfield, Spalding, Frazer, & Caherty (2000) examined the effect of psyching on neuromuscular performance and motor unit activation of the biceps brachii and triceps brachii in well-trained individuals during a maximal isometric elbow flexion task. The participants took part in one of the three conditions: psyching (PSY), where they were instructed to use an arousal-enhancing strategy, reading aloud (RA),

where they read a passage aloud and asked comprehension questions after the task, and mental arithmetic (MA), where they had to count backwards from 1,000 by sevens as quickly as they could. Although the ratings of arousal and attentional focus were greater for psyching than the comparative conditions, there were no significant differences in the force or EMG's produced across the conditions (Brody et al. 2000). It seems that there may have been a dissociation of the effects observed on the central and peripheral components of strength from the psychological intervention such that change was confined to the brain and did not extend to the efferent pathways (Brody et al., 2000).

The contradiction of this study compared to those generally reported in sport psychology literature, occurred most likely, because of two reasons. The first being the principle of specificity, as the participants were challenged differently (using a relatively small muscle group, rather than a large complex muscle group with multiple joints), as well as were dependent on maximum force within a short contraction time (less than four seconds), rather than being dependent on muscular endurance (Brody et al., 2000). The second reason for the lack of significant findings may be that the participants were so well trained physically. When challenged with a task that mimics one in their training, the subjects may have already achieved optimal development for this muscle action and as such, may have reached an adaptational ceiling for performance that would have precluded any effect of psyching (Brody et al., 2000). Untrained individuals may benefit from forms of mental preparation like psyching because, initially, they are not near their adaptational ceiling, and therefore, have considerably more opportunity for improvement (Brody et al., 2000).

Heart rate (HR) is a common method used in studies to employ a physiological

measure to assess arousal, but no relationship has been found between HR and enhanced strength performance (Dorney, Goh, & Lee, 1992; Whelan, Epkinds, & Meyers, 1990). We were aware of the arousal state of our subjects through the Intrinsic Motivational Inventory (IMI). This survey determined the effort (and motivation) each subject gave during testing. The IMI is a flexible assessment tool that determines subjects' levels of intrinsic motivation through interest-enjoyment, perceived competence, effort, and pressure-tension (McAuley, Duncan, & Tammen, 1989). The questions on the IMI can also be easily modified to fit a wide variety of activities. For example, the generic question, "I was pretty skilled at this activity" can be changed to "I was pretty skilled at jumping as high as I can," to better reflect the situation. The IMI has been employed in diverse settings, such as reading, learning, writing, and hidden figure puzzle tasks, and McAuley et al. (1989) demonstrated the internal consistency and the tenability of the IMI in a competitive sport setting (competitive basketball shooting task). The reliability and internal consistency of the IMI even exceeded the recommended for research contexts (McAuley et al. 1989).

The Effects of Sleep

Sleep is a variable that could potentially interfere with sport performance. Skein, Duffield, Edge, Short, & Mundel (2011) studied the effects of 30 hours of sleep deprivation on consecutive-day intermittent-sprint performance and muscle glycogen content using a free-paced exercise protocol designed to allow the manipulation of the exercise intensities by the participant (as observed in team-sport exercise). Thirty hours of sleep deprivation produced slower pacing strategies, reduced intermittent-sprint performance, reduced muscle glycogen content, reduced peak voluntary force and

voluntary activation, and negative perceptual strain (Skein et al., 2011). This was the first study to use simulated team-sport activity, with sleep deprivation seemingly having a negative effect on intermittent-sprint activity. Another study by Souissi, Sesboue, & Gauthier (2003), found that anaerobic performances (Wingate and sprint tests) were unaffected after 24 hours of no sleep, but were impaired after 36 hours without sleep.

Studies of short-term maximal effort have reported how supra-maximal performance can be maintained despite sleep deprivation. Symons, VanHelder, & Myles (1988) demonstrated no significant change in the isometric strength of flexors and extensors, peak isokinetic torque, muscular endurance, peak power output, fatigue index, or blood lactate after the Wingate anaerobic test. In addition, Takeuchi, Davis, Plyley, Goode, & Shephard (1985) further showed that 64 hours without sleep did not impair isometric hand-grip strength or peak torque for leg extension. However, 64 hours of sleep deprivation did impair vertical jump and knee extension torque at low velocity. We expect that if a subject only received a few hours of sleep the night before testing; little effect on strength and power production would occur.

Conclusion

Therefore, the aim of the present study was to observe the effect fatigue, determined by the length of a gymnastics practice, had on power production during exercises usually utilized to develop these features during weight room training. This determined the efficacy of the common practice of performing power training following a team practice.

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