EFFECTS OF A HIGH-VOLUME, LOW-INTENSITY, MULTI-SET SQUAT PROTOCOL ON POWER OUTPUTS

By

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I. INTRODUCTION

Individual responsiveness to resistance exercise poses a complex challenge for exercise specialists and coaches alike. Categorical variables that could manipulate responsiveness include: training status (Izquierdo, Häkkinen, Gonzalez-Badillo, Ibáñez, & Gorostiaga, 2002), training volume (Hester, Conchola, Thiele, & DeFreitas, 2014; Marshall, McEwen, & Robbins, 2011; Robbins, Marshall, & McEwen, 2012), training intensity/load (Cormie, McCaulley, Triplett, & McBride, 2007; Jiménez-Reyes et al., 2015; Kawamori et al., 2005; Loturco, Ugrinowitsch, Roschel, Tricoli, & González-Badillo, 2013; McBride, Haines, & Kirby, 2011), genetics (i.e., fiber-type composition) (Wilson et al., 2012), anthropometry (Garhammer, 1985), and gender (G. a Thomas et al., 2007; M. Thomas, Fiatarone, & Fielding, 1996). These variable constraints make it problematic to determine optimal prescriptions aimed at neuromuscular development and increased performance on an individualized basis (Marshall et al., 2011). Nonetheless, attempts to consider an individual's responsiveness to different training variables should be made.

Studies have shown that training for strength gains, particularly in a trained population, seems to be a function of both intensity (Schoenfeld, Peterson, Ogborn, Contreras, & Sonmez, 2015) and volume (Marshall et al., 2011). However, recent research suggests that manipulating training volume is preferred over training intensity in order to develop strength and power (Drinkwater et al., 2005; Finn et al., 2014; Hester et al., 2014; Iglesias-Soler, Carballeira, Sanchez-Otero, Mayo, & Fernandez-del-Olmo, 2014; Linnamo et al., 2000; Marshall et al., 2011; Robbins et al., 2012). Training volume is often described in terms of the number repetitions performed in either an exercise bout or during a particular exercise (i.e. sets x reps x exercises; sets x reps x load; sets x reps) (Robbins et al., 2012). However, there has been recent debate over the appropriate dose of volume during training for power improvement (Robbins et al., 2012).

Much of the recommendations for exercise practitioners have multiple-set exercise prescription involving 3 or 4 sets for lower, upper and whole body exercises (Baechle & Earle, 2008). Nevertheless, some exercise programs call for >3 or 4 sets per muscle group, per session. For example, protocols such as the “Smolov Method” and the “Hatch Squat Cycle” use high-volume (in excess of 6-sets) of moderate-to-high intensity (loads >70% maximal strength) training sessions up to 4 times per week for improvements in lower body strength. Furthermore, high volumes of resistance exercise for up to 6 weeks, as compared with low volumes, have been shown to be superior with respect to strength development (Robbins et al., 2012). It is interesting to note that while this improvement in strength may be attributed to increases in volume, it does not guarantee improvement for all individuals (Marshall et al., 2011; Robbins et al., 2012). With limited research investigating the effect of volume on neuromuscular adaptations, it is unclear if volume is a “one size fits all” concept as the other categorical factors stated previously can alter adaptation.

The total volume of exercise is often varied to increase or decrease the acute fatigue stimulus and subsequent training adaptation. In research observing skeletal muscle responses to increasing volume of resistance exercise, a proportional increase in two signaling molecules which are believed to acutely enhance the rate of protein synthesis in skeletal muscle appeared to be dependent on the increase of volume during resistance training (Terzis et al., 2010). Furthermore, increased exercise volume positively affects myofibrillar protein synthesis and an anabolic signaling molecule in young men (Burd et al., 2010). It seems as though inducing acute training fatigue by increasing training volume can lead to performance and hypertrophic improvements. However, further investigation is needed to better provide appropriate volume during resistance training.

Power can be defined as the rate of work or the product of force and velocity in respect to time. In today's athletic population, a large number of activities require a higher degree of muscular power. Both in sports and recreational exercise, power can be considered the most important element of exercise performance (Haff & Nimphius, 2012). Research suggests that the ability to express high rates of force development and high power outputs are critical performance characteristics central to success in most sporting events especially in activities that rely on jumping, change of direction, and/or sprinting performance (Baechle & Earle, 2008; Haff & Nimphius, 2012; Hoffman, Cooper, Wendell, & Kang, 2004; Stone, Moir, Glaister, & Sanders, 2002). Also, increases in power development have been shown to help improve activities of daily living and quality of life (Bean et al., 2003).

The ability to optimize muscular power output is considered fundamental to successful performance of many athletic and sporting activities (J. Cronin & Sleivert, 2005). One variable that is considered paramount in increasing muscular power and athletic performance in explosive tasks is the training load that produces peak power max (PPmax). PPmax is the highest amount of power produced within a set or movement. However, there are inconsistencies as to which load of resistance maximizes power output during various exercises and whether training at PPmax improves performance (Cormie, McCaulley, & McBride, 2007; Cormie, McCaulley, Triplett, et al., 2007; J. Cronin & Sleivert, 2005; González-Badillo, Izquierdo, & Gorostiaga, 2006; Haff & Nimphius, 2012; Kawamori & Haff, 2004; Martorelli et al., 2015; McBride et al., 2011). Furthermore, the ability to express high rates of PPmax is often related to an individual's overall strength levels and training status (J. Cronin & Sleivert, 2005; Stone et al., 2002). If PPmax is found to be important in improving athletic performance, then each individual's PPmax needs to be determined and training programs should be centered on PPmax parameters. The idea to train all individuals at one percentage of a load is fundamentally flawed due to individual differences in power output. Given that power output can vary with similar strength, PPmax needs to be further investigated to better understand power output responses and individualize programs.

The premise of maximizing the acute fatigue stimulus has led to the utilization of high-volume accumulation methods in the powerlifting, bodybuilding, and recreational resistance training environment for improvements in strength, power and athletic performance (Finn et al., 2014). In the context of exercise prescription, the goal to maximize the acute fatigue stimulus has led to numerous techniques that increase training volumes, including superset or compound sets, drop-set techniques, and forced or assisted repetition training. However, this training at excessive volume with very high intensity has been shown to correlate with overreaching responses (Fry & Kraemer, 1997). There is a lack of understanding how fatigue affects power within a training session during multiple sets of resistance exercise in a trained population. Further research is needed to better understand how to maximize a training stimulus without eliciting a possible overtraining response. The acute response to high volume training on power within a training session is currently unclear.

II. REVIEW OF LITERATURE

Due to its impact on performance, the examination of power outputs during various types of resistance exercise is heavily researched (Hester et al., 2014). Many studies focusing on muscular power are concerned with finding the optimal intensity for maximizing power during single set or low-volume training (Cormie, McCaulley, Triplett, et al., 2007; Izquierdo et al., 2002; McBride et al., 2011; G. a Thomas et al., 2007; M. Thomas et al., 1996). Furthermore, recent research has looked into the physiological adaptations to training and volume at these optimum intensities (Hoffman et al., 2004; Kawamori et al., 2005; Loturco et al., 2013; Martorelli et al., 2015).

Research on Load

The optimum load in any exercise is to allow for maximum power development and adaptation after a training stimulus. It is common practice for coaches and trainers to train their athletes at or around the optimal load of any movement. While this seems to be a better way to train for power improvement, research shows there are 3 intensity zones to improve power production (Haff & Nimphius, 2012). The first zone suggests using lower intensities (<50% of 1-RM) are optimum due to the ability to improve velocity of movement (D. Baker, 2001; D. G. Baker & Newton, 2007; Hester et al., 2014; Newton & Dugan, 2002). The next suggest using higher percentages (50-100% of 1-RM) are optimum due to the ability of increasing force and strength of the movement (Cormie, McCaulley, & McBride, 2007; Cormie, McCaulley, Triplett, et al., 2007; Martorelli et al., 2015; Stone et al., 2002). Lastly, some research suggests using a mixed methods approach of intensities in order to vary the stimulus between loads (J. Cronin & Sleivert, 2005; Haff & Nimphius, 2012; Kawamori & Haff, 2004; Loturco et al., 2013; McBride et al., 2011). The use of a mixed loads approach to maximize power output capacity allows for a superior increase in maximal power output and a greater transfer of training to improved sport performance because of a more well-rounded development of the force-velocity relationship (J. Cronin & Sleivert, 2005). By using lower percentages of 1-RM, higher velocities can be maintained while on the other hand, training at higher percentages of 1-RM greater force development can be generated. Limiting training to a certain load has the inherent nature of increasing power production around that percentage (Haff & Nimphius, 2012).

Power production may also change depending on the type of exercise that is performed (D. G. Baker & Newton, 2007). For example, in the back squat, maximum power development can occur between loads of 30–70% of 1-RM (Cormie, McCaulley, Triplett, et al., 2007; Loturco et al., 2013; McBride et al., 2011), whereas in the power clean exercise, power development can be maximized between loads of 65-95% of 1-RM (Hori et al., 2007; Kawamori et al., 2005; McBride et al., 2011). In theory, by utilizing multiple movements and derivatives of movements, such as the jump squat as a supplement to the back squat, power output can be increased by influencing either velocity or force (Haff & Nimphius, 2012).

It is often difficult for the strength and conditioning professionals to determine which percentages of 1-RM are the best approach for optimizing maximal strength, rate of force development, and power capacity. Ultimately, for many athletes, a continuum of loads are encountered during sporting play making it far more beneficial to develop the ability to maximize power output across a variety of loads (Haff & Nimphius, 2012).

Research on Volume

It is currently accepted that training for PPmax improvement should include an exercise prescription in a session ≤6 reps for 3-5 sets (Baechle & Earle, 2008; D. Baker, 2001; D. G. Baker & Newton, 2007; D. Baker & Newton, 2005; Haff & Nimphius, 2012; Martorelli et al., 2015). This recommendation is to avoid fatigue-induced decrements in lifting speed that is vital for maximizing power training effects (D. Baker, 2001; D. Baker & Newton, 2005). Consequently, it has become a staple in exercise prescription that low volume exercise bouts are necessary to maximize power and achieve the acute training adaptations. Because many of the previous studies have focused on assessing the optimal intensity that produces maximal power output during low volume exercise bouts, very little research has examined the effects of high volume exercise on muscular power.

In 2010, researchers examined the effects of volume on power output during the execution of a moderate-load muscular endurance training bout (Smilios, Hakkinen, & Tokmakidis, 2010). Participants performed squats at 4 sets of 20 repetitions with a load of 50% of 1-RM with 2 minutes of rest. During testing, if a participant could not finish a set, he or she was assisted to complete the set and the load was decreased for the next set by 10% of the previous set. Results showed that mean peak power for the set (PPavg) declined more during the execution of sets 3 and 4 (Smilios et al., 2010). PPavg is the averaged power values for all reps or movements within a set. Additionally, PP output during the 3rd set was lower ($p < 0.05$) than in the 1st and the 2nd set by 5.7 and 6.2%, respectively (Smilios et al., 2010). During the 4th set, PPavg was lower ($p < 0.05$) in all repetitions compared with the first 2 sets by 10.4 and 11.1%, respectively (Smilios et al., 2010). The authors suggested that during a moderate load muscular endurance session, power output declines in the latter sets (Smilios et al., 2010). This decline in power continued even with a reduced load to complete a high number of repetitions (Smilios et al., 2010). Power output did not change considerably during the execution of the first 2 sets. However, subjects reached fatigue and their power output declined rapidly during the 3^{rd} and 4^{th} sets indicated by the inability to maintain the velocity of movement (Smilios et al., 2010). However, the findings revealed that average velocity of each set did not change ($p > 0.05$) from set to set (Smilios et al., 2010). In summary, the authors stated that if the maintenance of movement velocity and power is of importance for an athlete, adjustments of the load should be made during a muscular endurance session to provide a stimulus of the appropriate velocity and duration (Smilios et al., 2010).

Hester et al., (2014) examined power outputs during a high-volume (5-set) low-load, speed-strength (40% of 1-RM) back squat protocol. The researchers wanted to determine whether the performance of additional repetitions above what is currently recommended at the given power training range was detrimental to the PPavg and PPmax output of the subsequent sets (Hester et al., 2014). The research revealed that as the set progressed, PPavg decreased throughout the 16 reps in each set. While this is expected, the authors suggested that this was most likely a result of fatigue (Hester et al., 2014). However, the results showed a lack of difference in PPmax between the sets ($p = 0.493$) (Hester et al., 2014). This indicated that maximum power can recover and be sustained with 2 minutes recovery between 5 sets of high volume squats (Hester et al., 2014). The findings of this study demonstrate the likelihood that training at optimal power ouputs can occur across high volume sets. The authors suggest that a protocol of this nature may be beneficial when the goal is to improve intermediate-term anaerobic performance, specifically intermittent weightlifting anaerobic endurance (Hester et al., 2014). In summary, the researchers found that performing additional repetitions on top of what is currently recommended within each set for power improvement did not affect the subjects' PPmax of subsequent sets.

This is in contrast to the results found by Smilios et al. (2010) who found PPavg to be significantly higher during sets 1 and 2 compared with sets 3 and 4. Hester et al. (2014) found that during high volume exercise, PPmax could be sustained with 2 minutes of rest. This may be likely due to inconsistent differences in load Hester (2014) used 40% of 1-RM while Smilios et al. (2010) used 50% of 1-RM with a decrease in load if participants needed assistance to complete the set) and in sets and reps. Additionally, Smilios et al. (2010) examined PPavg while Hester (2014) examined PPmax. Therefore, it is difficult to make comparisons between these two findings.

Based on limited data, the recommended amount of volume during training for power is unclear. While some studies show that PPmax could be maintained with with the appropriate amount rest, others have shown PPmax to decrease with an increase or constant volume. Furthermore, it has yet to be determined if PPmax can be maintained with a shorter rest period. Overall, recommendations for training for power seem to vary. The wide range of variation between volumes recommended from current research demonstrates the need for further investigation to better prescribe optimal training programs. Without a clearly defined volume stimulus for power output, maximum adaptations may not be realized when training at higher volumes. Further research may be needed to fully understand the effects of such high volume training to power output.

Research on Fatigue

In 2014, researchers examined the effects of fatigue and muscular activation during a high volume, power oriented exercise bout (Finn et al., 2014). The authors state that recent research shows that maximizing the acute fatigue stimulus to justify the prescription of any training intensity is an unproven belief (Finn et al., 2014). Some experts in the field speculate that higher threshold motor units can be recruited exercise methodologies that are fatiguing at higher volumes with low intensity. By using 8 sets at 75% of the participant’s 1-RM in the Bulgarian split squat at maximum repetitions, Finn et al., (2014) wanted to determine if a plateau could be reached in force generated before the completion of the high volume protocol. The results showed that repetitions in sets 1, 2 and 3 were significant different from each other. Furthermore; sets 1 and 2 repetitions were higher than sets 3 through 8 (Finn et al., 2014). Lastly; maximal force output was not statistically different from the end of the 5th to the 8th set, indicating that force observed was affected by fatigue during the first 4 sets and plateaued during later sets (Finn et al., 2014). These results indicate that work performed in the beginning of exercise bout may not be affected by overall fatigue; however, the individual's capacity to maintain force during high volume exercise with fatigue in the subsequent sets may change. The distinct separation of individuals who reached a force plateau earlier in the exercise bout and those who didn't may be a function of the relative training load being invalid across the participants (Finn et al., 2014). The authors concluded that individuals performing a resistance training bout will not perform the same number of repetitions using 1-RM-based prescription thus not accumulating the same volume to a given stimulus (Finn et al., 2014).

Research has shown that there are individual differences in acute responses to percentage-based resistance exercise prescription (D. Baker, 2001; D. G. Baker & Newton, 2007; J. B. Cronin, McNair, & Marshall, 2002; J. Cronin & Sleivert, 2005; Finn et al., 2014; Haff & Nimphius, 2012; Kawamori & Haff, 2004; Marshall et al., 2011; Robbins et al., 2012). Finn et al. (2014) suggested that a repetition maximum (e.g., 3-RM, 10-RM, 20-RM) based prescription may provide more constant adaptations across individuals. This could also allow for better examination of the relationship between acute and chronic training responses in training studies (Finn et al., 2014). However, previous research suggest that rather than performing a designated number of repetitions based on percentages of maximum weight, a set should cease when the PPmax drops below 90-95% of the PPmax achieved during the set (D. G. Baker & Newton, 2007). Interestingly, by making training prescription for speed strength specific training adaptations based on the percentage of the PPmax as an indicator of intensity instead of a percentage of 1-RM, optimal exercise prescription can be provided for each individual for maximizing power. Further research is warranted to fully understand the effects of fatigue on training for power output.

Research on Training

Researchers examined the training effects on lower body strength, velocity and rate of force development (RFD) after a 6-week protocol consisting of 1 set vs. 4 sets vs. 8 sets . The protocol called for a 2-day spilt training routine with the number of sets completed at maximum effort using a high load, 80% of back squat 1-RM until voluntary failure. Results showed that maximum muscle recruitment did not change after 6 weeks of resistance training in any groups along with a significant decrease in RFD and velocity (Marshall et al., 2011). The authors speculated that this can likely be attributed to participants maximizing their motor unit recruitment during a higher intensity squats (80% 1-RM) as compared to lower intensities (i.e. <80% 1-RM) along with a repetition to failure training model (Marshall et al., 2011). Therefore, further neuromuscular improvement by increasing intensity along with training until failure is unlikely to occur (Marshall et al., 2011). The results demonstrated a 6-week training program with a fatigue model may reduce velocity and RFD, which has important application during the force/velocity relationship. While an increase in volume at a high intensity can improve strength over a short amount of time (i.e. 6 weeks), Marshall et al., (2011) showed that it does have a significant decrease on mean power production. The authors suggested that if the intention of a training program is to develop power via neural adaptation, sub-maximal (<80% of 1-RM) intensity prescription may be warranted (Marshall et al., 2011).

Researchers examined the effects of a 10-week chest throw training program on upper-body power development in elite, female netball players. The participants were split into 3 different groups: a heavy group (≥80% 1-RM), a light group (30-60% of 1-RM) and a control group. While both treatment groups produced significantly higher velocities than the control group, the heavy group produced higher velocities, force and power post treatment than the power group (Cronin et al., 2002). The authors discussed the results stating that load associated in both strength and power variables and development in these areas equally effect velocity improvement (Cronin et al., 2002). Results also indicate that while percentages in load during weight training may differ, velocity of the actual movement should be considered when training for power production (Cronin et al., 2002). Development in areas such as the stretch shortening cycle or RFD may be more imperative when training for velocity/power specific movements.

Another training study investigated the effects of heavy (80% 1-RM), light-load (30% 1-RM) and a control group on strength, power and speed of movement in experienced weight trainers during an 8-week training program. Jump squats were used for both training and testing, and groups were equated for volume during the course of the program. After 8 weeks of training, both groups increased 1-RM significantly (10.17% and 8.23% for 80% 1-RM and 30% 1-RM groups, respectively) with no significant difference between groups (McBride, Triplett-McBride, Davie, & Newton, 2002). Similarly, there were no significant between-group differences in peak force, peak power or jump height pre- and post-training (McBride et al., 2002). Of the three sprints (5, 10 and 20m sprint time) and agility (T-test time) measures, the 30% 1-RM training proved superior to 80% 1-RM training on only one measure (10m sprint time) (McBride et al., 2002). Further investigation revealed that the light-load group had an overall trend of improved velocity capabilities regardless of load in the jump-squat tests while the heavy-load group had overall improved force capabilities in the jump squat test, regardless of load (McBride et al., 2002). Overall, heavy resistance training is effective at increasing force while the movement velocity is slow, but light resistance training increases acceleration capabilities during the higher velocity component of the movement.

The results of these studies suggest there is very little difference in the effects of heavy- and light-load training in terms of power and performance. It would seem that there is little to no difference between development of force and velocity during resistance training for improvement in power for sports specific skills. While both force and velocity are an important variable in improving power, the importance lies in developing both to optimize the full effects of a given power stimulus. There is no doubt that resistance training is imperative for improving both functional and sports performance. However, the importance in terms of force verses velocity specific training would appear to be questionable (Cronin & Sleivert, 2005). This may be due to discrepancies in power during resistance training and power during athletic/functional tasks. Thus, when the intent of a training program is to be as powerful as possible, any differences in training adaptation may not stem from differences in load, volume or fatigue but from the mechanical stimuli and the individual's intent to move as powerfully as possible within each movement.

III. RESEARCH QUESTION

Power output would expectedly decrease during a multiple set, high repetition back squat, due to fatigue. Since athletes need to produce power when in a fatigued state, training to maintain high power output is essential for many athletes. However, it is unknown if shorter rest periods than what is currently recommended for training for power improvement would have a more profound effect on an individual's ability to maintain power output. The purpose of this study was to examine the effects of a fatiguing, high-volume, power-oriented resistance training bout and determine if participants could maintain both PPavg and PPmax output with two different rest periods between sets (1 min vs. 2 min). We hypothesized that % decline, the percentage of decline from the rep with the highest PPmax to the rep with the lowest power output, would be significantly greater with 1-minute vs. 2-minutes rest period. We hypothesized that 1-minute rest periods would significantly decrease PPavg and PPmax from set 1 through set 8 due to restricted rest. We hypothesized that with 2 minutes of rest, PPavg and PPmax would not significantly differ between sets, similar to previous findings. Lastly, we hypothesized that PPavg and PPmax with 2 minutes of rest would be significantly greater than 1 minute of rest.

IV. METHODOLOGY

Experimental Design

Resistance trained individuals performed low intensity squats to determine the inter-set and intra-set effects of a high volume squat bout. Each participant visited the laboratory on 3 occasions with at least 48 hours in between as recommended by NSCA standards (Baechle & Earle, 2008) (Figure 1). During the first visit, participants were screened for inclusion criteria and perform a 1-RM test for the back squat. All participants performed the squat protocol until the hip crease was parallel with the knee crease. After the 1-RM testing, participants were familiarized with the squat protocol. The protocol consisted of 8 sets of maximum effort repetitions at an intensity of 45% of the participant's previously measured 1-RM. On the 2nd and 3rd visit, the subjects completed the back squat protocol. Sessions were broken up into 2 different conditions; a 1-minute rest between sets (Con1) and a 2-minutes rest between sets (Con2). Participants either completed Con1 or Con2 on the 2nd visit then repeated the testing with the other condition during the 3rd visit. Power output measurements for the back squat testing were measured using a Tendo Weightlifting Analyzer®. Between-set comparisons of PPavg, PPmax and % decline were analyzed and determined the effect of fatigue on power throughout the duration of the protocol.

Participants

Twenty-five resistance-trained men (n = 13) and women (n = 12) between the ages of 18 and 47 volunteered to participate in the study. Anthropometric data are reported in Table 1. Recruitment took place through social media advertisement, recruitment emails, flyers and word of mouth. Inclusion criteria for the study were: 1) participants were between the ages of 18 and 50 years old, 2) they must have minimum 1 year of resistance training, free weight and barbell experience, 3) they must not be taking any ergogenic supplements, 4) they must be able to perform resistance exercise and testing without any physical limitations, 5) have not sustained an acute lower body injury in the past 6 months, 6) no caffeine or stimulant consumption on testing day and 7) the participants had to capable of performing a parallel back squat. Participants then completed a weight training and health history questionnaire to verify their eligibility. According to the National Strength and Conditioning Association (NSCA), the point at which the squat becomes a parallel squat is when the thighs are parallel to the floor while maintaining an upright torso (Baechle & Earle, 2008).

Before any testing commenced, the participants had to complete an informed consent document as approved by Texas State's Institutional Review Board for human participants. After inclusion criteria were met and questionnaires were completed, an explanation of baseline measurements and testing procedures was given.

Baseline Measurements

Participants reported to the Human Performance Laboratory for a total of 3 separate visits. During their initial laboratory visit age, height, weight and back squat 1-RM test were measured and recorded. After the initial visit, participants reported on 2 separate occasions for the squat tests. Each test was separated by at least 48 hours in between as recommended by NSCA standards (Baechle & Earle, 2008).

1-RM Strength Testing

Participants performed the 1-RM test for the back squat on a Power Lift® multipurpose, adjustable half-rack system. The lift was performed with a 20-kg Olympic barbell. Before testing began, participants completed a light 5-minute bike and short dynamic warm-up. No static stretching was performed as there may be potential interference with maximal force/power production (Baechle & Earle, 2008). NSCA guidelines for a parallel squat were used to determine a successful lift (Baechle & Earle, 2008).

Each participant performed 5 air squats to determine the necessary squat depth. An elastic band was positioned across the rack designating the bar height associated with the parallel depth. This provided subjects with a kinesthetic feedback when correct depth was reached (Hester et al., 2014). Feet were instructed to be shoulder width apart with toes pointed out about 5 to 10°. The subjects were instructed to sit back with their hips then descend into a squat position while maintaining an upright torso. The barbell was centered across the participants back and while rested on his or her traps and shoulders. Hands were held slightly wider than shoulder width with thumbs wrapped around the bar. Lastly, they were instructed to perform the eccentric phase of each repetition as controlled as possible until the correct depth was reached and then to rapidly extend to complete extension as quickly as possible while maintaining flat feet. This technique was used to ensure that with each repetition participants were giving maximum effort (Baechle & Earle, 2008; Fry et al., 2014; Hester et al., 2014).

The 1-RM back squat testing began with a warm-up which consisted of 10 repetitions at approximately 50% of the subjects estimated 1-RM load. Participants continued by completing 1 to 2 more repetitions at approximately 70% and 80% of perceived 1-RM. A rest period of 3 minutes was given between sets to give participants time to recover. Following the warm-up, 1-RM attempts were performed. After each successful attempt, 5 to 10 pounds was added at the individual's discretion until a maximum or failed attempt was reached. The 1-RM recorded was the last successful repetition. After determination of the 1-RM, participants were then familiarized with the squat protocol. Familiarization included explanation of procedures and possible demonstration if needed.

Back Squat Protocol Procedures

Before the protocol began, participants went through a 5-minute, light bike warm up with a specific back squat warmup. The back squat specific warm up consisted of 3-sets of 5 repetitions, 1^{st} set at 30% 1-RM, the 2^{nd} and 3^{rd} set at 50% of 1-RM (Fry et al., 2014). After 5 minutes of rest, participants began the back squat protocol. The protocol consisted of 8-sets of maximum number of repetitions at an intensity of 45% of participant's previously measured 1-RM.

Prior to the test, the administrator instructed the participant to complete as many repetitions as possible until either the test administrator stopped the set due to form breakdown, the participant stopped the set due to volitional exhaustion, or Target-Peak Power (TPP) was reached for 2 consecutive reps during the set. TPP was established once the set PPmax was reached during the initial repetitions. PPmax values were displayed on the Tendo unit immediately after each repetition. The set PPmax value was multiplied by 80% to generate the TPP as the set was taking place (Target Peak Power = set PPmax×.80). This procedure was repeated and used for the following sets of the test. Lastly, the administrator gave verbal encouragement during the sets and allowed for water breaks in between sets.

The TPP was based on previous research showing that within a high volume squat bout, participants were able to maintain at least 80% percent of PPmax during a set (Fry et al., 2014; Hester et al., 2014; Luebbers & Fry, 2015). This TPP was also determined due to an accepted principle in training for power improvement that individuals should avoid training under fatigue with large reductions of power output and far from PPmax. Strength coaches want their athletes to maintain higher velocities at a given load for proper adaptation to training. It is accepted that fatigue should be avoided to enhance neuromuscular activation for power improvement.

The number of sets was based on previous research that investigated high volume training. Marshall et al., (2011) and Robbins et al., (2012), revealed that an 8-set protocol produced better strength gains for a 6-week period rather than using a 4-set or 1-set program (Marshall et al., 2011). Furthermore, Finn et al. (2014) examined the effects of an 8-set protocol on power outputs and neuromuscular activity. Lastly, Hester et al. (2014) used 5-sets to determine the effects of PPmax output during a fatiguing exercise. The intensity of 45% was based on previous research that suggests an intensity of 30–70% of 1-RM during the squat exercise is used to maximize the power output (Baechle & Earle, 2008; Cormie, McCaulley, Triplett, et al., 2007; Haff & Nimphius, 2012; Hester et al., 2014; Izquierdo et al., 2002; Kawamori et al., 2005; Loturco et al., 2013; Martorelli et al., 2015; G. a Thomas et al., 2007).

The protocol was comprised of two different rest periods; 1-minute (Con1) and 2-minute (Con2) rest between sets. Results from previous research showed that rest periods of 2 minutes between sets of high volume squats were sufficient for recovery (Hester et al., 2014). This allowed participants to produce similar PPmax values for 5 sets. However, research is limited on reducing rest periods during high volume squats.

Power Measurement

The power measurements for the back squat protocol were obtained using a Tendo Weightlifting Analyzer® (Tendo Power Analyzer V 314, Tendo Sports Machines; Tendin, Slovak Republic). The Tendo Weightlifting Analyzer® (Tendo) recorded power values during each lift using a cord that was strapped onto the bar. Power, in this case, was a measure of low-load, speed-strength, and squat exercise to an external load. The unit was then placed on the ground below the barbell so that the cord was directly above the unit during the back squat. Two variables were recorded from the Tendo unit after each set by an administrator: number of reps in set and the repetition power output. Research has demonstrated a high test-retest reliability (intra-class correlation coefficient ranging from 0.85 to 0.98) using these procedures for the assessment of muscular power during a full back squat exercise (Garnacho-Castaño, López-Lastra, & Maté-Muñoz, 2014). These repetition power output values were used to determine % decline, PPavg, and PPmax. The % decline was determined from the PPmax and the lowest repetition power output (PPmin) from each set for each participant (PPmax – PPmin)/PPmax × 100 (Hester et al., 2014). PPavg was the averaged sum of the repetition power output for each set. PPmax was the maximum repetition power output produced within a set.

Statistical Analysis

SPSS 22 was used to analyze the data (IBM SPSS, Inc, Chicago Illinois). A 2 (condition) x 8 (sets) repeated-measures analysis of variance (ANOVA) was used to examine between condition measurement differences on PPavg, PPmax, and % decline. A Wilks' lambda multivariate test was used to determine within condition differences. Pairwise Comparisons were used to examine between set differences. The results were considered significant if an alpha level of the relationships reached 0.05.

V. RESULTS

% Decline Results

The two way ANOVA showed a lack of interaction between conditions x sets, $F(1,48) = 0.037$, $p = 0.848$ (Table 2). The average % decline overall in Con1 was 30.56 ± 9.87 (Figure 2). The average % decline overall in Con2 was 30.24 ± 9.15 (Figure 3).

PPavg Results

The two way ANOVA showed a lack of interaction between conditions x sets, $F(1,48) = 0.224$, $p = 0.638$. However, there were a significant within condition effects: Con1 $F(7, 42) = 3.651$, $p < 0.05$; Con2 $F(7,42) = 3.855$, $p < 0.05$ (Table 3). Pairwise comparisons showed that within Con1, set 1 and set 2 PPavg were significantly higher than sets 3 through 8 ($p < 0.05$) (Figure 4). Set 3 and 4 showed a lack of significant difference ($p = 0.202$), but were significantly greater from sets 5 through 8. Set 5 through set 8 were not significantly different ($p > 0.05$). In Con2, pairwise comparisons showed that sets 1, 2 and 4 were not significantly different ($p > 0.05$), but were significantly greater than sets 3, 5, 6, 7, and 8 ($p < 0.05$) (Figure 5). Between sets 3 and 4, there were a slight, yet significant increase ($p = 0.064$). Upon further investigation, Con1 results showed that using the PPavg of the highest set (set 1), greater decrease in the percentage of PPavg started from set 2 (1^{st} – 100%, 2^{nd} – 93.88%, 3^{rd} – 91.73%, 4^{th} – 90.05%, 5^{th} – 86.29%, 6^{th} – 84.81%, 7^{th} – 86.51%, 8^{th} – 85.85%). Moreover, Con2 results the PPavg of sets 2 through set 8 were maintained above 90% (1^{st} – 100%, 2^{nd} – 98.08%, 3^{rd} – 94.13%, 4^{th} – 94.96%, 5^{th} – 93.44%, 6^{th} – 92.14%, 7^{th} – 90.59%, 8^{th} – 90.57%).

PPmax Results

The two way ANOVA showed a lack of interaction between conditions x sets, $F(1,48) = 0.276$, $p = 0.602$. Multivariate test show that there was significant differences within Con1, $F(7,18) = 0.424$, $p < 0.05$. However; no significant difference across 8 sets within Con2, $F(7, 18) = 0.543$, $p = 0.088$. (Table 4). Pairwise comparisons showed that within Con1, participants decreased significantly in PPmax from set 1 through set 4 ($p < 0.05$) (Figure 6). Set 1 was significantly greater from the rest of the condition, as was set 2 ($p < 0.05$). Set 3 and set 4 lacked significant differences; however, they were significantly greater then set 5 through 8. From set 5 to set 8, there was a lack of difference in PPmax produced ($p > 0.05$). Further investigation into Con1 results show that participants were able to maintain above 90% of PPmax produced from set 1 through the 4th set (1^{st} – 100%, 2^{nd} – 94.11%, 3^{rd} – 91.84%, 4^{th} – 90.51%) with a decrease below 90% starting with set 5 through set 8 (5^{th} – 86.81%, 6^{th} – 85.31%, 7^{th} – 86.06%, 8^{th} – 87.12%). Additionally, Con2 results show that participants were able to maintain above 90% of PPmax produced from set 1 through the 5th set (1st – 100%, 2nd – 96.19%, 3rd – 92.18%, 4th – 92.94%, 5th – 92.21%) with a decrease below 90% in set 6 through set 8 (6th – 88.74%, 7th – 87.09%, 8th – 88.85%).

VI. DISCUSSION

In this study, % decline, PPavg, and PPmax were measured over the duration of a high volume, low load squat bout to determine if participants could maintain power output with varying rest periods between sets (1 min vs. 2 min). To the author's knowledge, this is the first study to examine power output over the duration of a maximal-effort high-volume, low intensity back squat protocol with minimal rest. Most importantly, this was the first study to use a percentage of PPmax during a set as a stopping point for exercise. This novel idea presented in this study was used simulate such activities where power is performed for longer durations under fatigue.

Results showed that there was no significant difference ($p = 0.638$) in PPavg between conditions; however, there were significant within set differences. Within Con1, findings showed a significant decrease in PPavg during set 5. Starting from set 5 through set 8, PPavg began to have no significant change and a PPavg production plateau was reached. The significant decrease in PPavg between each set of the conditions was most likely due to fatigue. In Con1, the percentage of decrease between the sets was greater than Con2. During Con2, participants were able to maintain at least 90% of PPavg produced for a high volume protocol of 8 sets. By decreasing rest to 1 minute, participants were able to only maintain above 90% of PPavg for 4 sets, half of what was found with 2 minutes of rest. While this data was not analyzed, results show a clear dissimilarity between the two conditions. While there is no difference between 1 and 2 minutes of rest between sets on set PPavg, PPavg would significantly decrease within a set of low-load, high volume, speed strength exercise regardless of rest periods.

Participants had significant decrease in PPmax within Con1 from set 1 through 4 and did not recover quickly enough to produce analogous values until set 5 through set 8. These results were similar to those found to Smilios et al. (2010) where PPmax values continued to decrease with sustained volume for 4 sets. However, Smilios et al. (2010) had participants squat to a designated number of repetitions and the researchers would change the load depending on if the participants needed help during the set. The authors attributed this decrease in power to the individuals' inability to maintain the velocity of movement even though results stated that average velocity of each set did not change from set to set (Smilios et al., 2010). By helping participants during the squat movement, velocity could have been compromised. Additionally, if the participant were to fail during a set, load was changed, thus changing overall power output. In the current study, each participant completed each squat on his or her own. If he or she failed to do so, the set was terminated by the administrator. Moreover, load was constant regardless if a participant failed during a set. While loss of velocity due to high volume exercise could be a possible explanation for the significant decrease in PPmax from set 1 through set 4 during Con1, further comparisons cannot be made to previous research due to differences in methods. Another explanation for the significant decrease in PPmax within Con1 would be the increase in neuromuscular fatigue due to minimum rest. By having participants complete a high volume squat bout with 1 minute of rest, the effects of fatigue were likely more pronounced on PPmax outputs. A 10% decrease in PPmax output between sets during a high volume bout with 1 minute of rest would be considered acceptable for training athletes near PPmax levels, albeit a statistically significant decrease. Being able to maintain 90% of maximum PPmax repeatedly could be a valuable tool for exercise prescription on sport specific activities where movements are produced repeatedly under high levels of fatigue with little rest. With minimal rest (1 minute), participants were able to maintain at least 90% of PPmax for a high volume exercise bout for 4 sets. For increases in PPmax capacity, 4 sets of a low load, high volume squat bout until 80% of TTP with 1 minute of rest would be recommended to maintain at least 90% of PPmax.

Within Con2, findings showed that there was a significant decrease in PPmax between sets 1, 2 and set 3 then a lack of significant difference from set 3 through set 8. The findings in PPmax within Con2 contrast those found by Hester et al. (2014). In previous research, individuals were able to sufficiently recover between sets with 2 minutes of rest to produce similar PPmax values. However, in the previous research, participants performed the squat bout using a lighter load (40% of 1-RM) and limited the amount of reps within a set (16 reps). Also, the researchers only investigated a protocol using 5 sets. While this is still considered a high-volume protocol, the current study used a higher percentage of 1-RM (45%) and a higher volume protocol (8 sets of unlimited reps until 80% of TTP). Further analysis also shows that participants performed on averaged a difference of 22 reps more during Con2 of the current study than in research by Hester et al. (2014) (102.28 ± 2.66 vs 80 reps). Thus, in the previous study, fatigue may have been truncated and the effects of volume may not have taken full effect. Despite the discrepancies between studies, PPmax production began to be maintained by set 3 through set 8. As stated beforehand, being able to maintain 90% of PPmax repeatedly would be a valuable tool for exercise prescription on sport specific activities where movements are produced repeatedly under high levels of fatigue with little rest. In other words, after the first 2 sets, participants were able to recover enough between sets to produce similar PPmax values, establishing a PPmax maintenance phase. Furthermore, with 2 minutes of rest between sets, participants were able to maintain at least 90% of PPmax for a high volume exercise bout for 5 sets. For increases in the ability to maintain a relatively high level of PPmax, 5 sets of a low load, high volume squat bout until 80% of TTP with 2 minute of rest would be recommended to maintain at least 90% of PPmax.

With findings showing a similar pattern in PPavg and PPmax between Con1 and Con2 respectively, we can reason that both PPavg and PPmax are codependent of each other. The results suggest that, regardless of rest period intervals, within a set of fatiguing, high-volume, power-oriented resistance training bout, individuals will have a significant decrease in power output. Once rest begins, power production can recover to reproduce increases in PPavg and PPmax. With both 1 and 2 minutes of rest, power production continued to decrease until a maintenance phase was reached within the protocol. However, the percentage of decline from set 1 at which individuals decreased was different between conditions. Power is typically greatly affected by high levels of fatigue. By minimizing the amount of rest between sets could hinder an individual's ability to produce high power outputs with an increase of volume if they are not adapt to do so. Force is related to the change in velocity during movements. If the force during an exercise does not change, change in velocity remains constant. When fatigue occurs, force will decrease resulting in a change in velocity. Muscle activation may be the same or increase with fatigue and a decrease in force (Finn et al., 2014).

Possible explanations for the significant decreases in power could be the increase in neuromuscular fatigue as volume increases. Previous research has shown that neuromuscular activity may increase from set to set and during each set, up to a point, to overcome fatigue and sustain the required power output; however, voluntary neuromuscular activation does not linearly increase with increases in exercise volume (Ranieri & Di Lazzaro, 2012). Also, performing a moderate to high volume resistance training bout where load is constant will not necessitate a near-maximal motor unit recruitment (Finn et al., 2014). While neuromuscular effects were not measured in the current study, a decline in the motor unit firing rate during maximal, voluntary contractions could be a possibility for the decline in power production within the study.

Increases in muscular blood lactate concentrations, reductions in the stretch shortening cycle (SSC) efficiency and a reduction in cross-bridge force are involved in the mechanisms of fatigue and are possible explanations for power output decrease during the test. Previous findings have shown that after 6 sets of 6 repetitions of the squat at 60% of 1-RM, blood lactate concentration increased significantly from pre to post-exercise condition regardless of rest periods used (Martorelli et al., 2015). Contrary to belief, this increase in the blood lactate concentration was not associated with impaired muscle power output, and the performance was maintained over the whole exercise session (Martorelli et al., 2015). The results suggested that despite increases in blood lactate, muscle power performance remained stable (Martorelli et al., 2015). However, in the current study, lactate concentrations were not measured and participants mentioned periods of muscular “tightness” and “pump” during testing.

SSC inefficiency could be a possible explanation of power output decline. The continued use of the SSC leads to a reduction in mechanical efficiency and increased use of stored energy (D. G. Baker & Newton, 2007; Hester et al., 2014; Ranieri & Di Lazzaro, 2012). Over time, the breakdown in the SSC can lead to changes in mechanical movement patterns: an alternating flexion/extension pattern to a less effective co-contraction pattern (Ranieri & Di Lazzaro, 2012). Also, this change in mechanical patterning becomes less effective as fatigue develops. Lastly, research has shown that the initial decrease in force is due to a reduction of force generated by cross-bridges connections (Nocella et al., 2011). Force decreases by 10–15% during initial phases of repetitive stimulation of a skeletal muscle (Nocella et al., 2011). In summary, decreases in power output throughout the test may be attributed to multiple factors: 1) neuromuscular fatigue, 2) an increase in muscular blood lactate concentrations, 3) SSC inefficiency and 4) reductions in cross-bridge force.

Despite demonstrating the sings of fatigue, participants were still able to maintain above 90% of maximum power produced from set 1 in both PPavg and PPmax within Con1 and Con2 for service amount of sets. However, Con1 had greater decreases in PPavg and PPmax over the protocol. The percentage at which participants declined from set 1 until the level of power plateaued was greater than Con2. This could be due to the decrease in rest between sets, causing more fatigue. Furthermore, participants were able to produce an average of 11 more reps within Con2 than Con1 (102.28 ± 2.66 vs. 91.56 ± 2.19 respectively). Regardless of the differences, as each condition progressed, participants were able to reach a power production maintenance phase. In theory, there could be a point at which, regardless of fatigue from earlier sets, individuals could maintain power output during high volume exercise. Either the inefficiencies previously stated reach a point to which they can no longer affect power out or an individuals' adaptations to training is so great that they could handle such volume has yet to be determined. Regardless of such, current recommendations suggest that in a resistance training bout, the amount of volume that occurs should be limited to maintain a higher PPmax. The current accepted method of training for power is primarily limited to producing near peak power for the entire set by completing low repetitions while maintaining high velocities for a given load with increased rest. Nevertheless, during sports or functional performances, exercise volume cannot be controlled or limited. Instead, sports and functional performances are limited by time or score. By prescribing training programs based off an individual's PPmax, programming can be individualized for increases in power production during sport specific activities. Being able to maintain 90% of maximum PPmax could be a valuable tool for exercise prescription on sport specific activities where movements are produced repeatedly under high levels of fatigue with little rest. During sports with little intermitted rest such as American football, soccer or volleyball, a player has to perform dynamic movements (sprinting, throwing, jumping, diving etc. etc.) repeatedly as powerful as possible for long durations of time. In theory, by maintaining a minimum of 90% of PPmax, the level at which an athlete produces power could increase with training. Little is known about PPavg and PPmax values during sporting events so correlations cannot be made. Further investigation is required to determine if training with high volumes at power outputs produced in this study is associated with improved performance. Additionally, it has been stated before that it is recommended that a PPmax oriented training set should cease (irrespective of the repetition number) when power output achieved during a repetition drops below either 90 or 95% of maximum power attained during that set (D. G. Baker & Newton, 2007). This implication can be important for athletic performance exercise prescription for those whose goal is to train for power improvement under fatigue (i.e. high-dynamic, long duration sports with little to no rest). While training under a fatiguing state is needed to simulate power production during sporting events that involve fatigue, athletes need to be trained to maintain high levels of power output. The results in this study demonstrate the level of power produced with 2 different protocols that involve significant fatigue. Our results show that the 1-minute rest may not provide enough recovery to maintain a relatively high level of power needed in some sports. If the goal is to maximize PPmax output in an acute bout of resistance training, increasing rest to decrease fatigue between sets is ideal. For increases in PPavg maintenance, a protocol using 8 sets of 45% of 1-RM until 80% of TTP is reached within a set with 2 minutes of rest so that 90% of PPavg can be maintained is recommended. For increases in PPmax capacity, a protocol using 5 sets of 45% of 1-RM until 80% of TTP is reached within a set with 2 minutes of rest so that 90% PPmax can be maintained is recommended. An evaluation of relative power produced in different sports under fatiguing conditions is needed in further investigations.

In the present study, the overall % decline average in Con1 was 30.56 ± 9.87% and the overall % decline average in Con2 was 30.24 ± 9.15%. Hester et al. (2014) previously found that participants had an overall % decline average of 31.3% across the 5 sets. Additionally, Fry et al. (2014) found that during the Kansas Squat Test, a power output capacity test containing of 1 set of 15 reps with 9 seconds between squats, % decline was 20.4 ± 13.9%. While this was a 1 set, maximum effort test, multiple sets were not analyzed, making comparisons to the current study impossible. While there were no significant differences between Con1 and Con2, the findings are similar to those found by both Hester (2012) and Fry (2014). Hester and Fry provide evidence that power output is negatively affected during a high-repetition set. However, a similar % decline occurred in our study that included a higher volume compared to previous studies.

VII. LIMITATIONS

A limitation in our study was the various levels of training statuses within our population. The 25 participants were all included into the study due to at least 1 year of resistance training using a barbell. The training status of the subjects varied and included the following: recreationally trained (minimum 3 days/week), hypertrophy training (3-4 sets of 8-15 reps, high volume), heavy strength training (reps >80% of 1-RM, high load/force), cross-training (multiple training modes), and former high school and current college athletes. These variations in training status may have impacted power outputs during the test. It is likely that the force/velocity relationship may vary between the different sport-specific activities and/or biomechanical characteristics of the open and closed upper/lower kinetic chains as supported by Izquierdo et al. (2002). For example, those participating in heavy strength training would be less adapt to producing faster velocities on the force-velocity curve during low loaded conditions. In theory, those individuals during a high volume, fatiguing test would likely not be able to maintaina high power output due to the sheer amount of reps involved as opposed to an individual who is trained in high volume training (i.e. hypertrophy). The effects of the individual's training may have played an impact in the test results. Limiting the study to just one training methodology and/or determining differences in power output capacity between sport-specific activities would be recommended for further research.

Another limitation in our study was the novel idea of having a power threshold to stop the set. While determining research methods, we decided to investigate the effects of a high fatiguing test on power. Using this methodology, we could simulate fatigue that may occur during game-like situations or in a maximum exercise bout. Within sports and athletic activities, power does not remain constant. Sport-specific and non-sport-specific motions consist of closed and open chain, dynamic and static, and fast and slow movements. To simulate the ever changing environment of power output in activity, we felt it necessary to allow for near complete failure of power output during the set. In previous research, Hester et al. (2014) found that individuals were able to maintain an overall percent decline in PPmax of 31.3% across the 5 sets. Furthermore, PPavg percent decline for each set was 19.58%. Fry et al. (2014) found that during the Kansas Squat Test, a power output capacity test, % decline was 20.4 ± 13.9%.

In conclusion, we determined that a 20% decrease in PPmax (thus 80% of PP of the highest power repetition within a set) would be the cutoff threshold. During each set, the individual completed as many repetitions as possible until either the test administrator stopped the set due to form breakdown, the individual stopped the set due to volitional exhaustion, or TPP was reached. Furthermore, to ensure that participants had reached near power fatigue, we determined that the cutoff would require 2 repetitions back to back below the 80% of TPP threshold. This method eliminated the instance of a mishap on a rep and allowed a chance for the individual to regain power and reach above the set TPP threshold. In the present study, the average % decline overall in Con1 was 30.56 ± 9.87% and the average % decline overall in Con2 was 30.24 ± 9.15%. These values were similar to what was previously found (Fry et al., 2014; Hester et al., 2014). In some instances, participants would produce a repetition that would be below the TPP threshold; however, they would regain energy to produce above the threshold. In some cases, that particular rep would be the lowest power repetition. Also, we feel that some participants may have “gamed” the test anticipating the degree of fatigue in subsequent sets. This preservation of energy for further sets would decrease the chance of an individual producing maximum power output potential. This energy preservation was possible and may have had an effect on the results. A slight mishap on form, a quick loss of energy and/or breath, “gaming” the protocol or mental toughness could have been a limiting factor for decreased power opposed to the factor of fatigue. However, maximum effort was encouraged by the researchers prior to and during the set to overcome these limitations.

VIII. CONCLUSION

The findings of this study show that there were no significant PPavg and PPmax differences between conditions of 1 min rest between sets and 2 min rest during a high-volume power-oriented back squat protocol. On the other hand, significant within PPavg and PPmax condition differences between rest periods were found. While there is no difference between rest between sets, within each set, PPavg and PPmax would significantly decrease until a power output maintenance phase was reached. The % decline across 8 sets in both Con1 and Con2 was similar to previous research. Further investigation of our study showed that PPavg in Con1 fell below 90% occurring at set 5-8 and for Con2 all 8 sets were above 90. For PPmax, Con1 below 90% occurred at set 5-8 and for Con2 below 90% was at 6-8. Current recommendations for training suggest that the amount of volume that occurs should be limited to maintain a higher PPmax. However, sports and functional performances are not limited by volume, but by time or score. During sports with little intermitted rest, an individual has to perform dynamic, complex movements repeatedly as powerful as possible for long durations of time. Training under a fatigued state is needed to simulate power production during sporting events that involve high levels of fatigue. Being able to maintain 90% of PPmax could be used as exercise prescription on sport specific activities where movements are produced repeatedly. This could be a valuable tool for exercise prescription on sport specific activities. By staying above a minimum of 90% of PPmax during training, the level at which an athlete can maintain peak power could increase in performance. A protocol of this nature may be favorable for athletes when training to improve power capacity against external loads.

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TABLES

Table 1. Participants characteristics.

	Age	Height (cm)	Weight (kg)	1-RM (kg)	45% of 1-RM (kg)
M	25.52	169.82	75.85	120.59	54
±*SD*	7.23	8.92	16.9	41.64	18.74

Table 2. Group averaged % Decline across 8 sets for both Con1 and Con2. (*) signifies significant difference within the condition ($p < 0.05$).

Averaged % Decline								
Condition	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7	Set 8
Con1	27.77	28.02	28.93	29.77	31.87	33.10*	29.40	35.59*
Con2	30.43	29.19	28.64	31.44	29.88	27.06	32.77	32.45

Table 3. Group PPavg (W) across 8 sets for both Con1 and Con2. (*) signifies significant difference within the condition ($p < 0.05$).

Avg Power (W)								
Condition	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7	Set 8
Con1	812.85*	763.14*	745.59*	732.03*	701.48	689.39	703.25	697.89
Con2	821.79*	806.09*	773.52	780.39*	767.84	757.23	744.51	744.33

Table 4. Group PPmax (W) across 8 sets for both Con1 and Con2. (*) signifies significant difference within the condition ($p < 0.05$).

PPmax								
Condition	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7	Set 8
Con1	930.52*	875.72*	854.56*	842.2*	807.76	793.84	800.84	810.64
Con2	970.72	933.8	894.88	902.16	894.24	861.44	845.4	862.52

FIGURES

Figure 1. Study Schematic.

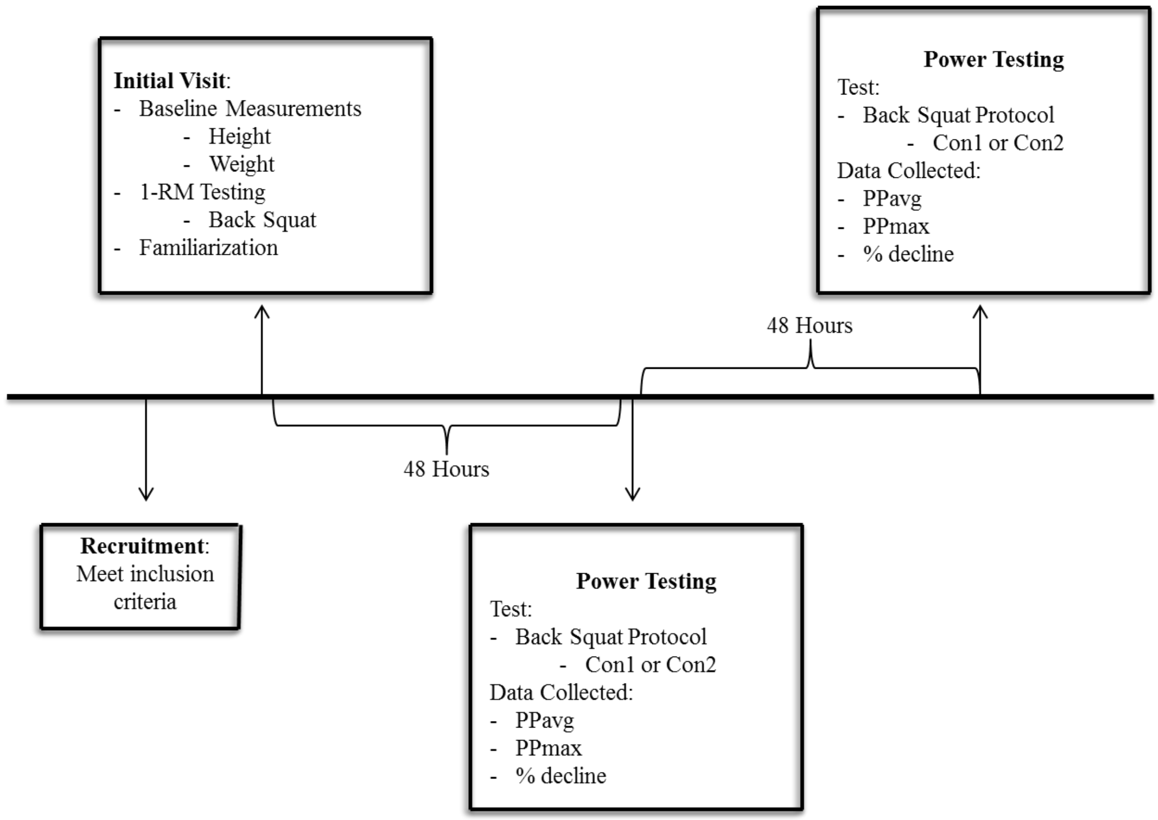


Figure 2. Group averaged % Decline across 8 sets for Con1. (*) signifies significant difference within the condition ($p < 0.05$).

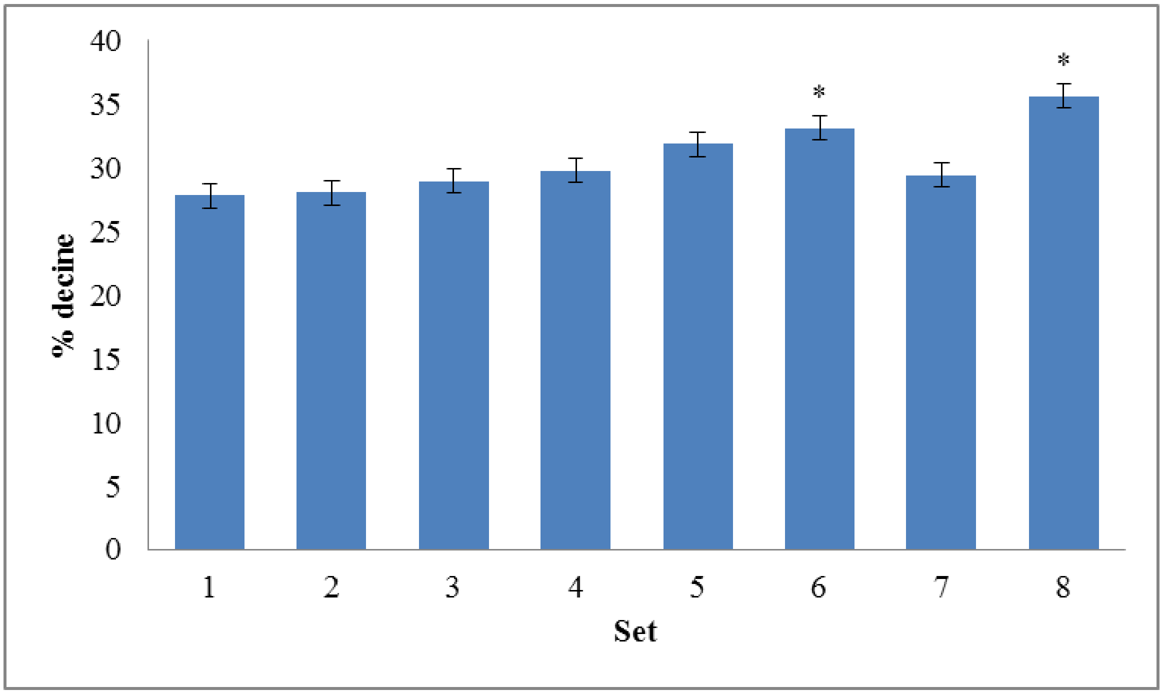


Figure 3. Group averaged % Decline across 8 sets for Con 2.

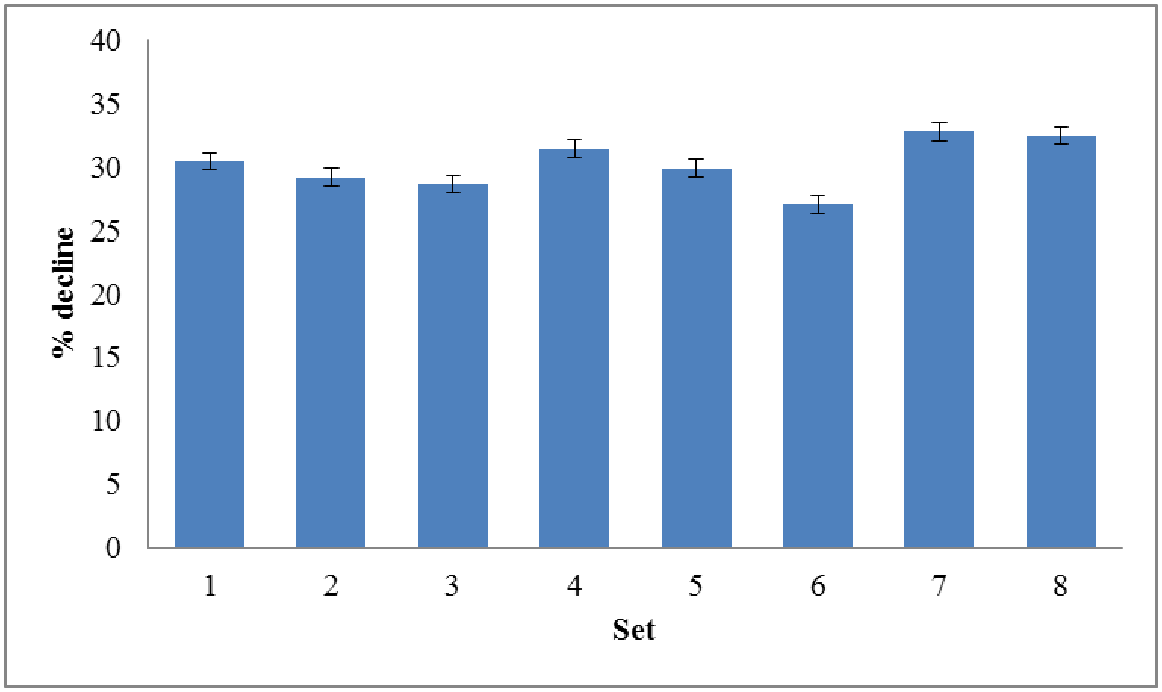


Figure 4. Condition 1 results. Group PPavg (W) across 8 sets. Pairwise comparisons were used to examine within condition differences. Sets 1 and 2 PP was significantly higher than sets 3 through 8. Set 3 and 4 showed a lack of significant difference, but was significantly greater from sets 5 through 8. Set 5 through set 8 was not significantly different.

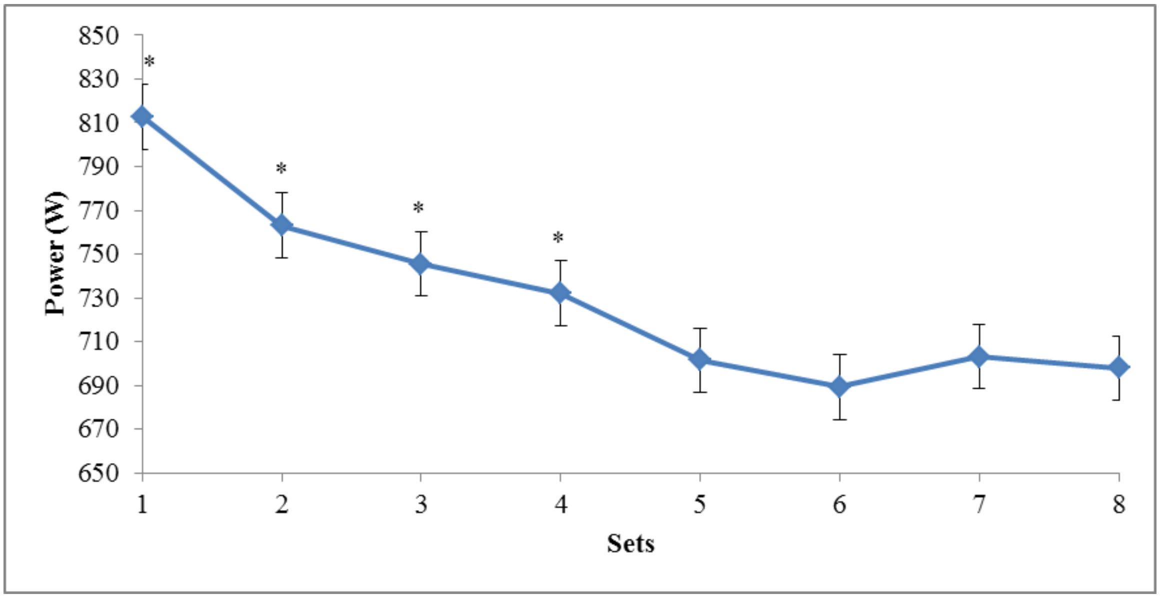


Figure 5. Condition 2 results. Group PPavg (W) across 8 sets. Pairwise comparisons were used to examine within condition differences. (*) indicates lack of significant differences between values for sets 1, 2 and 4; however, significantly greater than sets 3, 5, 6, 7, and 8.

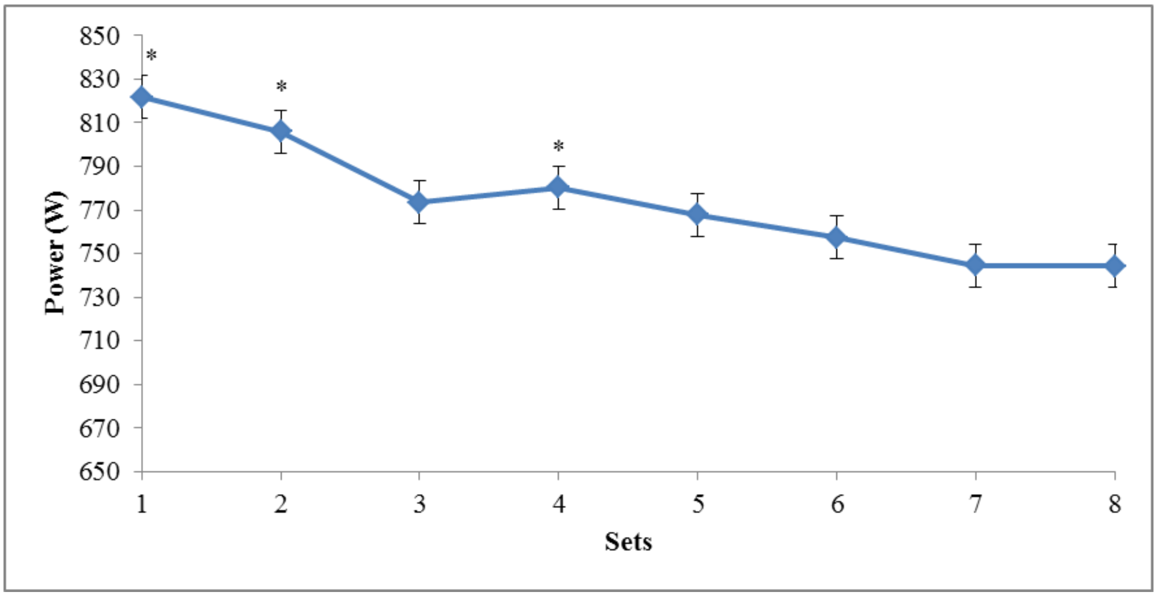


Figure 6. Condition 1 results. Group PPmax (W) across 8 sets. Pairwise comparisons were used to examine within condition differences. Participants decreased significantly from set 1 through set 4. Set 1 was significantly greater from the rest of the condition, as was set 2. Set 3 and set 4 lacked significant differences; however, they were significantly greater then set 5 through 8. From set 5 to set 8, there was a lack of difference in PPmax produced.

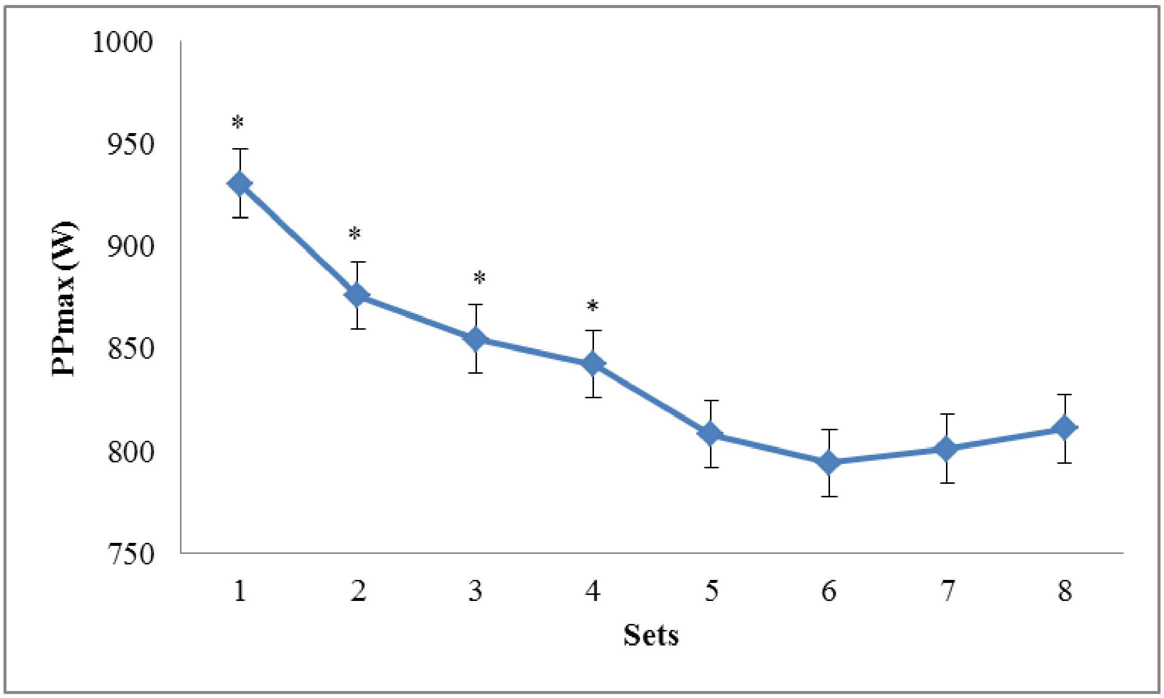
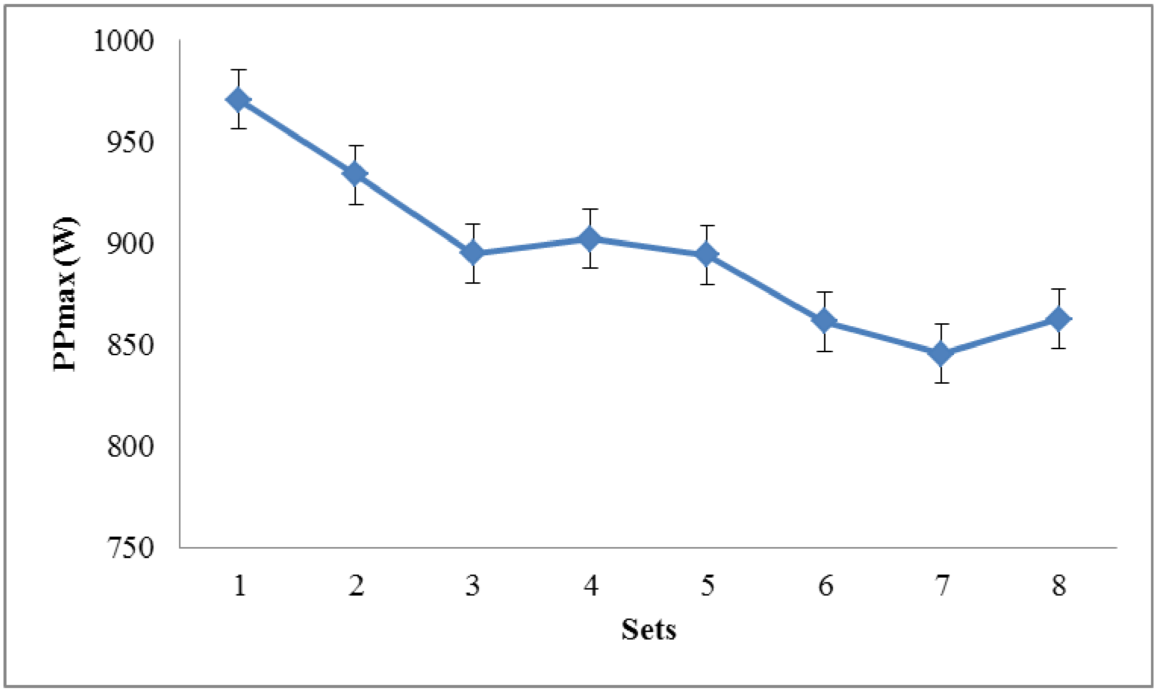


Figure 7. Condition 2 results. Group PPmax (W) across 8 sets.



X. APPENDIX

Appendix A: Participation Consent Form

CONSENT FORM

Study Title: Effects of a High-volume, Low-intensity, Multi-set Squat Protocol on Power Outputs

Principal Investigator (**PI**): Josh Harris – jhh62@txstate.edu 512-963-0096
Co-Investigator: Kevin McCurdy – km55@txstate.edu

You are being asked to participate in a project conducted through Texas State University. The University requires that you give your signed agreement to participate in this project. The principal investigator, Josh Harris, will explain to you in detail the purpose of the project, the procedures to be used, and the potential benefits and possible risks of participation. You may ask the investigator any questions you have to help you understand this research project. A basic explanation of the research is given below. Please read this explanation and discuss with the researcher any questions you may have. If you then decide to participate in the project, please sign on the last page of this form in the presence of the investigator who explained the project to you. You will receive a copy of this form to keep for your personal records.

1. Purpose of the Research – The purpose of this study is to examine the effects of a high volume, low intense squat bout and determine if participants can maintain power output with minimal rest between sets.
   Explanation of the procedures –During their initial laboratory visit: age, height, weight and back squat 1 repetition max (1-RM) test will be measured and recorded. After the initial visit, participants will report on 2 separate occasions for the squat tests. The squat test consists of 8-sets of maximum effort repetitions at an intensity of 45% of participants previously measured 1-RM. One test will have a 1 minute rest period between sets while the other will have 2 minutes rest. A minimum of 48 hours of recovery is required between squat tests. All sessions will take about 30 minutes to 1 hour.

2. Discomfort and risks anticipated – Muscle and joint injury are possible while lifting weights so procedures have been taken to minimize the risks. Muscle soreness may occur after the tests; therefore, you will be provided time to recover and provided with a light warm-up and stretching exercises before participating in each test.

3. If you are injured as a result of participation in this study, personnel certified in first aid/cpr will be present to provide care. A certified athletic trainer will be available to provide care and advise you to seek further medical care if needed. For any serious injury that requires immediate medical care, emergency medical services will be called.

4. Benefits of participating in this research project- Subjects will better understand their strength ability through the various evaluations. Also, subjects and society will be gain knowledge of the best exercises that will improve muscle fitness of the legs that is related to sport performance and prevention of leg injuries.

5. Confidentiality assurance – The practice sessions will occur within a group setting while the tests will be conducted on an individual basis. Names and individual test scores will not be used in any report, presentation or published article.

6. Right to refuse and/or withdraw with no penalty, i.e. "Refusal to participate in this study will have no effect on any future services you may be entitled to from the University. Anyone who agrees to participate in this study is free to withdraw from the study at any time without penalty."

If you have any questions or concerns about your participation in this study, you may contact the Principal Investigator, PI Josh Harris – 512-963-0096.

This project 2017107 was approved by the Texas State IRB on [10/17/2016]. Pertinent questions or concerns about the research, research participants' rights, and/or researchrelated
injuries to participants should be directed to the IRB Chair, Dr. Jon Lasser (512-245-3413 - lasser@txstate.edu) and to Becky Northcut, Director, Research Integrity & Compliance (512-245-2314 - bnorthcut@txstate.edu).

DOCUMENTATION OF CONSENT
I have read this form and decided that I will participate in the project described above. Its general purposes, the particulars of involvement and possible risks have been explained to my satisfaction. I understand I can withdraw at any time.

___________________________________ ____________
Participant Signature Date

___________________________________ ____________
Principal Investigator Signature Date