Examining The Influence of Recovery Strategy and Rest Interval Length on Performance in Trained and Untrained Individuals

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EXAMINING THE INFLUENCE OF RECOVERY STRATEGY AND REST INTERVAL LENGTH ON PERFORMANCE IN TRAINED AND UNTRAINED INDIVIDUALS

By

Neil Pettit

A Thesis
Submitted to the Faculty of Graduate Studies through the Department of Kinesiology in Partial Fulfillment of the Requirements for the Degree of Master of Human Kinetics at the University of Windsor

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October 22, 2015
DECLARATION OF ORIGINALITY

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ABSTRACT

The purpose was to investigate the influence of recovery strategy (active vs. passive) and rest interval length (60 vs. 120 seconds) on performance after two high intensity interval training (HIIT) workouts with a battling rope (BR; ten 30 second intervals). Trained participants (9 male/11 female) completed a 4 week BR HIIT program while untrained participants (10 male/10 female) were new to BR protocol. There were no significant differences between pre- and post-test push up or sit up performance as a result of recovery strategy or rest interval length for both workouts. However, blood lactate varied by gender and training status immediately after the BR and/or five minutes post-BR. Differences in blood lactate levels suggest training status and recovery strategy can affect lactate profile during a BR HIIT workout but further research is needed to examine the role of lactate, fatigue, and performance.
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LIST OF ABBREVIATIONS/SYMBOLS

Active Recovery (AR)
Adenosine Tri-Phosphate (ATP)
American College of Sport Medicine (ACSM)
Central Nervous System (CNS)
Electro-Myograph (EMG)
Excessive Post-Exercise Oxygen Consumption (EPOC)
Heart Rate (HR)
High Intensity Interval Training (HIIT)
Maximum Oxygen Consumption (VO$_2$ max)
One Repetition Maximum (1RM)
Onset of Blood Lactate Accumulation (OBLA)
Passive Recovery (PR)
Percentage of Maximal Heart Rate (%MHR)
Physical Activity Readiness Questionnaire (PAR-Q)
Range of Motion (ROM)
Standard Deviation (SD)
CHAPTER 1
RESEARCH ARTICLE
INTRODUCTION

Designing an effective exercise programs can be a challenging feat. The strength and conditioning specialist must consider a wide range of variables including load, volume, type of exercise, and many other variables that cater to the goals of the exerciser, oftentimes overlooking the recovery strategy. Recovery is an important aspect of exercise program design since muscular fatigue is often a major determinant of performance (Allen & Westerblad, 2004). There are two broad causes of muscular fatigue, (1) a lack of availability of metabolic substrates, and (2) an accumulation of metabolic by-products that lead to eventual muscular contractile failure (Davis & Bailey, 1997). Concerning metabolic by-products, it is often lactate accumulation, and the subsequent rise in muscle acidity, that is often associated with fatigue (Sahlin, 1986), though this assumption may not be entirely accurate.

With regards to resistance training, the American College of Sport Medicine (ACSM) recognizes a wide variety of trainable characteristics within a training program (ACSM, 2009). The ACSM (2009) recognizes the importance of rest interval length on performance, since a suggested rest interval length is given for nearly every training domain. Literature on rest interval length is quite extensive and shows that rest intervals from two to five minutes is ideal for increasing strength or maintaining performance (Pincivero, Lepar, & Karunakara, 1997; Pincivero & Campy, 2004; Willardson & Burkett, 2005; Ratamess, Chiarello, Sacco, Hoffman, Faigenbaum, Ross, & Kang, 2012). If the focus is on metabolic conditioning or caloric cost, however, a rest interval that is
one minute or less is ideal (Marcinik, Hodgdon, Mittleman, & O’Brien, 1985; Kraemer, Noble, Clark, & Culver, 1987; Haltom, Kraemer, Sloan, Hebert, Frank, & Tryniecki 1999).

Aside from the mention of rest interval length in the ACSM position paper, there is little mention of any other intrasession recovery strategies (i.e., during the individual session). It is often assumed that a rest interval is to be done with the exerciser limiting movement (termed passive recovery) in order to prepare for the next set or exercise. Newer research, however, suggests that active recovery (i.e., movement with lighter loads during the recovery phase) is thought to be able to clear the metabolic by-products more quickly (Gupta, Goswami, & Sadhukhan, 1996; Baldari, Videira, Madeira, Sergio, & Guidetti, 2004; Coffey, Leveritt, & Gill 2004; Greenwood, Moses, Bernardino, Gaesser, & Weltman, 2008). While time between workouts often allows for sufficient lactate clearance and recovery (Barnett, 2006), recovery strategy is important between sets/exercises due to the shorter time period. Bogdanis, Nevill, Lakomy, Graham, and Louis, (1996) found a four minute period of active recovery enabled a higher power output when compared to a passive four minute rest period during a maximal 30 second sprint on a cycle ergometer and Spierer, Goldsmith, Baran, Hryniewicz, and Katz (2004) found active recovery improved performance on a repeated Wingate test when compared to passive recovery. These two studies suggest an improvement of performance associated with active recovery when compared to passive recovery, which may be indicative of an improved lactate clearance for improved performance outcomes.

However, there is not a full consensus with regards to intrasession active recovery and performance, as Toubekis, Smilios, Bogdanis, Mavridis, and Tokmakidis, (2006)
reported that active recovery hindered performance in repeated swim trials. The answer to this debate may lie in the intensity of the active recovery as not all research has used a similar methodology. Research to date has shown that active recovery between 28% and 63% of maximal oxygen uptake (VO₂ max) has been shown to significantly clear lactate over passive recovery (Davies, Knibbs, & Musgrove, 1970; Dodd, Powers, Callender, & Brooks, 1984; Hermansen, & Stensvold, 1972; Belcastro, & Bonen, 1975; Bogdanis et al., 1996; Gupta et al., 1996; Spierer et al., 2004). Clearly, the range of intensity leads to much interpretation and offers little information designing optimal recovery strategy during exercise programming.

With specific consideration to resistance training workouts, there is little literature examining intrasession active recovery when compared to cardiovascular exercise. Corder, Potteiger, Nau, Figoni, and Hershberger (2000) reported that low intensity active recovery (i.e., 4 minutes) between sets (i.e., six sets of barbell back squats at 85% of 10 repetition maximum) allowed for significantly more repetitions during a final maximal performance set. The low intensity active recovery group also had significantly less lactate accumulation during the workout (Corder et al., 2000). Similarly, Hannie, Hunter, Kekes-Szabo, Nicholson, and Harrison (1995) reported more repetitions during a final maximal performance set after four 65% of one repetition maximum sets of barbell bench press with 2 minutes of either active or passive recovery. These two studies suggest that active recovery can improve performance during a moderate intensity resistance training workout and possibly during anaerobic exercise. It is unclear, however, if active recovery would aid performance in a circuit training workout or workouts with shorter rest intervals (<2 minutes). Furthermore, no research has investigated recovery strategy
among trained vs. untrained participants, and no research could be found investigating the use of smaller vs. larger muscle groups with regards to recovery strategy.

Active recovery is often incorporated during high intensity interval training (HIIT). HIIT training is a form of exercise that involves repeated intervals of intense exercise interspersed by rest intervals. It is believed that HIIT is effective at increasing VO$_2$ peak, as well as whole body fat oxidation (Talanian, Galloway, Heigenhauser, Bonen, & Spriet, 2007). As little as 6 ~15 minute HIIT sessions is enough to improve the body’s oxidation and exercise capacity (Gibala & Jones, 2013). Given the benefits of HIIT training, it is no surprise this training method is gaining popularity among athletes and recreational exercisers. Moreover, HIIT training has been shown to increase the time an exerciser is able to perform at >90% of VO$_2$ max in a workout compared to steady state training (Buchheit & Laursen, 2013), which is an important benefit for the high performance athlete. With the increasing popularity of HIIT training, there comes the question of how to best maintain performance throughout a HIIT workout. This is particularly important for athletes who want to perform at the highest level possible during their workouts, whereby recovery strategy may come into play. Perhaps the most obvious element of recovery strategy, as far as HIIT is concerned, is the length of rest to take between intervals. It has been shown that training programs that incorporate longer rest intervals are more beneficial in increasing strength (Pincivero, Lephart, & Karunakara, 1997), however, shorter rest intervals are more beneficial for a higher metabolic response (Ratamess et al., 2012). When HIIT training is included in a program in order to burn body fat, short rest intervals are more appropriate. Scudese, Willardson, Simao, Senna, Freitas de Salles, and Miranda (2013) found significant differences in
bench press performance between one and two minute rest intervals with better performance observed after the two minute rest interval. This study used near maximal loads, which leads to the possibility that there may be performances differences in an upper body dominant HIIT workout with differing short rest interval times (i.e., one minute vs. two minutes).

Therefore, the purpose of this study is to examine the influence of training status, recovery strategy, and rest interval length on performance and lactate levels using high intensity intervals with a battling rope. The specific objectives of this study are to identify performance outcomes and post workout lactate measures as a function of training status (i.e., trained vs. untrained), recovery strategy (i.e., passive vs. active), and recovery time (i.e., 60 vs. 120 seconds) by gender.

METHODS

All procedures were approved by the Research Ethics Board at the University of Windsor (REB#13-019).

Participants

Participants for this study were recruited from the University of Windsor. Forty participants, as well as an additional eight participants for the control group, were recruited for this study. Participants were between 17 – 29 years of age and were required to be recreationally active by working out a minimum of twice per week for the previous six months. Both males and females were recruited with the goal to have equal representation of both genders. This population was chosen because it was determined that they are relatively healthy and active enough to be able to manage the intensity of the workout. Participants were divided into two groups based on training status (i.e., trained
vs. untrained). The trained participants had just completed a four week training program with the battling rope through a different study at the University of Windsor (PI: Colin McAuslan), while the untrained participants were new to the battling rope as a workout tool. McAuslan’s (2013) training program consisted of four weeks of HIIT training with the battling rope three times per week, with 10 working intervals, each lasting 30 seconds, interspersed with 60 seconds of recovery. Participants were recruited through word of mouth, email, and through short class presentations. Before participants began the study, each were given a Consent to Participate in Research (Appendix A), Participant Information Sheet (Appendix B), and filled out a Physical Activity Readiness Questionnaire (Par Q, Appendix C).

Among the trained and untrained groups, participants were randomly assigned to either the active or passive recovery group. In addition to the exercising participants, 8 control participants were recruited to determine whether the pre-test would have an effect on post-test results (without the HIIT workout). The control group performed baseline maximal push ups and sit ups, followed by 45 minutes of passive recovery, and then another maximal push up and sit up test. According to a paired samples t-test, no differences were observed in push up and sit up performance, therefore, it was determined that the HIIT workout would have a measured effect on performance (See Appendix D).

**Instruments**

For this study, maximal push ups until failure and maximal sit ups performed in one min, arm ergometer VO2 max, blood lactate measures, heart rate, and rate of perceived exertion (RPE) were recorded. Push ups were instructed to be done with full
range of motion, with the chin touching the floor. Female participants performed push ups from a kneeling position, while male subjects performed push ups from the toes. Participants performed push ups until muscular failure (ACSM, 2005). Sit ups were performed with the hands placed behind the head with the elbows touching the knees in order for the repetition to count with the feet anchored by the researcher. Participants were instructed to perform as many sit ups as they could for one minute (Pollack, Wilmore, & Fox, 1978). See Appendix E for push up and sit up protocols. Aerobic capacity was determined through a maximal oxygen consumption test (VO₂ max test) on an arm ergometer (Appendix F). A Monark Arm Ergometer (Model 881) was used with the participants’ shoulder joint in line with the axis of the arm ergometer pedals. Participants followed a modified Astrand protocol; each stage lasted two minutes, and increased 10 watts with each new stage. Before the beginning of the test, participants were fitted with a Hans Rudolph facemask (Model V2), which was attached to a testing apparatus (Cosmed Quark CPET: Metabolic Cart) that measured VO₂. Participants also were equipped with a Polar Heart Rate Monitor (Model E40). All equipment used was sterilized before and after each use by participants. Participants were instructed to maintain a 60 rotations per minute (RPM) cadence throughout the test. The VO₂ max test started at 10 watts and was increased every two minutes for a maximum of 100 watts. The VO₂ max test was completed when participants voluntarily withdrew or could no longer maintain a cadence of 60 RPM at the given watts. If the maximum wattage of 100 watts was maintained for two minutes at 60 RPM, the cadence was increased 10 RPM every two minutes until the participant was unable to maintain the cadence or withdrew. For the active recovery group, 20% of the maximum wattage obtained in this test was
used to determine recovery intensity. Active recovery was selected at 20% maximum wattage because it was deemed impractical to have a running VO2 measurement during the battling rope workout; as well the intensity was determined to be light enough in intensity during trial runs of the study protocol. Exercising at a specific HR zone would have been impractical as HR would be significantly elevated post HIIT interval, especially during the 60 second rest interval HIIT workout. However, according to the corresponding stage of the VO2 max test, 20% wattage represented 64.8 ± 8.5% of age predicted maximum heart rate (220 – age). During the battling rope exercises, lactate was measured using a Lactate Scout Analyzer and disposable Medlance 1.8mm 21G Autolancet. This tool was used to obtain a drop of blood from the participant’s ear lobe (see Appendix G). Alcohol swabs were used during the lactate measurement and all lancets and swabs were disposed in a clearly marked bio-hazardous container. The researcher wore protective gloves and safety goggles during the measurement of lactate.

Using the same protocol as McAuslan (2013), male participants used a 3.81 cm in diameter, 11.340 KG, and 15.24 meters long battle rope while female participants used a 3.81 cm diameter, 9.072 KG, 12.192 meters long rope. The difference in rope used by the two genders was determined because of the level of difficulty female participants displayed when using the 15.24 meter long rope. During the HIIT exercise, heart rate was monitored using Polar Heart Rate Monitors (Model E40).

Procedure

Prior to the current study, trained participants completed a 4 week battling rope training program (as described in the previous section). For the purpose of this study, trained and untrained participants were further divided into active or passive recovery
sub-groups through randomization (see Figure 1). All data collection forms that were used in the present study are in Appendix H. Participants were instructed on emergency procedures (see Appendix I) before initiation of baseline testing. All participants completed baseline testing and two experimental training conditions (60 second rest interval length and 120 second rest interval length), as described below.

**Baseline Testing.** Baseline testing included a warm-up, maximal sit ups, VO2 max test on the arm ergometer, five minutes of rest, and maximal push up test. The warm-up consisted of 20 jumping jacks, 10 arm circles each way, 10 alternate lunges, 10 stick ups, and 10 push ups (see Appendix J for detailed explanation). The push up and sit up measures ensured reliability for maximal push up and sit up tests on the subsequent testing days, as well as an opportunity to coach proper form before the workout days. Rating of perceived exertion (Appendix K) was recorded for each stage of the VO2 max test using a modified Borg scale of perceived exertion on a scale of 1 – 10 (Borg, 1982). Rating of perceived exertion was also recorded for each interval completed on the battling rope. A brief familiarization of the battling rope followed for the untrained group, such that each participant tried one 30 second round each of double whip and alternate whip (see Appendix L) with one minute of rest between rounds. Approximately 48 hours later, the two testing days were completed.

**Testing Sessions.** Testing was spread across two days (days were randomized and had a minimum and maximum of 48 hours and five days apart, respectively) and were identical in structure (with the exception of the rest interval; i.e., participants either had 60 second rest intervals or 120 second rest intervals depending on randomization). Upon entry to the lab, participants were seated for 5 minutes before having a blood lactate
measurement. Each participant completed a warm up (same protocol as the baseline testing day), three minutes of rest, followed by a maximal push up test and maximal sit up test (five minutes rest in between). After another five minutes of rest, participants commenced the battling rope workout. Five minute rest periods were employed in order to minimize effects of fatigue and maximize performance (Willardson & Burkett, 2005). Each workout took approximately 45 minutes to one hour to complete, and entailed 10 rounds (30 seconds each) alternating between double whip and alternate whip method. Depending on earlier randomization, the passive recovery groups were instructed to sit during the rest interval and minimize movements, while the active recovery groups were instructed to utilize the cycle ergometer (see Appendix M) immediately after each interval (i.e., maintaining a 60 RPM cadence at 20% of maximum wattage obtained during the VO₂ max test).

Following the battling rope workout, participants immediately had a blood lactate measurement taken, followed by another five minutes of passive or active recovery (based on their randomization), and subsequently, a final blood lactate measurement. The testing session ended with a maximal push up test and maximal sit up test. Participants were allowed one minute to transition from the maximal push ups to the maximal sit ups, in order to decrease recovery time between the battling rope workout and the maximal sit up test. See Figure 2 for illustration of testing session.

Data Analysis

Data collected from the two testing days were analyzed using SPSS version 21.0 (Armonk, NY) for Windows. Direct comparison of the two genders was not completed due to the different length of the battling rope used during the HIIT workout, as well as
the different method for pre- and post-test push ups. A Shapiro-Wilk test was performed to test for normal distribution of the data. Maulchy’s test of sphericity was also performed to ensure the assumption of sphericity was met. SPSS was used to detect any significant outliers. All statistical assumptions were met.

Separate repeated measures analyses were utilized to determine pre- and post-test push ups/sit ups differences in each training session by gender. Repeated measures analyses were used to determine the difference in outcome (dependent variables were push ups or sit ups) by training status (i.e., trained vs. untrained) and recovery strategy (i.e., active vs. passive) as independent predictors. Separate repeated measures analyses were used to determine the difference in outcome (dependent variables were resting lactate, lactate accumulation, and lactate clearance) by training status (i.e., trained vs. untrained) and recovery strategy (i.e., active vs. passive) as independent predictors.

Heart rate values (post-interval, recovery, pre-interval HR) were converted to a percentage of maximum heart rate (%MHR) by using the calculation \( \frac{HR}{(220 - \text{Age})} = \%MHR \). This was used instead of participants absolute HR in order to account for age when determining intensity. A repeated measures analysis was used to determine the difference in outcome (%MHR post-interval, mid recovery for 120 second rest interval, and pre-interval) by training status (i.e., trained vs. untrained) and recovery strategy (i.e., active vs. passive). Post interval %MHR was then used as the outcome variable and a repeated measures analysis was performed with training status and recovery strategy as independent predictors. Lastly, separate repeated measures analyses for each gender were used to determine RPE differences by training and recovery status. Mean differences
were considered statistically significant at \( p < .05 \), however, practical significance was accepted at \( p < .07 \).

**RESULTS**

**Descriptive Statistics**

Nineteen males (mean age = 23.05 ± 3.08 years) and 21 females (mean age = 21.62 ± 2.37 years) participated in the current study. Among the male participants, trained \((n = 9)\) and untrained \((n = 10)\) participants had a mean arm ergometer VO\(_2\) max of 35.671 (± 6.667) ml/min/kg and 32.607 (± 4.871) ml/min/kg, respectively. Among females, trained \((n = 11)\) and untrained \((n = 10)\) participants had a mean arm ergometer VO\(_2\) max of 33.549 ml/min/kg (± 3.629) and 32.293 ml/min/kg (± 4.382), respectively. VO\(_2\) max differences were not significant between trained and untrained groups. See Appendix N for participant arm ergometer VO\(_2\) max scores.

**Performance Measures**

**Push ups.** Tables 1 (males, 60 second rest), 2 (females, 60 second rest), 3 (males, 120 second rest), and 4 (females, 120 second rest) describe pre- and post-test push up performance. Male push up performance dropped significantly as a result of the HIIT workout for both the 60 second rest interval workout \((F = 15.759, p < .001)\) and the 120 second rest interval workout \((F = 25.170, p < .001)\). Female push up performance also dropped significantly from pre-HIIT workout in both the 60 second rest interval workout \((F = 9.632, p = .006)\) and 120 second rest interval workout \((F = 13.250, p = .002)\). However, according to the repeated measures analyses, the difference in push up performance as a function of training status (i.e., trained vs. untrained) and recovery
status (i.e., active vs. passive) were not significant, nor were there any interactions, for either gender at the 60 second and 120 second rest interval HIIT workouts.

**Sit ups.** Tables 5 (males, 60 second rest), 6 (females, 60 second rest), 7 (males, 120 second rest), and 8 (females, 120 second rest) describe pre- and post-test sit up performance. Male sit up performance dropped significantly as a result of the HIIT workout for both the 60 second rest interval workout ($F = 5.518, p = .033$) and the 120 second rest interval workout ($F = 9.463, p = .008$). Female participants had a significant drop in sit up performance as a result of the HIIT workout with 60 seconds rest intervals ($F = 7.556, p = .014$), however, the 120 second rest condition indicated no significant drop in sit up performance. According to the repeated measures analysis, there were no significant differences in sit up performance as a result of training status and recovery strategy for either gender. Surprisingly though, untrained females had significantly better sit up performance than trained females ($F = 10.131, p = .005$) during the 60 second rest interval HIIT workout.

**Lactate**

**60 second rest interval HIIT workout.** Blood lactate was measured at resting state (RL), immediately post-HIIT workout (IL) and five minutes post-HIIT workout (PL). Tables 9 (males) and 10 (females) display mean lactate values for each measurement point for the 60 second rest interval HIIT workout. As expected, there was a significant increase in blood lactate levels as a result of the HIIT workout for the 60 second rest interval HIIT workout ($F = 145.093, p < .001$ for males and $F = 165.255, p < .001$ for females). According to the multivariate analysis of variance, recovery strategy had a significant impact on blood lactate values in males ($F = 4.108, p = .039$), as active
recovery had significantly lower blood lactate values by the last lactate measure, whereas blood lactate increased from immediately post-workout to five minutes post-workout in passive recovery participants. Although not statistically significant \((F = 3.126, p = .075)\), these differences were more pronounced in trained male participants compared to untrained male participants, as active recovery male participants tended to have higher mean blood lactate values immediately post-workout. Aside from trained active participants, measures showed a drop in blood lactate five minutes post-workout, whereas, passive recovery participants had an increase in blood lactate. Recovery strategy or training status had no significant impact in lactate levels in female participants.

**120 second rest interval HIIT workout.** Male and female blood lactate data for the 120 second rest interval HIIT workout can be seen on Tables 11 and 12, respectively. As was the case with the 60 second rest interval HIIT workout, there was a significant increase in blood lactate levels as a result of the HITT workout for the 120 second rest interval workout for males \((F = 208.581, p < .001)\) and for females \((F = 135.442, p < .001)\). According to the multivariate analysis of variance, there were no significant differences in blood lactate values for males as a result of recovery strategy and training status for male participants. There were also no significant differences in blood lactate as a result of training status for females; however, female participants had a significant difference as a function of recovery strategy \((F = 7.594, p = .005)\). Active recovery participants had higher lactate values immediately after the workout but lower five minutes post-workout compared to passive recovery. The multivariate analysis also showed significant differences in blood lactate as a result of training status and recovery strategy \((F = 4.158, p = .035)\). Trained active (vs. passive) recovery females had lower
lactate values, however, untrained active (vs. passive) recovery females observed a higher mean lactate immediately post-workout but lower mean lactate five minutes post-workout.

Heart Rate

60 second rest interval HIIT workout. Heart rate data for the 60 second rest interval workout is presented in Tables 13 (males) and 14 (females). The repeated measures analysis demonstrated that %MHR increased significantly as a result of the HIIT interval for the 60 second rest interval workout for males (post-HIIT interval = 86.4 ± .4%, pre-HIIT interval = 65.5 ± 1.7%, \( F = 150.35, p < .001 \)) and females (post-HIIT interval = 87.3 ± .3%, pre-HIIT interval = 67.4 ± 1.7%, \( F = 146.637, p < .001 \)). Furthermore, it was found that recovery strategy led to a significant difference in pre- and post-test %MHR. Males in the active recovery group had a lower mean post-HIIT interval %MHR and higher pre-HIIT interval %MHR compared to passive recovery post-HIIT interval and pre-HIIT interval (\( F = 6.462, p = .012 \)). Similar results were observed for females, such that the active recovery group had a lower mean post-HIIT interval %MHR and a higher pre-HIIT interval %MHR compared to those in the passive recovery group post-HIIT interval and pre-HIIT interval (\( F = 4.462, p = .036 \)). There was no significant interaction between training status and HR for both males and females during the 60 second rest interval workout.

120 second rest interval HIIT workout. Heart rate data during the 120 second rest interval HIIT workout are presented in Table 15 (males) and 16 (females). The repeated measures analysis demonstrated that %MHR increased significantly as a result of the HIIT interval for males (post-HIIT interval = 86.2 ± .3%, mid-recovery = 64.3 ± 1.6%,}
pre-HIIT interval = 59.1 ± 1.5%, $F = 604.776$, $p < .001$) and females (post-HIIT interval = 85.7 ± 0.4%, mid-recovery = 62.7 ± 1.6%, pre-HIIT interval = 57.5 ± 1.5%, $F = 525.525$, $p < .001$). According to the multivariate regression analysis, recovery strategy influenced male participants’ %MHR, such that the active recovery group observed a lower mean post-HIIT interval %MHR, higher mid-recovery, and higher pre-HIIT interval %MHR compared to those in the passive recovery group post-HIIT interval, mid-recovery and pre-HIIT interval ($F = 15.030$, $p < .001$). Similarly, females in the active recovery group observed a lower post-HIIT interval %MHR, a higher mid-recovery %MHR, and a higher pre-HIIT interval %MHR compared to those in the passive recovery group post-HIIT interval, mid-recovery interval and pre-HIIT interval ($F = 421.484$, $p < .001$).

A three way interaction between %MHR, recovery strategy, and training status for male participants was observed ($F = 3.225$, $p = .042$). Trained, active recovery participants had a lower %MHR across HR measurements when compared to untrained, active recovery participants. Further, trained passive recovery participants had lower %MHR compared to untrained passive recovery. There were no significant findings with regards to HR and training status in female participants during the 120 second rest interval workout.

**Rating of Perceived Exertion**

Figures 3 (males, 60 second rest), 4 (females, 60 second rest), 5 (males, 120 second rest), and 6 (females, 120 second rest) display mean RPE values the various workouts. Among males, RPE significantly increased by the end of the HIIT workout in both the 60 second rest interval workout ($F = 34.174$, $p < .001$) and the 120 rest interval
workout \((F = 32.077, p < .001)\). Among females, RPE also significantly increased throughout the HIIT workout in the 60 second rest interval workout \((F = 86.986, p < .001)\) and the 120 second rest interval workout \((F = 102.204, p < .001)\). There were no significant differences as a result of recovery strategy and training status on RPE for males for both workouts. Females also had no significant differences as a result of recovery strategy and training status on RPE for the 60 second rest interval workout. However, for the 120 second rest interval HIIT workout trained female participants reported higher RPE values than untrained participants \((F = 3.753, p = .014)\). Additionally, female participants who performed active recovery reported significantly lower RPE values than passive recovery participants \((F = 3.558, p = .018)\).

**DISCUSSION**

Regarding performance, it is widely accepted that trained individuals are going to perform better than untrained individuals. Strength and conditioning professionals must cater training programs accordingly when working individuals who have an athletic background or new to exercise (ACSM, 2009). But this is not simply a matter of an individual being trained or untrained. Rather, there are varying degrees of training status and athletic ability and these athletic characteristics can be trained based on modifications of a training program. In the position stand on resistance training, the ACSM (2009) determined individuals training status based on the duration of training. For example, those who are new to resistance training are beginners; those who have been using resistance training regularly for six months are considered intermediates; and those who resistance train on a consistent basis for years with significant improvements are considered advanced trainers (ACSM, 2009). However, due to specific adaptations based
on the specificity of a training program, individuals who would be considered advanced according to ACSM guidelines may have unique training adaptations depending on training characteristics emphasized in their respective training programs. Kraemer, et al. (1987) examined differences in exercisers who typically use a very short rest interval in their workouts and exercisers who typically use long rest intervals and reported that bodybuilders (who used short rest intervals) were able to use a greater percentage of their 1RM, in addition to suffering significantly lower incidents of dizziness and nausea, compared to the trained power lifters (who used long rest intervals). Considering that the participants of this study would be considered advanced according to ACSM guidelines, yet have significant differences in performance under differing conditions, suggests variability within a population due to unique training adaptations. It is possible that these differences extend to new exercise tools, such as kettlebells and battling ropes, as well as a unique training program, such as HIIT. Differences could exist between individuals who have been exercising the same duration but using different equipment and different programs.

A previous study reported that a four week battling rope HIIT program increased fitness and performance parameters in active college aged participants (McAuslan, 2013). Among male participants, push up performance increased (11.1%), rope cadence increased (14%), and round by round RPE decreased (13.5%) as a result of the four week training program. Among females, an increase in VO2 max (7.8%), increase in peak VO2 during the workout (8.4%), an increase in push ups (36.4%), and sit ups (10.1%) were observed. It was felt an interesting continuation of this study could examine possible differences in fatigue when comparing the participants who had just completed the
battling rope HIIT program and those who are new to the battling rope as a workout tool, yet would be considered a trained population in the sense they have performed purposeful exercise a minimum of twice per week for the last six months.

The present study examined the influence of training status, recovery strategy, and rest interval length on performance when using an upper body dominant HIIT protocol with battling ropes. The present study contributes to research examining fatigue and recovery by suggesting neither training status nor recovery strategy influence performance during an upper body dominant HIIT workout utilizing a 60 or 120 second rest interval. With regards to performance implications, both a 60 and 120 second rest interval yielded no significant differences in performance when performing an alternating double whip and alternate whip battling rope HIIT workout, with the exception of untrained (vs. trained) female participants able to significantly maintain their sit up performance. Interestingly, recovery strategy had a significant influence on blood lactate among male and female participants; however, this did not translate to performance differences.

The performance measures used in the present study were pre- and post-test push up and sit up tests. Push up tests are a commonly used by strength and conditioning professionals to assess upper body strength and muscular endurance (Baechle & Earle, 2000). Since the battling rope HIIT workout used in the study engages predominantly the muscles of the upper body, the push up was deemed an appropriate test of performance. Abdominal strength is also important, as participants must display strong core stabilization throughout the workout to maintain proper form. Additionally, there is some hip flexion/extension during the workout, especially during the double whip style of
battling rope. Since the sit up test is a commonly used form of assessing abdominal strength and endurance (Baechle & Earle, 2000), it was also used as a performance measure. There were no significant differences in the two performance measures between active or passive recovery groups. According to YMCA normative data for push up performance (Hoffman, 2006) male participant pre-workout numbers scored between the 80 and 90 percentile while female participants pre-workout numbers scored in the 90 percentile for their push up score. The high score in push ups is not surprising as participants were all recreationally active, with the trained group recently completing a four week battling rope training program. It was surprising, however, that there was no significant difference in ability to maintain push up performance between trained and untrained participants as McAuslan (2013) showed that push up performance improves after a four week battling rope HIIT program in both male and female participants. It should be noted that trained participants of the present study did have a higher mean in push up performance (trained males = 39.11, untrained males = 35.40; trained females = 40.91, untrained females = 36.00), but were not able to maintain their push up performance post-HIIT workout to a significant degree when compared to the untrained participants. It is possible that untrained participants selected for the present study were engaged in upper body dominant workouts prior to data collection, which would negate any possible differences in ability to maintain push up performance. For future research, this could be controlled by having a lower body dominant HIIT program performed prior to testing.

Previous research indicates that an acute battling rope training session can bring about heart rates as high as 94% of age predicted maximum, lactate levels of 11.9
mmol/L, and peak METs of 10.1 (Fountaine & Schmidt, 2015). According to ACSM guidelines on cardiorespiratory exercise (ACSM, 2011), an acute battling rope HIIT workout would be considered vigorous exercise. Considering findings by McAuslan (2011), as well as Fountaine and Schmidt (2015), it is likely that a HIIT style battling rope workout would bring about physiological adaptations that will increase performance if part of a chronic training program. However, an acute battling rope workout drops push up performance regardless of training experience with the battling rope, recovery strategy, and recovery time up to 120 seconds as shown in the present study for both males and females.

With regards to sit up performance at the pre-test, male participants were ranked 40-50 percentile and female participants ranked in the 40 percentile. There were no significant differences in sit up performance between trained and untrained participants. Past research suggested that a four week battling rope HIIT workout can improve sit ups in female participants, however, the increase is modest (10.1%) and there was no significant improvement for male participants (McAuslan, 2013). The results of the pre-test (in the current study) indicate that the participants of this study were high performers when compared to the general population with regards to push ups but below average performers with regards to sit ups. When compared to McAuslan’s (2013) performance measures following the four week training program, male participants performed a higher number of push ups in the present study (37.7 vs. 33.3) and lower sit up repetitions (41.4 vs. 47.5). Female participants performed less push ups (38.5 vs. 39.7) and slightly less sit ups (37.2 vs. 37.8). It should be noted, that the trained participants of the present study were able to further increase their push up performance since the completion of
McAuslan’s study. With regards to training status, there were no significant differences in performance, although untrained (vs. trained) female participants were able to perform a higher sit up percentage at post-test during the 60 second rest interval workout in both the active and passive recovery groups. This is a surprising finding since literature suggests individuals trained with a workout stimulus would be better adapted for that stimulus when compared to individuals new to the stimulus (ACSM, 2009; Fleck, 1999). One could argue that the trained participants would be better trained in hip flexion/extension with the battling rope training; however, this was not reflected in female sit up performance. The finding of the present study suggests detraining of the abdominals and hip flexors may have occurred. However, as observed by McAuslan (2013), female participants improved their sit up performance at the conclusion of the 4 week training program. The explanation for this could be the amount of effort put into the workout as trained female participants had a significantly higher RPE than untrained females during the 120 second rest interval HIIT workout in both active and passive groups. This lower perceived exertion level during the workout itself could have enabled untrained participants to perform better in the post-test. It is important to note that there was no significant difference in %MHR between trained and untrained female participants to strengthen this point. It is possible that the sit up is a weak indicator of performance regarding the battle rope workout. It is also possible that trained participants were simply lacking motivation as they were involved with the battle rope HIIT workout for over four weeks prior to the current study, while untrained participants were new to the experience. Considering the findings of the present study, sit ups may be a poor measure of performance when performing a battle rope HIIT workout. Future research
could incorporate electromyographical analysis in order to determine muscle recruitment in battle rope exercise and abdominal and hip flexor muscle recruitment could be determined.

This anomaly aside, training status had no influence in participants’ ability to maintain post-test performance, as there were no significant differences in performance for trained and untrained participants. However, it must be noted that the trained individuals followed a four week training program, which is on the low end of ACSM’s position in that it takes four to six weeks to make training adaptations to a new training stimulus (2009). Although it has been shown a four week battling rope program can bring significant increases in performance within participants (McAuslan, 2013), it is possible that performance differences between groups may have occurred if the initial training program was of longer duration for the trained participants or sit ups were being trained specifically. Also, untrained participants in the current study were untrained in the sense they did not participate in a 4 week battling rope training program leading up to the present study. The untrained participants were still recreationally active as they trained a minimum twice per week for the last 6 months leading up to data collection. If untrained participants were truly untrained in the sense they were new to exercise or sedentary for an extended period of time, performance differences would have likely occurred.

It is important to note that push ups and sit ups are not the only performance measure that could have been used in a study of this nature. Future research should include other measures of performance in order to determine whether there is any benefit to performance when using differing recovery strategies. One possibility is the number of ground contacts the battling rope makes per interval throughout the workout. Generally
speaking, the more ground contacts the rope makes, the better the exerciser is performing. If strict range of motion (ROM) requirements are established, the number of ground contacts could act the same way as rotations per minute would on a cycle ergometer. Though it is important to note, the exerciser could simply find the exercise easier with more ground contacts as McAuslan (2013) found no change in peak VO$_2$ with higher ground contacts. Nevertheless, combined with blood lactate, HR, RPE, push ups, and perhaps sit ups, this could give a more complete examination of fatigue and performance during a battling rope HIIT workout. Another option is a final interval performed until failure with the time until failure used as a measure. A similar variable was used by Corder et al., (2000) when measuring differences in performance between active and passive recovery when performing a barbell back squat. After all working sets were completed, participants completed a set at 65% of their 1RM and maximal reps were recorded. It was found that participants who performed light intensity active recovery were able to complete more repetitions of the barbell back squat compared to passive recovery. An interval that would last until failure could work much the same way in a future battling rope study and would be more related to the task than push ups or sit ups. A researcher would need to set strict ROM and cadence requirements and have the participant to perform a battling rope interval as long as possible until they can no longer maintain ROM and/or cadence, or the participant voluntarily withdrawals. For future research, it would be worthwhile to examine alternate performance measures to investigate the influence of recovery strategy on an upper body dominant HIIT workout. It is also important that future research incorporates standardized recovery periods throughout the testing schedule. During the initial study design it was felt that varied
recovery time prevents cool down after warm up (i.e., 3 minutes of rest between warm up and push up test) and minimizes recovery from the HIIT workout (i.e., one minute of recovery between push up and sit up tests post-HIIT workout). However, this may have yielded inaccurate findings, as a study design with the same amount of rest between push ups and sit ups should be incorporated in future research.

The majority of literature examining recovery strategy has been done on lower body dominant exercise, such as intervals on a cycle ergometer (Gupta et al., 1996; Mazzeo, Brooks, Schoeller, & Budinger, 1986; Bond, 1991; Coffey et al., 2004; Bogdanis et al., 1996; Spierer et al., 2004). The present study contributes to active recovery strategy by examining a strictly upper body recovery strategy on a HIIT workout. However, there has been considerable literature examining interval training and recovery on swimming. For instance, Toubekis et al. (2006) found that active recovery reduced performance in subsequent 50m sprint times following eight 25m sprints interspersed by 45 seconds of either active or passive recovery. Blood lactate was significantly higher among passive recovery participants. A subsequent study by Toubekis, Peyrebrune, Lakomy, & Nevill (2008) conducted on eight elite swimmers reported higher peak lactate values associated with passive recovery (18.3 mmol/L) compared to active recovery (14.1 mmol/L) when participants performed four intervals of 30 seconds of maximal tethered swimming followed by 30 seconds of recovery (active or passive) followed by four intervals of 50 yard sprints with two minutes of recovery (active or passive). Despite the significant differences in peak lactate between passive and active groups, there were no significant differences in the 50 yard sprint times.
With regards to the present study, an arm ergometer was the exercise tool used to examine recovery strategy on performance during the HIIT protocol that utilized a battling rope. The battling rope is upper body dominant as the muscles that act on the elbow and shoulder joints are primarily involved in the exercise. Although there is little literature on the battling rope as a workout tool, some studies have examined upper body exercise and recovery strategy, although, they are in the minority when compared to lower and whole body recovery. McAuslan (2013) reported that a four week HIIT program with the battle rope, an upper body dominant exercise using passive recovery, increased many fitness parameters such as VO$_2$ max, push up performance, and rope cadence. A study examining rock climbers determined that utilizing active (vs. passive) recovery during rock climbing, which is demanding of the upper body musculature, would improve performance on subsequent climbs (Heyman, Geus, Mertens, & Meeusen, 2009). However, this study made the assumption that superior lactate clearance was a possible causal factor in improved climbing performance. Based on the study results on swimmers, this isn’t necessarily the case (Toubekis et al., 2006; Toubekis et al., 2008).

An important difference between the rock climbing study and the present study is that Heyman et al. (2009) utilized a lower body cycle ergometer as active recovery, not an upper body form of active recovery like the present study. The potential of lactate uptake of the larger muscle groups of the lower body is greater than the smaller musculature of the upper body (Vah Hall, 2000). However, the current study shows that the upper body musculature is capable of lactate uptake during active recovery, though not to the degree to invoke differences in performance. Regarding the present study, active recovery male participants had lower mean lactate values five minutes post workout (8.528 mmol/L)
than passive recovery male participants (10.140 mmol/L) during the 60 second rest interval HIIT workout, yet there was no significant difference in either push up or sit up performance. This was also the case for females during the 120 second rest interval HIIT workout as passive recovery participants had a five minute post workout mean blood lactate of 8.800 mmol/L compared to active recovery participants who had a mean blood lactate of 6.373 mmol/L. Despite the significant differences in blood lactate depending on recovery strategy, these differences did not translate to differences in performance.

As shown in the literature, utilizing a form of lower body active recovery has a higher lactate clearance when compared to passive recovery (Spierer et al., 2004), but what this means for performance is unclear. Even if there is a consensus that active recovery is superior to passive recovery in lactate clearance, there are mixed findings when examining active recovery’s impact on performance. Dupont, Moalla, Matran, & Berthoin (2007) found passive recovery was superior to active recovery during 15 second recovery periods in achieving higher peak power during repeated Wingate tests. It appears that very low rest time, ~15 seconds, passive recovery is superior to active recovery. The Dupont et al. study (2007) contrasts a study by Bogdanis et al. (1996) that utilized two maximal 30 second cycle sprints with four minutes of prescribed recovery, in which active recovery was shown to be more beneficial as participants completed more total work. Further, peak torque dropped when performing active (vs. passive) recovery during repeated weighted knee extensions (Zarrouk, Rebai, Yahia, Souissi, Hug, & Dogui, 2011). These results, combined with the lack of performance differences in the present study, question the role that lactate plays in fatigue. As discussed in Gladden’s review of literature (2004), lactic acid and the subsequent disassociation with hydrogen
may not be causal of fatigue. Instead, it is merely a single factor in fatigue, which is a complex process that includes many elements, such as substrate depletion and tissue hypoxia (Gladden, 2004). The results of the current study contributes to the findings that lower post workout lactate levels, corresponding with active recovery, does not necessarily equate to better performance, since performance did not change significantly according to recovery strategy.

With regards to a battling rope workout influence on lactate accumulation, the present study observed similar results to what McAuslan (2013) reported using the similar protocol participants. However, Fountaine and Schmidt (2015) reported higher mean lactate values (11.17 ± 1.5 mmol/L for male participants and 12.1 ± 1.5 mmol/L for female participants) using a heavier battling rope (i.e., 16.33 KG compared to 11.340 KG for males and 9.072 for females in the present study). Yet, an alternate interval protocol was used with 15 seconds of double whip battling rope exercise followed by 45 seconds of rest for 10 rounds (Fountaine and Schmidt, 2015); which indicates the importance of protocol. Further research should investigate the nature of the weight of the rope and how that influences recovery time.

Another interesting finding is the differences in lactate profiles between trained and untrained female participants. As discussed earlier, specificity is an important component when designing a training program and because of this there could be different training adaptations depending on the nature of the training program. With regards to blood lactate, McAuslan (2013) reported that a four week battling rope HIIT program utilizing 60 second rest intervals and 30 second working intervals did not have a significant impact in blood lactate when comparing pre- and post-HIIT training program.
With regards to the present study, the lack of significant differences in trained and untrained males, and females during the 60 second rest interval HIIT workout, supports this finding. However, training status did play a role in female participants during the 120 second rest interval, as active recovery reduced blood lactate five minutes post-HIIT workout to a greater degree in trained female participants compared to untrained female participants (see Table 12).

This leads to the suggestion that a unique training adaptation existed due to the four week battling rope program undertaken by the trained female participants, but not males. Previous research indicates that HIIT can lower maximal lactate accumulation in as little as four weeks (Soultanakis, Mandaloufas, & Platanou, 2012). This can be partially attributed to higher metabolic clearance in trained individuals (MacRae, Dennis, Bosch, & Noakes, 1992). With regards to the present study, active recovery had a more profound impact at reducing blood lactate in trained female individuals when compared to individuals new to the battling rope workout tool. The monocarboxylate transporter, MCT 1 and MCT 4, is the primary mechanism for the uptake of lactate into active skeletal muscle (Brooks, Dubouchaud, Brown, Sicurello, & Butz, 1999). MCT 1 and MCT 4, as well as the actions of the enzyme lactate dehydrogenase, regulate levels of lactate in the body by converting lactate to pyruvate and eventual oxidation through the Krebs Cycle. Since chronic exercise improves these mechanisms (Thomas, Bishop, Lambert, Mercier, & Brooks, 2012), trained female participants were perhaps likely better able to oxidize lactate during active recovery compared to untrained female participants.
The question becomes why males did not benefit from the same training effect as females? Careful consideration must occur when drawing on the present study to make conclusions on sex differences in lactate metabolism and recovery strategy. Males and females were treated under different conditions as males used a heavier and longer rope (11.340 KG, 15.24 meters) when compared to females (9.072 KG, 12.192 meters). This may have an influence over lactate accumulation as Fountaine and Schmidt (2015) observed much higher lactate values in female participants when the same length of rope was used. However, the difference in the effect training status on lactate accumulation during active recovery, or lack of difference in the case of males, warrants a closer look at possible sex differences. Simoneau and Bouchard (1989) examined biopsies of both male and female vastus medialis muscle tissue and observed that females have a higher ratio of type I fibres to type II fibres than men. Because of the oxidative nature of type I fibres, specifically the greater number of mitochondria, this could provide additional sites for the oxidation of lactate. Additionally, a study (Esbjornsson-Liljedhal, Sundberg, Norman, & Jansson, 1999) examined metabolic response in males and females after a 30 second maximal sprint on a cycle ergometer. After the maximal sprint, blood was drawn and a muscle biopsy of the vastus medialis was taken. Researchers reported that males (compared to females) accumulated 22% more lactate in response to the sprint. The study also observed a glycogen sparing effect as female type I fibers had 50% greater glycogen content then males. According to a literature review on sex differences in human performance (Hicks & Ditor, 2001) these two studies highlight potential sex differences in glycolytic metabolism that is a growing field of research. The present study does seem to support possible sex differences in the metabolism of lactate but further research needs
to be done in order to determine possible sex differences when performing a battling rope HIIT workout.

When examining only training status and blood lactate, there were no significant differences between trained vs. untrained participants, which was also observed in McAuslan’s study (2013). The muscle groups involved in the exercise could explain one possible reason. A battling rope workout is largely upper body dominant and relies on the smaller muscles of the shoulder girdle as opposed to the large muscles that act on the hip. It is likely a lower body dominant HIIT program would have a larger training effect on the lactate profiles of participants, even when considering an upper body dominant workout such as a battling rope workout. This is largely because of the increased vasculature of larger muscles in the body increases the potential for lactate clearance since there is greater surface area for blood lactate to be diffused into oxidative muscle fibres. Additionally, larger muscles contain a greater number of mitochondria, the organelle responsible for oxidizing lactate in the active skeletal muscle. It is possible with a longer training program, for example, six weeks instead of four weeks, and/or an active recovery protocol that utilized the larger musculature of the lower body, these differences would have been more pronounced. Future research could also incorporate a four week lower body dominant exercise program to be run alongside a four week battle rope HIIT program in order to further explore possible differences in performance.

Another finding of McAuslan (2013) is the rise in blood lactate after five minutes of recovery compared to immediately post exercise. With regards to the passive recovery participants, this finding was consistent with the present study. However, active recovery participants had a reduced blood lactate level after five minutes of recovery. During
passive recovery, blood lactate increases from immediately post-HIIT workout to five minutes post-HIIT workout because of the delay in intramuscular lactate to diffuse into the blood (Brooks, 1999). A possible explanation for the drop in blood lactate during active recovery is the role skeletal muscle plays in lactate uptake during light intensity exercise (active recovery). This light exercise likely increases the uptake of lactate by the skeletal muscle (Brooks, 1986), and without submaximal exercise, lactate is more likely to be converted to glycogen; which is stored and released through the liver to replenish glucose used during exercise. This pathway of lactate uptake is a slower process than oxidation by mitochondria of muscle cells (Brooks, 1999); therefore, it will take longer for blood lactate to drop when compared to active recovery.

With regards to VO\(_2\) max, there were no significant differences between trained and untrained groups. Although trained subjects had a higher mean VO\(_2\) max, they were not significantly different among groups. These values seem low for active individuals; however, the maximal aerobic capacity testing was done using an upper body VO\(_2\) max test (i.e., arm ergometer) and not whole body VO\(_2\) max. Bulthuis, Drossaers-Bakker, Oosterveld, Van Der Palen, and Van De Laar (2010) found a mean difference of 18.6 ml/kg/min between a VO\(_2\) max test done on an arm ergometer compared to a bicycle ergometer. The following formula, VO\(_2\) max = 25.85 + 0.75 (arm ergometer VO\(_2\) max), has been used and been shown to be valid and reliable (Bulthuis et al., 2010) to convert arm ergometer VO\(_2\) max scores to whole body VO\(_2\) max scores. By using this formula, we can convert trained male participants mean VO\(_2\) max score to 52.62 ml/min/kg and untrained (yet active) males score to 50.25 ml/min/kg. Trained female participants mean VO\(_2\) max would then equate to 51.01 ml/min/kg and untrained (yet active) females would
equate to 50.07 ml/min/kg. According to VO₂ max normative values, these values are high compared to the general population of the same age as men typically have VO₂ max of 43-52 ml/min/kg and women typically have a VO₂ max of 33-42 ml/min/kg (Wilmore, Costill, & Kenney, 2008). It is likely these values are inflated since the VO₂ max testing protocol differed from the protocol used by Bulthuis and colleagues (2010). Bulthuis et al. (2010) utilized a six minute test that began at 25W at a cadence of 55-65 RPM and increased 5W every minute for the first three minutes. After three minutes, the resistance was maintained and the test continued for another three minutes with the goal of obtaining a steady state HR (maximum fluctuation of five bpm) within 60-85% of expected age predicted (220 – age) maximum HR by the sixth minute of the test. This protocol differs widely from the present study, making the predictive formula obtained perhaps invalid for the present study. Additionally, a study performed on army cadets using a treadmill VO₂ max test (Thomas, Lumpp, Schreiber, & Keith, 2004) found a VO₂ max among males of the study at 49.6 ml/min/kg and females at 40.8 ml/min/kg. Considering the emphasis on physical training among army cadets, this supports the notion that the equation developed by Bulthuis et al. (2010) is not valid for the present study. Comparing VO₂ max data in the present study to other data is difficult because the little research on the arm ergometer as a tool for testing maximal aerobic capacity. However, VO₂ max scores are similar to those found by McAuslan (2013) who found a mean VO₂ max in males and females of 35.07 ml/kg/min and 33.5 ml/kg/min, respectively. More research needs to be done on arm ergometer VO₂ max testing and alternate protocols in order to infer VO₂ max scores on the arm ergometer to whole body VO₂ max measures.
Most literature (Borgdanis et al., 1996; Draper, Bird, Coleman, & Hodgson, 2006; Heyman et al., 2009; Spierer et al., 2004; Toubekis et al., 2008) indicates that active (vs. passive) recovery leads to a higher HR during submaximal exercise. This was also the case with the current study, however, when looking at %MHR immediately post-HIIT interval, significantly higher %MHR was found in the passive (vs. active) recovery groups regardless of training status for both male and female participants during the 60 second rest interval HIIT workout. Lower post-HIIT interval %MHR and higher pre-HIIT interval %MHR among active recovery participants regardless of training status was also the case for the 120 second rest interval HIIT workout for both genders. This was surprising given that active recovery participants %MHR was higher than passive recovery participants during mid recovery (during 120 second rest interval workout) and pre-HIIT interval. Although this difference in %MHR was seen in both trained and untrained participants, trained active male participants were working at a lower %MHR compared to untrained active participants. Additionally, trained passive participants were working at a lower %MHR compared to untrained passive participants. This could suggest higher working intensity among untrained (vs. trained) male participants. Interestingly, the effect of training status and recovery strategy was not seen in %MHR of female participants. This leads to the possibility that trained male participants were beginning to plateau and/or adapted to the workload. Although McAuslan (2013) found no statistical difference in peak HR from pre- and post-training program in males and females, it was noted that a progressive model should be used when utilizing battling rope HIIT program, in particular with male participants who typically begin an upper body training program with more upper body strength and muscular endurance. The
statistical difference in %MHR between trained and untrained males supports the notion that a progressive model should be incorporated in a battling rope HIIT program.

Regarding the differences in %MHR and recovery strategy, there may be an increased performance capacity among active recovery participants for both genders since post-HIIT interval %MHR is lower among active recovery groups. However, according to the performance measures used in the present study, there were no differences in performance that would suggest this. Although age was used in order to predict %MHR (see Data Analysis), the Karvonen Formula where resting heart rate is measured and included in the formula could have been used to get a more accurate representation of intensity when analyzing HR of participants and may have revealed further interactions between HR, recovery strategy, and training status. It would have also been possible to incorporated absolute HR, however, it was felt that using %MHR would be a more accurate reflection of intensity given there is a ten year age difference between participants. A percentage of peak HR obtained during the VO\textsubscript{2} max testing was not used due to low peak HR values obtained. This is due to the VO\textsubscript{2} max test being upper body dominant. Due to the smaller vasculature and resulting cardiac output, a lower peak HR value was observed compared to a whole body or lower body VO\textsubscript{2} max test. Additionally, different performance measures could have been employed to highlight the differences in HR and any changes in performance. With the present study, it appears this lower post-HIIT interval HR among active recovery male participants does not influence any differences in performance.

Based on the results of the present study, intrasession active recovery performed at 20% of maximum wattage on an arm ergometer does not have a positive or negative
effect on performance. Nevertheless, the present study has practical implications for the strength and conditioning professional. For example, if the goal is to burn as many calories as possible in the workout, which is often the case when performing HIIT with short rest intervals, active recovery at a submaximal intensity may be employed without sacrificing performance. Based on the present study, active recovery for either 60 or 120 seconds at 20% of maximum wattage can be utilized without sacrificing performance. Additionally, having a rest interval length of two minutes has the same impact on performance as one minute and does not appear to impact perceived exertion. The present study suggests that utilizing upper body active recovery for an upper body dominant exercise, such as battling rope training, will have little implications on performance but will enhance metabolic washout when compared to passive recovery, though this may not be as evident when compared to lower body active recovery. Future research should examine other forms of active recovery and/or performance measures during battling rope training in order to have a complete understanding of the possible performance differences with lower body recovery strategies when using the battling rope as a workout tool as well as further explore the role of lactate in fatigue.
REFERENCES


Table 1. Summary of mean (±SD) pre- and post-HIIT workout push up repetitions until failure using a 60 second rest interval HIIT workout among males

<table>
<thead>
<tr>
<th>Group</th>
<th>Pushups</th>
<th>Pushup%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males, n= 19</td>
<td>Pre</td>
<td>37.7 (3.6)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>30.5 (4.1)</td>
</tr>
<tr>
<td>Active Trained n= 4</td>
<td>Pre</td>
<td>48 (21.2)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>37.0 (14.3)</td>
</tr>
<tr>
<td>Active Untrained, n= 5</td>
<td>Pre</td>
<td>41.0 (20.3)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>38.8 (29.2)</td>
</tr>
<tr>
<td>Passive Trained, n= 5</td>
<td>Pre</td>
<td>32.0 (10.0)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>22.6 (8.9)</td>
</tr>
<tr>
<td>Passive Untrained, n = 5</td>
<td>Pre</td>
<td>29.8 (8.7)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>23.6 (10.9)</td>
</tr>
</tbody>
</table>

Notes. Active refers to active recovery whereas passive refers to passive recovery. Active recovery was performed at 20% of maximum wattage of each participant. Passive recovery included sitting idle during recovery time. Push up% percentage of pre-workout push ups to post-workout push ups.

Values are mean (± SD)

Pre-performance push ups vs. post-performance push ups *p < .05
<table>
<thead>
<tr>
<th>Group</th>
<th>Push ups</th>
<th>Push up%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females, $n = 21$</td>
<td>Pre</td>
<td>38.5 (2.9)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>33.0 (2.8)</td>
</tr>
<tr>
<td>Active Trained, $n = 6$</td>
<td>Pre</td>
<td>48.83 (8.86)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>35.0 (12.8)</td>
</tr>
<tr>
<td>Active Untrained, $n = 5$</td>
<td>Pre</td>
<td>39.6 (14.0)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>34.6 (16.4)</td>
</tr>
<tr>
<td>Passive Trained, $n = 5$</td>
<td>Pre</td>
<td>41.0 (19.4)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>33.0 (12.1)</td>
</tr>
<tr>
<td>Passive Untrained, $n = 5$</td>
<td>Pre</td>
<td>32.4 (7.1)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>29.2 (8.4)</td>
</tr>
</tbody>
</table>

*Notes.* Active refers to active recovery whereas passive refers to passive recovery. Active recovery was performed at 20% of maximum wattage of each participant. Passive recovery included sitting idle during recovery time. Push up% percentage of pre-workout sit ups to post-workout push ups. Values are mean ($\pm$ SD). Pre-performance push ups vs. post-performance push ups *$p < .05$
Table 3. Summary of mean (±SD) pre- and post-HIIT workout push up repetitions until failure using a 120 second rest interval HIIT workout among males

<table>
<thead>
<tr>
<th>Group</th>
<th>Push ups</th>
<th>Push up%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males, n= 19</td>
<td>Pre</td>
<td>36.7 (3.4)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>30.1 (3.3)</td>
</tr>
<tr>
<td>Active Trained, n= 4</td>
<td>Pre</td>
<td>46.8 (20.9)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>34.5 (12.3)</td>
</tr>
<tr>
<td>Active Untrained, n= 5</td>
<td>Pre</td>
<td>39.4 (17.4)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>35.2 (20.8)</td>
</tr>
<tr>
<td>Passive Trained, n= 5</td>
<td>Pre</td>
<td>31.8 (10.0)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>26.2 (9.6)</td>
</tr>
<tr>
<td>Passive Untrained, n = 5</td>
<td>Pre</td>
<td>29.0 (8.0)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>24.4 (10.9)</td>
</tr>
</tbody>
</table>

Notes. Active refers to active recovery whereas passive refers to passive recovery. Active recovery was performed at 20% of maximum wattage of each participant. Passive recovery included sitting idle during recovery time. Push up% percentage of pre-workout push ups to post-workout push ups. Values are mean (± SD) Pre-performance push ups vs. post-performance push ups **p < .001
Table 4. Summary of mean (±SD) pre- and post-HIIT workout push up repetitions until failure using a 120 second rest interval HIIT workout among females

<table>
<thead>
<tr>
<th>Group</th>
<th>Push ups</th>
<th>Push up%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females, n = 21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>39.7 (2.7)</td>
<td>82.1 (17.4)*</td>
</tr>
<tr>
<td>Post</td>
<td>32.5 (2.8)</td>
<td></td>
</tr>
<tr>
<td>Active Trained, n = 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>43.17 (10.93)</td>
<td>84.25 (23.73)</td>
</tr>
<tr>
<td>Post</td>
<td>37.5 (16.8)</td>
<td></td>
</tr>
<tr>
<td>Active Untrained, n = 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>37.6 (7.7)</td>
<td>78.93 (12.8)</td>
</tr>
<tr>
<td>Post</td>
<td>30.2 (10.3)</td>
<td></td>
</tr>
<tr>
<td>Passive Trained, n = 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>46.2 (20.1)</td>
<td>82.72 (19.5)</td>
</tr>
<tr>
<td>Post</td>
<td>36.6 (13.7)</td>
<td></td>
</tr>
<tr>
<td>Passive Untrained, n = 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>31.8 (6.8)</td>
<td>82.23 (15.7)</td>
</tr>
<tr>
<td>Post</td>
<td>25.6 (5.1)</td>
<td></td>
</tr>
</tbody>
</table>

Notes. Active refers to active recovery whereas passive refers to passive recovery. Active recovery was performed at 20% of maximum wattage of each participant. Passive recovery included sitting idle during recovery time. Push up% percentage of pre-workout push ups to post-workout push ups. Values are mean (± SD). Pre-performance push ups vs. post-performance push ups *p < .05
Table 5. Summary of mean (±SD) pre- and post-HIIT workout maximum sit up repetitions for one minute using a 60 second rest interval HIIT workout among males

<table>
<thead>
<tr>
<th>Group</th>
<th>Sit ups</th>
<th>Sit up%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male, n = 19</td>
<td>Pre</td>
<td>41.4 (2.2)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>38.5 (1.7)</td>
</tr>
<tr>
<td>Active Trained, n = 4</td>
<td>Pre</td>
<td>47.5 (15.93)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>40.8 (9.64)</td>
</tr>
<tr>
<td>Active Untrained, n = 5</td>
<td>Pre</td>
<td>37.8 (5.9)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>38.0 (5.6)</td>
</tr>
<tr>
<td>Passive Trained, n = 5</td>
<td>Pre</td>
<td>40.2 (9.5)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>37.8 (9.5)</td>
</tr>
<tr>
<td>Passive Untrained, n = 5</td>
<td>Pre</td>
<td>40.0 (3.8)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>37.6 (3.9)</td>
</tr>
</tbody>
</table>

Notes. Active refers to active recovery whereas passive refers to passive recovery. Active recovery was performed at 20% of maximum wattage of Each participant. Passive recovery included sitting idle during recovery time. Sit up% percentage of pre-workout sit ups to post-workout sit ups. Values are mean (± SD) Pre-performance sit ups vs. post-performance sit ups *p < .05
Table 6. Summary of mean (±SD) pre- and post-HIIT workout maximum sit up repetitions for one minute using a 60 second rest interval HIIT workout among females

<table>
<thead>
<tr>
<th>Group</th>
<th>Sit ups</th>
<th>Sit up%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td></td>
</tr>
<tr>
<td>Female, n = 21</td>
<td>37.2 (1.9)</td>
<td>95.5 (9.5)*</td>
</tr>
<tr>
<td>Post</td>
<td>35.9 (2.0)</td>
<td></td>
</tr>
<tr>
<td>Active Trained, n = 6</td>
<td>39.5 (8.5)</td>
<td>93.3 (4.0)**</td>
</tr>
<tr>
<td>Post</td>
<td>36.8 (8.1)</td>
<td></td>
</tr>
<tr>
<td>Active Untrained, n = 5</td>
<td>38.4 (4.6)</td>
<td>99.8 (6.9)**</td>
</tr>
<tr>
<td>Post</td>
<td>38.4 (6.2)</td>
<td></td>
</tr>
<tr>
<td>Passive Trained, n = 5</td>
<td>31.2 (9.7)</td>
<td>88.1 (15.4)**</td>
</tr>
<tr>
<td>Post</td>
<td>28.4 (11.1)</td>
<td></td>
</tr>
<tr>
<td>Passive Untrained, n = 5</td>
<td>39.6 (11.4)</td>
<td>101.2 (3.7)**</td>
</tr>
<tr>
<td>Post</td>
<td>40.0 (11.0)</td>
<td></td>
</tr>
</tbody>
</table>

Notes. Active refers to active recovery whereas passive refers to passive recovery. Active recovery was performed at 20% of maximum wattage of each participant. Passive recovery included sitting idle during recovery time. Sit up% percentage of pre-workout sit ups to post-workout sit ups. Values are mean (± SD)

Pre-performance sit ups vs. post-performance sit ups *p < .05
Trained vs Untrained **p < .05
Table 7. Summary of mean (±SD) pre- and post-HIIT workout maximum sit up repetitions for one minute using a 120 second rest interval HIIT workout among males

<table>
<thead>
<tr>
<th>Group</th>
<th>Sit ups</th>
<th>Sit up%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male, n = 19</td>
<td>40.9 (2.0)</td>
<td>91.7 (10.6)*</td>
</tr>
<tr>
<td></td>
<td>37.7 (2.3)</td>
<td></td>
</tr>
<tr>
<td>Active Trained, n = 4</td>
<td>45.5 (13.9)</td>
<td>94.9 (13.2)</td>
</tr>
<tr>
<td></td>
<td>43.8 (18.0)</td>
<td></td>
</tr>
<tr>
<td>Active Untrained, n = 5</td>
<td>36.4 (6.0)</td>
<td>95.7 (9.2)</td>
</tr>
<tr>
<td></td>
<td>34.8 (6.5)</td>
<td></td>
</tr>
<tr>
<td>Passive Trained, n = 5</td>
<td>41.4 (8.9)</td>
<td>83.8 (7.7)</td>
</tr>
<tr>
<td></td>
<td>35.0 (9.1)</td>
<td></td>
</tr>
<tr>
<td>Passive Untrained, n = 5</td>
<td>40.2 (4.2)</td>
<td>93.2 (10.9)</td>
</tr>
<tr>
<td></td>
<td>37.2 (3.3)</td>
<td></td>
</tr>
</tbody>
</table>

Notes. Active refers to active recovery whereas passive refers to passive recovery. Active recovery was performed at 20% of maximum wattage of each participant. Passive recovery included sitting idle during recovery time. Sit up% percentage of pre-workout sit ups to post-workout sit ups. Values are mean (± SD) Pre-performance sit ups vs. post-performance sit ups *p < .05
Table 8. Summary of mean (±SD) pre- and post-HIIT workout maximum sit up repetitions for one minute using a 120 second rest interval HIIT workout among females

<table>
<thead>
<tr>
<th>Group</th>
<th>Sit ups</th>
<th>Sit ups%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female, n = 21</td>
<td>Pre</td>
<td>36.6 (2.1)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>35.8 (2.1)</td>
</tr>
<tr>
<td>Active Trained, n = 6</td>
<td>Pre</td>
<td>38.3 (8.1)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>35.8 (9.2)</td>
</tr>
<tr>
<td>Active Untrained, n = 5</td>
<td>Pre</td>
<td>39.0 (5.3)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>38.0 (5.7)</td>
</tr>
<tr>
<td>Passive Trained, n = 5</td>
<td>Pre</td>
<td>31.0 (11.3)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>31.6 (10.6)</td>
</tr>
<tr>
<td>Passive Untrained, n = 5</td>
<td>Pre</td>
<td>38.0 (11.6)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>37.8 (12.5)</td>
</tr>
</tbody>
</table>

Notes. Active refers to active recovery whereas passive refers to passive recovery. Active recovery was performed at 20% of maximum wattage of each participant. Passive recovery included sitting idle during recovery time. Sit up% percentage of pre-workout sit ups to post-workout sit ups. Values are mean (± SD)
Table 9. Summary of mean (±SD) blood lactate among male participants using a 60 second rest interval battling rope HIIT workout

<table>
<thead>
<tr>
<th>Group</th>
<th>60s rest workout</th>
<th>Blood Lactate mmol/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active, n= 9</td>
<td>RL</td>
<td>1.623 (.209)</td>
</tr>
<tr>
<td></td>
<td>IL</td>
<td>9.600 (.684)*</td>
</tr>
<tr>
<td></td>
<td>PL</td>
<td>8.528 (.660)*</td>
</tr>
<tr>
<td>Passive, n = 10</td>
<td>RL</td>
<td>1.74 (.197)</td>
</tr>
<tr>
<td></td>
<td>IL</td>
<td>9.100 (.645)*</td>
</tr>
<tr>
<td></td>
<td>PL</td>
<td>10.14 (.622)*</td>
</tr>
<tr>
<td>Active Trained n= 4</td>
<td>RL</td>
<td>1.525 (.818)</td>
</tr>
<tr>
<td></td>
<td>IL</td>
<td>8.000 (1.744)**</td>
</tr>
<tr>
<td></td>
<td>PL</td>
<td>7.775 (2.001)**</td>
</tr>
<tr>
<td>Active Untrained, n= 5</td>
<td>RL</td>
<td>1.720 (.726)</td>
</tr>
<tr>
<td></td>
<td>IL</td>
<td>11.200 (.771)**</td>
</tr>
<tr>
<td></td>
<td>PL</td>
<td>9.280 (.896)**</td>
</tr>
<tr>
<td>Passive Trained, n= 5</td>
<td>RL</td>
<td>1.440 (.546)</td>
</tr>
<tr>
<td></td>
<td>IL</td>
<td>9.180 (3.025)**</td>
</tr>
<tr>
<td></td>
<td>PL</td>
<td>9.460 (2.989)**</td>
</tr>
<tr>
<td>Passive Untrained, n = 5</td>
<td>RL</td>
<td>2.040 (.351)</td>
</tr>
<tr>
<td></td>
<td>IL</td>
<td>9.100 (2.378)**</td>
</tr>
<tr>
<td></td>
<td>PL</td>
<td>10.820 (1.331)**</td>
</tr>
</tbody>
</table>

Notes. Active refers to active recovery (performed at 20% of maximum wattage of participant) whereas passive refers to passive recovery (sitting idle during recovery time). RL refers to lactate measure taken before HIIT workout after 5 minutes rest. IL refers to lactate measure taken immediately post-HIIT workout. PL refers to lactate measure taken 5 minutes after HIIT workout. Active vs Passive * p < .05. Trained vs. Untrained **p < .08
**Table 10. Summary of mean (±SD) blood lactate among female participants using a 60 second rest interval battling rope HIIT workout.**

<table>
<thead>
<tr>
<th>Group</th>
<th>60s rest workout</th>
<th>Blood Lactate mmol/L</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RL</td>
<td>1.507 (.155)</td>
</tr>
<tr>
<td>Active, n = 11</td>
<td>IL</td>
<td>8.972 (.508)</td>
</tr>
<tr>
<td></td>
<td>PL</td>
<td>7.693 (.581)</td>
</tr>
<tr>
<td>Passive, n = 10</td>
<td>RL</td>
<td>1.870 (.161)</td>
</tr>
<tr>
<td></td>
<td>IL</td>
<td>9.520 (.530)</td>
</tr>
<tr>
<td></td>
<td>PL</td>
<td>9.220 (.607)</td>
</tr>
<tr>
<td>Active Trained, n = 6</td>
<td>RL</td>
<td>1.533 (.463)</td>
</tr>
<tr>
<td></td>
<td>IL</td>
<td>8.783 (.937)</td>
</tr>
<tr>
<td></td>
<td>PL</td>
<td>7.067 (1.894)</td>
</tr>
<tr>
<td>Active Untrained, n = 5</td>
<td>RL</td>
<td>1.480 (.259)</td>
</tr>
<tr>
<td></td>
<td>IL</td>
<td>9.160 (1.948)</td>
</tr>
<tr>
<td></td>
<td>PL</td>
<td>8.320 (2.033)</td>
</tr>
<tr>
<td>Passive Trained, n = 5</td>
<td>RL</td>
<td>1.900 (.652)</td>
</tr>
<tr>
<td></td>
<td>IL</td>
<td>11.280 (1.798)</td>
</tr>
<tr>
<td></td>
<td>PL</td>
<td>10.340 (2.097)</td>
</tr>
<tr>
<td>Passive Untrained, n = 5</td>
<td>RL</td>
<td>1.840 (.590)</td>
</tr>
<tr>
<td></td>
<td>IL</td>
<td>7.760 (1.958)</td>
</tr>
<tr>
<td></td>
<td>PL</td>
<td>8.100 (1.619)</td>
</tr>
</tbody>
</table>

**Notes.** Active refers to active recovery whereas passive refers to passive recovery. Active recovery was performed at 20% of maximum wattage of participant. Passive recovery included sitting idle during recovery time. RL refers to resting lactate measure taken before HIIT workout after 5 minutes of passive rest. IL refers to lactate measure taken immediately post-HIIT workout. PL refers to lactate measure taken 5 minutes after HIIT workout.
Table 11. Summary of mean (±SD) blood lactate among male participants using a 120 second rest interval battling rope HIIT workout

<table>
<thead>
<tr>
<th>Group</th>
<th>120s rest workout</th>
<th>Blood Lactate mmol/L</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RL</td>
<td>IL</td>
</tr>
<tr>
<td>Active, n= 9</td>
<td>1.747 (.133)</td>
<td>9.290 (.522)</td>
</tr>
<tr>
<td>Passive, n = 10</td>
<td>1.84 (.125)</td>
<td>9.720 (.492)</td>
</tr>
<tr>
<td>Active Trained n= 4</td>
<td>1.775 (.340)</td>
<td>8.200 (2.128)</td>
</tr>
<tr>
<td>Active Untrained, n= 5</td>
<td>1.720 (.311)</td>
<td>10.380 (.432)</td>
</tr>
<tr>
<td>Passive Trained, n= 5</td>
<td>1.780 (.630)</td>
<td>9.580 (2.171)</td>
</tr>
<tr>
<td>Passive Untrained, n = 5</td>
<td>1.900 (.071)</td>
<td>9.860 (.885)</td>
</tr>
</tbody>
</table>

Notes. Active refers to active recovery whereas passive refers to passive recovery. Active recovery was performed at 20% of maximum wattage of participant. Passive recovery included sitting idle during recovery time. RL refers to resting lactate measure before HIIT workout after 5 minutes of passive rest. IL refers to lactate measure taken immediately post-HIIT workout. PL refers to lactate measure taken 5 minutes after HIIT workout.
Table 12. Summary of mean (±SD) blood lactate among female participants during a 120 second rest interval battling rope HIIT workout

<table>
<thead>
<tr>
<th>Group</th>
<th>120s rest workout</th>
<th>Blood Lactate mmol/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females, Active, n = 11</td>
<td>RL</td>
<td>1.443 (.154)</td>
</tr>
<tr>
<td></td>
<td>IL</td>
<td>8.365 (.658)*</td>
</tr>
<tr>
<td></td>
<td>PL</td>
<td>6.373 (.484)*</td>
</tr>
<tr>
<td>Females, Passive, n = 10</td>
<td>RL</td>
<td>1.79 (.161)</td>
</tr>
<tr>
<td></td>
<td>IL</td>
<td>9.19 (.688)*</td>
</tr>
<tr>
<td></td>
<td>PL</td>
<td>8.800 (.505)*</td>
</tr>
<tr>
<td>Active Trained, n = 6</td>
<td>RL</td>
<td>1.467 (.532)</td>
</tr>
<tr>
<td></td>
<td>IL</td>
<td>8.050 (2.568)* †</td>
</tr>
<tr>
<td></td>
<td>PL</td>
<td>5.867 (1.623)* †</td>
</tr>
<tr>
<td>Active Untrained, n = 5</td>
<td>RL</td>
<td>1.420 (.286)</td>
</tr>
<tr>
<td></td>
<td>IL</td>
<td>8.680 (1.878)* †</td>
</tr>
<tr>
<td></td>
<td>PL</td>
<td>6.880 (1.481)* †</td>
</tr>
<tr>
<td>Passive Trained, n = 5</td>
<td>RL</td>
<td>1.820 (.756)</td>
</tr>
<tr>
<td></td>
<td>IL</td>
<td>10.420 (2.321)* †</td>
</tr>
<tr>
<td></td>
<td>PL</td>
<td>10.320 (2.054)* †</td>
</tr>
<tr>
<td>Passive Untrained, n = 5</td>
<td>RL</td>
<td>1.760 (.297)</td>
</tr>
<tr>
<td></td>
<td>IL</td>
<td>7.960 (1.713)* †</td>
</tr>
<tr>
<td></td>
<td>PL</td>
<td>7.280 (1.066)* †</td>
</tr>
</tbody>
</table>

Notes. Active refers to active recovery whereas passive refers to passive recovery. Active recovery was performed at 20% of maximum wattage of participant. Passive recovery included sitting idle during recovery time. RL refers to resting lactate measure before HIIT workout after 5 minutes of passive rest. IL refers to lactate measure taken immediately post-HIIT workout. PL refers to lactate measure taken 5 minutes after HIIT workout. Active vs. Passive *p < .05, Trained vs. Untrained †p < .05
Table 13. Summary of male mean (±SD) heart rate data pre- and post-HIIT interval as dictated by recovery strategy and training status during the 60 second rest interval HIIT workout

<table>
<thead>
<tr>
<th>Recovery Status</th>
<th>HR Measure</th>
<th>Mean %MHR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active n=9</td>
<td>1</td>
<td>65.5 (1.7)*</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>68.4 (2.5)**</td>
</tr>
<tr>
<td>Trained n=4</td>
<td>1</td>
<td>81.7 (.9)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>66.2 (3.7)</td>
</tr>
<tr>
<td>Untrained n=5</td>
<td>1</td>
<td>88.3 (.8)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>70.7 (3.3)</td>
</tr>
<tr>
<td>Passive n=10</td>
<td>1</td>
<td>87.7 (.6)**</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>62.5 (2.3)**</td>
</tr>
<tr>
<td>Trained n=5</td>
<td>1</td>
<td>84.7 (.8)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>59.0 (3.3)</td>
</tr>
<tr>
<td>Untrained n=5</td>
<td>1</td>
<td>90.8 (.8)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>66.0 (3.3)</td>
</tr>
</tbody>
</table>

Notes. Active refers to active recovery whereas passive refers to passive recovery. HR Measure refers to the measuring point of HR (i.e., 1 refers to post-HIIT interval and 2 refers to pre-HIIT interval). Values are mean (±SD).

Pre- vs. post-HIIT interval *p < .001
Active vs. passive recovery **p < .05
Table 14. Summary of female mean (±SD) heart rate data pre- and post-HIIT interval as dictated by recovery strategy and training status during the 60 second rest interval HIIT workout

<table>
<thead>
<tr>
<th>Recovery Status</th>
<th>HR Measure</th>
<th>Mean %MHR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active n=11</td>
<td>1</td>
<td>86.3 (.5)**</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>69.8 (2.3)**</td>
</tr>
<tr>
<td>Trained n=6</td>
<td>1</td>
<td>84.2 (.6)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>67.5 (3.1)</td>
</tr>
<tr>
<td>Untrained n=5</td>
<td>1</td>
<td>88.4 (.7)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>72.2 (3.4)</td>
</tr>
<tr>
<td>Passive n=10</td>
<td>1</td>
<td>88.3 (.5)**</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>64.9 (2.4)**</td>
</tr>
<tr>
<td>Trained n=5</td>
<td>1</td>
<td>89.6 (.7)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>65.8 (3.4)</td>
</tr>
<tr>
<td>Untrained n=5</td>
<td>1</td>
<td>87.1 (.7)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>64.0 (3.4)</td>
</tr>
</tbody>
</table>

Notes. Active refers to active recovery whereas passive refers to passive recovery. HR Measure refers to the measuring point of HR (i.e., 1 refers to post-HIIT interval, 2 refers to pre-HIIT interval). Values are mean (±SD). Pre- vs. post-HIIT interval *p < .001 Active vs. passive recovery **p < .05
Table 15. Summary of male mean (±SD) heart rate data pre-, mid-
recovery, and post-HIIT interval as dictated by recovery strategy and
training status during the 120 second rest interval HIIT workout

<table>
<thead>
<tr>
<th>Recovery Status</th>
<th>HR Measure</th>
<th>Mean % MHR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active n=9</td>
<td>1</td>
<td>85.8 (.5)**</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>69.0 (2.4)**</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>64.4 (2.2)**</td>
</tr>
<tr>
<td>Trained n=4</td>
<td>1</td>
<td>83.5 (.7)¹</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>68.1 (3.5)¹</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>63.2 (3.2)¹</td>
</tr>
<tr>
<td>Untrained n=5</td>
<td>1</td>
<td>88.2 (.7)¹</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>70.0 (3.2)¹</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>65.6 (2.9)¹</td>
</tr>
<tr>
<td>Passive n=10</td>
<td>1</td>
<td>86.5 (.5)**</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>59.5 (2.2)**</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>53.7 (2.0)**</td>
</tr>
<tr>
<td>Trained n=5</td>
<td>1</td>
<td>84.5 (.7)¹</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>56.1 (3.2)¹</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>51.4 (2.9)¹</td>
</tr>
<tr>
<td>Untrained n=5</td>
<td>1</td>
<td>88.6 (.7)¹</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>62.9 (3.2)¹</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>56.1 (2.9)¹</td>
</tr>
</tbody>
</table>

Notes. Active refers to active recovery whereas passive refers to passive
recovery. HR Measure refers to the measuring point of HR (i.e., 1 refers to
post-HIIT interval, 2 refers to 60 seconds into recovery, 3 refers to pre-
HIIT interval).
Values are mean (±SD).
Active vs. passive recovery **p < .05
Trained vs. Untrained ¹ p < .05
Table 16. Summary of female mean (±SD) heart rate data pre-, mid-recovery, and post-HIIT interval as dictated by recovery strategy and training status during the 120 second rest interval HIIT workout

<table>
<thead>
<tr>
<th>Recovery Status</th>
<th>HR Measure</th>
<th>Mean %MHR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active n=11</td>
<td>1</td>
<td>84.2 (.5)**</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>66.8 (2.2)**</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>62.5 (2.0)**</td>
</tr>
<tr>
<td>Trained n=6</td>
<td>1</td>
<td>81.6 (.7)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>65.2 (3.0)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>61.6 (2.8)</td>
</tr>
<tr>
<td>Untrained n=5</td>
<td>1</td>
<td>86.7 (.8)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>68.4 (3.2)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>63.3 (3.0)</td>
</tr>
<tr>
<td>Passive n=10</td>
<td>1</td>
<td>87.2 (.5)**</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>58.7 (2.3)**</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>52.6 (2.1)**</td>
</tr>
<tr>
<td>Trained n=5</td>
<td>1</td>
<td>88.1 (.8)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>57.9 (3.2)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>51.8 (3.0)</td>
</tr>
<tr>
<td>Untrained n=5</td>
<td>1</td>
<td>86.3 (.8)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>59.5 (3.2)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>53.3 (3.0)</td>
</tr>
</tbody>
</table>

Notes. Active refers to active recovery whereas passive refers to passive recovery. HR Measure refers to the measuring point of HR (i.e., 1 refers to post-HIIT interval, 2 refers to 60 seconds into recovery, 3 refers to pre-HIIT interval). Values are mean (±SD). Pre- vs. post-HIIT interval *p < .001 Active vs. passive recovery **p < .05
Figure 1: Participant randomization. Two testing sessions randomized and counterbalanced using 60 second rest intervals and 120 second rest intervals.
**Figure 2.** Testing session schedule. () indicates blood lactate measure. High intensity interval training (HIIT) included 10 intervals alternating between alternate whip (5 intervals) and double whip style (5 intervals) of battling rope exercise with 60 second and 120 second rest intervals (the order dependent on random selection). Intervals performed as fast as possible. Warm up consists of 20 jumping jacks, 10 arm circles each way, 10 stick ups, 10 lunges, and 10 push ups. Max push ups performed until failure while max sit ups performed as many repetitions as possible in one minute.
Figure 3. RPE post HIIT interval during 60 second rest interval workout among males. Male (n=19) RPE on scale of 1-10 rated immediately post-HIIT interval during the 60 second rest interval workout. Increase over time, *p < .001
Figure 4. RPE post HIIT interval during 120 second rest interval workout among males. Male (n=19) RPE on scale of 1 – 10 rated immediately post-HIIT interval during the 120 second rest interval workout. Increase over time, *p < .001
Figure 5. RPE post HIIT interval during 60 second rest interval workout among females. Female (n=21) RPE on scale of 1-10 rated immediately post-HIIT interval during the 60 second rest interval workout. Increase over time, *p < .001
Figure 6. RPE post HIIT interval during 120 second rest interval workout among females. Female (n=21) RPE on scale of 1 – 10 rated immediately post-HIIT interval during the 120 second rest interval workout. Increase over time, *p < .05 trained vs. untrained, active vs. passive, ŵp < .05
CHAPTER 2
REVIEW OF LITERATURE

Introduction

When examining exercise science literature, there is a wealth of conflicting and often confusing information. Many opposing schools of thought exist when discussing many training principles, from most effective warm ups to proper cool down procedures and everything in between. The strength and conditioning professional is forced to read and critically analyze a wide variety of literature and rely on experience in order to understand what works best for their clients. There has been a paradigm shift in recent years regarding functional training and warm up routines, with an emphasis on sport specific movements and dynamic stretching replacing old school models consisting of static stretching. We are getting a better understanding of what works well in a warm up in order to maximize performance and increase power and strength, but little is known how to maximize power and strength gains during the workout itself. Although there is much literature focusing on repetition ranges, periodization, plyometrics, etc. to increase these two fitness parameters, there is little information on interset recovery in order to maximize fitness gains. That is, what can an athlete do in between sets of resistance exercise in order to maximize performance in following sets? In addition to this question, new forms of exercise are gaining popularity with strength coaches and personal trainers in an effort to increase the functionality of a training program. Examples include battling rope and kettlebells. Although many fitness enthusiasts swear by these new methods, little literature presently exists on the effectiveness of these new modes of resistance training.
In the following review of literature, the impact resistance training has on performance will be examined as well as some of these new anaerobic training methods. For if there is no performance or health benefits to these forms of exercise then interset recovery is moot. Mechanisms of anaerobic fatigue, which will lead into research discussing recovery and more specifically, interset recovery, will all be examined.

Resistance Training

In today’s society that is obsessed with the ideal body and celebrates those in peak physical shape, it is hard to believe that resistance training was once frowned upon; especially in the world of sports where competition leads to a win at all cost attitude. This mentality has been highlighted in a poll featured in Sport Illustrated (Goldman & Klatz, 1992) where a group of 198 Olympic caliber athletes were asked if they would take a drug that would guarantee they would win their event for the next five years but cause an early death. More than half said they would (Bamberger & Yaeger, 1997). Although this article is examining psychology of steroid abuse in sport, it also shows that elite athletes will do almost anything to improve performance. Early in the 20th century, resistance training was seen to inhibit performance (Kraemer, Duncan, & Volek, 1998). It wasn’t until post World War II that literature began to examine the benefits of resistance training. With soldiers returning home from the war, resistance training was seen as a tool for rehabilitation (Delorme & Watkins, 1948). Prior to this, literature was focused on animal participants using impractical methods (MacQueen, 1954). Scientists of this time were able to apply these methods to athletes and noticed that Olympic athletes of the day that excelled tended to incorporate resistance training into their athletic training.
Even in the 1950s, early exercise physiologists recognized a resistance training program was not as simple as lifting a weight in a repetitive fashion. What we see from the early resistance training literature is the concept of progressive resistance training (Delorme & Watkins, 1948; MacQueen, 1954); the idea of manipulating resistance training variables, such as load, in order to accomplish training goals. Progressive resistance training aside, there are many variables to consider. These variables have been expanded over the years and are outlined in the American College of Sport Medicine (ACSM) latest position stand on resistance training for healthy adults (ACSM, 2009). The position paper describes the importance of many training principles including progression, periodization, muscular loading, volume, exercise selection, exercise order, velocity of exercises, sport specific exercises, agility, and rest periods. This paper was meant to be an extensive review of resistance training and a resource for the strength and conditioning professional. However it is not without controversy. According to a critical analysis of the 2002 edition of the ACSM position paper, many of the claims offered by the ACSM were unsubstantiated (Carpinelli, Otto, & Winett, 2004). Although this was a critique of the previous edition of the ACSM position stand on resistance training (2002), much of what was criticized was largely unchanged in the recent edition. In particular, the current ACSM position states that novice, intermediate, and advanced resistance trainers needs differ greatly from one another in terms of resistance training program prescription and application of training principles. This highlights the inability of exercise science literature to reach consensus on a variety of fitness topics.

In order to help answer the debate on whether or not the novice trainer needs differ greatly to the advanced trainer and perhaps differing interset recovery strategies,
we must delve deeper into the literature. First of all, how is the beginner trainer distinguished from the advanced trainer? The ACSM (American College of Sport, 2009) considers individuals who are new to resistance training as beginners; those who have been using resistance training regularly for six months intermediates; and those who resistance trained on a consistent basis for years with significant improvements as advanced trainers. This is where some argue on how these types of trainers are distinguished (Carpinelli et al., 2004). First let us consider differences between the trained and untrained resistance exerciser. It is known that strength increases associated with chronic resistance training is not only due to hypertrophy, but neural mechanisms as well (Moritani, & deVries, 1979). When examining a weighted knee extension exercise over a 60 day period, researchers found that the rise in electro-myographic activity (EMG) accounted for the unexplained increase in maximum voluntary force that couldn’t be explained by lack of the increased of cross sectional area of the quadriceps (Narici, Roi, Landoni, Minetti, & Cerretelli, 1989). Because there is little increase in cross sectional area of the muscle during the first initial weeks of training, it can be assumed that the initial increase in strength is due to neural factors in untrained individuals (Fleck, 1999). These initial strength increases are typically much greater than that is seen in a trained individual in the same amount of time; as much as 10% increase or more in strength in the untrained individual (Hakkinen, 1985). The increase in neural activation, as pointed out by Fleck (1999), with training is further exemplified by pre- and adolescent resistance training. One study found that pre-pubescent children can increase their isotonic strength as much as 22.6% in eight weeks of training (Ozmun, Mikesky, & Surburg, 1994). There was no increase in the cross sectional area of the working muscle
in the study, however, there was a 16.8% increase in EMG amplitude. These findings support the importance of neural activation in untrained individuals. Another study (Schiotz, Potteiger, Huntsinger, & Denmark, 1998) examining different training protocols on reserve officer training corps found increase of 8.3% and 5.0% increase in bench press strength across the two tested protocols, respectively, and a 9.7% and 11.7% in squat strength, respectively over a ten week period. The participants in this study were predominantly trained for cardiovascular endurance and had limited resistance training experience. When we compare studies done on elite and advanced individuals in terms of resistance training experience, a different picture emerges. One study (Hakkinen, Komi, Alen, & Kauhanen, 1987) examined training over the course of one year in 13 elite weight lifters, and reported that training protocol, as given by the strength coaches of the athletes, brought about small insignificant changes for the snatch and clean and jerk strength. In contrast with the quick gains shown in Schiotz et al. (1998) with untrained exercisers, the elite group had virtually no changes in strength over an entire training year. Although these findings do not necessarily warrant the increased categorization of beginner, intermediate, and advanced, they do support the separate categorization of the trained and untrained categories and perhaps an elite group as well. The ACSM position stand on resistance training for healthy adults (2009) argues that because untrained individuals respond well to nearly every resistance training intervention, largely due to neural factors; it is irresponsible to infer the results of an untrained sample to a resistance trained population.

As more research was done on the human body’s adaptation to resistance training, we now see a consensus that resistance training is beneficial even for sports that are not
physical in nature. A recent study examining the strength characteristics of tenpin bowlers found that elite bowlers had stronger forearm muscles when looking at internal rotation (Razman, Cheong, Wan Abas, & Abu Osmand, 2012). Although one could argue this is because of repetitive motion of bowling, enhancing the strength of these muscles through resistance training could only help a bowling athlete. It is no surprise that we see modern athletes across the sporting world participating in resistance training exercise. As pointed out in the ACSM position stand on resistance training for healthy adults (ACSM, 2009), resistance training can positively influence ones power, strength, muscular endurance, coordination, and agility, among others. This makes resistance training very attractive for athletes; be it recreational or professional.

An important element to a successful resistance training program is the concept of progression. The ACSM (ACSM, 2009) defines progression as “the act of moving forward or advancing toward a specific goal over time until the target goal has been achieved” (ACSM, 2009, p. 687). Kraemer & Ratamess (2004) describe progressive resistance training further as changing an exercise program in order to entice a new challenge on to the body and force the body to adapt to this new stimulus. The concept of progressive resistance training is broken down into three training principles: progressive overload, specificity, and variation. It is important to note the rest interval length can play a role in all three of these training principles.

Throughout the years of athletes participating in resistance training, we have seen a drastic change in the physical profile of the modern athlete. In a review of longitudinal changes to athletes playing for the Montreal Canadiens of the National Hockey League, it was found that players in 2003 were 17 kilograms heavier than that of players in the
1980s with an increased body mass index (BMI) of 2.3kg/m$^2$ (Montgomery, 2006). The researcher concluded that the increase in BMI was not due to increased fat mass since body fat percentage was largely unchanged since it was first measured in 1981. A caveat to the paradigm of today’s athletes being bigger and stronger than previous decades may be the athletes of the National Football League. Kraemer et al. (2005) reported offensive and defensive linemen to be significantly heavier than athletes of the 1970s, however, little difference exists among other positions. More literature is needed in this area to determine strength differences between today’s athletes compared to previous decades of various sports.

**New Forms of Resistance Training.** Training principles with respect to resistance training are constantly evolving as new forms of practices of resistance training modalities are often ahead of the literature. Two forms of resistance training that have become popular within the decade in North America are training with *kettlebells* and *battling ropes*. While the popularity of these two pieces of equipment is rising, there is little literature to quantify the results that the equipment can have with respect to physical conditioning.

Farrar, Mayhew, & Koch (2010) recently performed a study that examined kettlebells using an aerobic training protocol. Participants consisted of ten male college students, although they were recreationally trained, had no previous experience with kettlebells. The participants performed twelve minutes of two handed kettlebell swings for maximum repetitions using a 16 KG kettlebell. The study found that this protocol enabled participants to work at an intensity that would improve cardiorespiratory fitness. More specifically, researchers found that the workout enabled participants to work at a
percentage of heart rate and ventilation of oxygen (VO\textsubscript{2}) max that would illicit improvements in VO\textsubscript{2} max and resting heart rate over a chronic training program.

Another interesting study used kettlebells as a workplace health intervention (Jay et al., 2011). The study used 40 participants who came from occupations with high incidents of pain in the neck, shoulders, and lower back. The participants had a mean age of 44 years and were mostly women. Participants performed 10 intervals of 30 seconds with 30-60 seconds of rest, three times a week for eight weeks. The exercise performed was a one-handed kettlebell swing, though easier progressions were also implemented. The participants in the experimental group reported fewer pain incidents in the neck, shoulder, and back than the control group. Interestingly, aerobic conditioning did not improve in the experimental group. The intensity of the protocol in this study was much less intense than the Farrar et al. (2010) study, perhaps changes in the protocol to make the workout more intense could have brought about greater changes in aerobic conditioning.

There is little literature that discusses the benefits of many new forms of resistance training, such as battling rope and kettlebells. However, based on what literature there is, it seems that the above examples could be included appropriately in a resistance training program to further increase the anaerobic conditioning of exercisers. The vast majority of resistance training programs target the anaerobic energy systems of the body, the dominant energy system is often either the creatine phosphate system or the anaerobic glycolytic system. When training for power and strength, these are the energy systems that need to be trained. However, these systems are also the most susceptible to fatigue.
**Anaerobic Fatigue**

Fatigue can be defined as “an acute impairment of exercise performance that includes both an increase in the perceived effort necessary to exert a desired force or power output and the eventual inability to produce that force or power output” (Davis & Bailey, 1997, p. 47). When discussing fatigue in general with regards to exercise, there are two broad types: peripheral fatigue and central nervous system (CNS) fatigue. CNS fatigue deals with mechanisms of fatigue associated with the brain and spinal column, which likely plays a large role in chronic fatigue such as overtraining syndrome. Peripheral fatigue is associated with failure of the contraction process in the muscle itself. For the purpose of this paper, factors contributing to peripheral fatigue will be discussed more fully. Two factors that often contribute to peripheral fatigue, as discussed by Davis and Bailey (1997), are the accumulation of metabolic by-products and the lack of availability of metabolic substrates. When discussing anaerobic exercise, the metabolic by-product lactate often accumulates and the performance is dependent on substrates such as glycogen and creatine phosphate.

**Lactate Formation.** Muscle fatigue is often a major detriment in performance for the athlete or non-athlete as repeated muscular contractions are made during exercise (Allan & Westerblad, 2004). Generally speaking, those who fatigue later than those who fatigue sooner at the same intensity, are regarded to have better physical conditioning. It is interesting that we still do not have a complete understanding on the mechanisms of fatigue. Instead, literature on the topic of fatigue has led to a series of theories that usually build on one another. Obvious contributors to fatigue would be energy depletion, such as circulating glucose and glycogen depletion, and lactate formation.
Lactic acid, and subsequently lactate, accumulates during high intensity exercise with insufficient supply of oxygen (Sahlin, 1986). Lactic acid and lactate are often used interchangeably in the exercise world; however, they are not quite the same. Lactic acid is formed in the muscle first and releases hydrogen ions which either forms with sodium or potassium ions. This is a result of pyruvate being produced as a by-product of anaerobic glycolysis. The formation of hydrogen with either sodium or potassium forms the compound known as lactate (Wilmore, Costill, & Kenney, 2008). Hydrogen ions typically disassociate from lactic acid quickly and become lactate. Though these two metabolic by-products are not the same, they are related to each other and for this reason are often used interchangeably. The release of hydrogen ions increases intramuscular acidity. This high acidity impairs muscular contractile and enzyme function (Sahlin, 1986). It has been shown that lactate accumulates primarily in fast twitch muscle fibres during anaerobic training (Tesch, Sjodin, Thorstensson, & Karlsson, 1978). This was shown by histochemical staining vastus lateralis muscle samples from nine male participants in order to distinguish slow twitch and fast twitch muscle fibres. Muscle biopsies were taken during rest and again immediately after 25 contractions of the muscle and 50 contractions. A significantly greater lactate concentration in fast twitch muscles after 25 contractions but began to equalize in the two fibre types after 50 contractions. This rapid accumulation of lactate in fast twitch muscle fibres is a contributor to the muscle fibres susceptibility to fatigue during anaerobic training. However, this statement is not without debate. A review of literature from Cairns (2006) suggests that lactate accumulation is overemphasized in its contribution to fatigue and more research needs to be done to examine the decrease of ATP and creatine phosphate in relation to fatigue.
**Creatine Phosphate Degradation.** The phosphagen system is the primary energy system for explosive exercise, such as lifting a maximal weight, as well as the initial energy system in some higher intensity sub-maximal exercise, such as a 100 meter sprint. This energy produces adenosine tri-phosphate (ATP) through the breakdown of creatine phosphate through the action of the enzyme creatine kinase (Wilmore, Costill, & Kenney, 2008). The capacity of the phosphagen system is limited as creatine phosphate stores deplete rapidly and it is suggested that this system can sustain 3 to 15 seconds of a maximal sprint before the body relies on the anaerobic glycolytic system for ATP formation. Because of the importance of this energy system in the role of lifting maximal weight, replenishing creatine phosphate stores quickly can greatly benefit performance during resistance training exercise.

Although creatine phosphate resynthesis occurs rapidly, it is dependent on blood flow to the working muscle in order for resynthesis. It is suggested (Sahlin, Harris, & Hultman, 1979) that circulation to the working muscle brings oxygen to the muscle while disposing metabolic by-products such as lactate and hydrogen ions out of the muscle. Although lactate and hydrogen ions is not a by-product of the phosphagen system, it is a by-product of anaerobic glycolysis, which is likely the secondary energy system to the phosphagen system during high intensity exercise. The anaerobic glycolytic system becomes the primary energy system once creatine phosphate stores are depleted. Also, creatine phosphate resynthesis during recovery is linked to mitochondrial bound creatine kinase (Bessman & Carpenter, 1985). This suggests that the body is reliant on the oxidative energy system during recovery in order to replenish creatine phosphate stores.
It is important to understand the connection of the anaerobic glycolytic energy system to creatine phosphate depletion and resynthesis in order to appreciate the role of recovery in anaerobic training. As mentioned above, the anaerobic glycolytic energy system does not work independently of the phosphagen system. This has been shown in studies that included procedures to exhaust the phosphagen system in the study design (Signorile, Ingalls, & Tremblay, 1993; Boobis, Williams, & Wooten, 1983; Jacobs, Tesch, Bar-Or, Karlsson, & Dotan, 1983). Interestingly, one study (Pernow & Wahren, 1962) has shown an increase in lactate accumulation with as little of five seconds of maximal exercise. This illustrates, even during the initial stages of intense exercise, the creatine phosphagen system does not work independently of glycolytic system. Additionally, Sahlin et al., (1979) have reported that a decrease in muscle pH due to hydrogen ions can limit the resynthesis of creatine phosphate.

Because of the importance of the oxidative system and the metabolic washout of by-products of anaerobic glycolysis in creatine phosphate resynthesis, the connection can be made to recovery strategies. If a certain recovery strategy is shown to enhance metabolic washout of these by-products that impair creatine phosphate resynthesis, then an argument can be made that this recovery strategy is optimal in a training program.

**Glycogen Degradation.** The glycolytic energy system can be separated into anaerobic glycolysis and aerobic glycolysis. For the purpose of this paper, focus will be on anaerobic glycolysis. The anaerobic glycolytic system involves the breakdown of glucose in order to produce ATP (Wilmore, Costill, & Kenney, 2008). As alluded to in the previous section, the anaerobic glycolytic system is the dominant energy system for energy production for high intensity exercise lasting up to two minutes, excluding the
initial dominance of the phosphagen system. Before glycogen can be used by the body, it must be broken down into glucose or glucose-1-phosphate. This process is known as glycogenolysis. Through a series of chemical reactions, this glucose is eventually converted to pyruvate. The ATP generated from these reactions goes on to supply the energy needed for the full conversion of glucose to pyruvate and eventually to support muscle contraction. This process creates three ATP per glycolytic unit (Wilmore, Costill, & Kenney, 2008), which is sparse compared to the oxidative energy system and thus glycogen is depleted rapidly in order to meet the energy demands of the body causing excessive amounts of lactate to be produced (Allen, 2004). The combination of lactate production and reduced levels of glycogen may eventually lead to muscular contraction failure.

**Active versus Passive Recovery**

Recovery is an often overlooked aspect in the strength and conditioning world. According to Jeffreys (2005), recovery is basically a return to homeostasis. This involves normalization of physiological functions such as the cardiac cycle, restoration of energy stores, and the replenishment of key enzymes such as phosphofructokinase. The two strategies to obtain optimal recovery can be broken into passive and active recovery strategies. While passive recovery is meant to achieve recovery through inactivity, active recovery is defined as a means of recovery through submaximal exercise (Baechle & Earle, 2000). Recovery strategies have mainly been studied using intersession recovery and intrasession recovery strategies. Applied to resistance training, interset recovery, rest interval length, and active interset recovery are all important considerations when designing a program.
**Intersession Recovery.** When examining the issue of the superior recovery modality of active rest or passive rest, the majority of literature examines intersession training sessions (i.e., recovery protocol in between workouts) by measuring recovery indicators after an intense bout of activity. The general assumption is that active recovery enhances lactate clearance in the body, which enables superior performance in subsequent workouts. Gupta et al. (1996) found that active recovery at 30% of VO\(_2\) max was superior to passive rest or massage therapy for lactate clearance when examining participants on a cycle ergometer during a graded protocol to exhaustion. This echoes a study by Davies, Knibbs, & Musgrove (1970) who reported that 35-45% of VO\(_2\) max on the bicycle ergometer was the most efficient at lactate clearance following six minutes of riding at 80% of VO\(_2\) max on the bicycle ergometer. Other studies have reinforced this intensity (e.g., 30%-45% of VO\(_2\) max) of active recovery (Dodd, Powers, Callender, & Brooks, 1984; Belcastro, & Bonen, 1975) for optimal lactate clearance. However, in a study (Hermansen, & Stensvold, 1972) examining active recovery conditions following a 30 minute continuous graded run, 63% of VO\(_2\) max was found to be most beneficial. The previously mentioned studies examined active recovery primarily using a bicycle ergometer, whereas the latter examined active recovery after an intense treadmill run. This leads to the possibility that the optimal intensity of active recovery could be exercise specific. Additionally, these studies fail to present a narrow range in optimal intensity of active recovery as the range could be anywhere between 30% and 63% of VO\(_2\) max. This seems to indicate that a more appropriate measure of active recovery intensity is needed.

While the above studies examined lactate clearance at varying intensities of active recovery using a percentage of maximal oxygen uptakes, many other studies use a
percentage of lactate threshold. Since lactate threshold is defined as “the point at which blood lactate begins to accumulate substantially above resting conditions” (Wilmore, Costill, & Kenney, 2008, p. 109), it makes sense to have this measure when testing lactate clearance. This method directly measures the workload in relation to lactate being produced and is a more viable option of testing than VO₂ max percentages (Menzies et al, 2010). Greenwood et al. (2008) examined varying intensities of active recovery using percentages of lactate threshold in elite swimmers (e.g., a maximal effort 200 yard swim, followed by 10 minutes of the recovery protocol, and another 200 yard maximal swim) and found active recovery at 100% of lactate threshold (versus passive recovery and 50% and 150% of lactate threshold) had the greatest lactate disappearance following a 200 yard maximal swim. Another study examining soccer players and active recovery (Baldari et al., 2004) also used anaerobic threshold in combination with ventilatory threshold. Researchers had participants recover from a six minute run at 90% of VO₂ max at either minus 50% of lactate threshold and ventilatory threshold difference, ventilatory threshold, or plus 50% of lactate threshold ventilatory threshold difference. Results suggest that active recovery at ventilatory threshold or minus 50% of the difference to be more efficient at lactate clearance. Meyer, Gabriel, & Kindermann (1999) also reported that there is wide variability in VO₂ max in relation to lactate threshold. Considering the variability of VO₂ max to workload and the definition of lactate threshold, the validity of a study can be questioned when determining the optimal active recovery intensity without lactate threshold as a parameter since an intensity of active recovery should not produce enough lactate to hinder lactate clearance.
It is generally accepted in the literature that active recovery is superior to passive recovery in lactate clearance. One could conclude that, based on this evidence, active recovery will lead to improved performance in subsequent exercise. However, as argued by a recent review of literature (Barnett, 2006), this may be the wrong approach as there is sufficient lactate clearance through passive rest as well if adequate rest between sessions is followed. The review went on to question the efficacy of literature supporting active rest during intersession training as much of the studies were performed on untrained participants and cannot be inferred to the experienced exerciser. As discussed earlier, untrained participants respond favourably to many treatments where trained participants do not (ACSM, 2009), or at least not to the same degree.

Additionally, it is important to consider the metabolism of lactate when considering the efficacy of intersession active recovery. Mazzeo et al. (1986) investigated lactate oxidation and disposal differences in six healthy male participants during light intensity exercise or high intensity exercise on a cycle ergometer. The researchers found that although there was a fivefold increase in lactate production during the high intensity exercise, there was also a direct relationship to lactate oxidation and metabolic rate. Lactate oxidation increased with an increase in metabolic rate. This demonstrates the body’s ability to wash out metabolic by-products even after intense exercise. Furthermore, a study examining isokinetic muscle function after a bout of high intensity exercise and differing rest protocols (Bond, 1991), found no significant difference in muscle strength and muscle fatigue between active rest and passive groups despite significant differences in blood lactate levels between the two groups. A study (Coffey et al., 2004) comparing three different recovery modalities: active recovery, passive
recovery, and contrast temperature water immersion on run performance, found that although there was significantly more lactate clearance in the active recovery and contrast water immersion, there was no difference in subsequent performance. The study concluded that running performance returned to baseline after a four hour period. These studies suggest that lactate clearance is not an indicator of the quality of the recovery protocol when examining intersession recovery as the body seems to be very efficient at oxidizing lactate if given sufficient time between workouts. However, when there is less than four hours to recover and closer to four minutes, lactate clearance and active recovery may be more important.

**Intrasession Recovery.** Intrasession recovery examines recovery strategies that take place within the workout itself. Sufficient lactate clearance becomes more important when the recovery time becomes significantly less, such as between repeated runs or between sets of a resistance training workout. Although it is easy to assume that active recovery is more efficient in lactate clearance and, therefore, must be superior to passive recovery in intrasession recovery, not all literature supports this conclusion. When studying active recovery on repeated sprint swimming performance, Toubekis et al. (2006) found that active recovery (e.g., 50% and 60% of their 100 metre max velocity) hindered performance in subsequent swims, whereas Bogdanis et al. (1996) demonstrated that a period of four minutes of active recovery (at 40% of V0₂ max) in between maximal 30 second sprints on a cycle ergometer enabled a higher power output in the second sprint when compared to passive recovery. It is surprising that two studies examining active recovery within a training session that have similar participants in terms of age, sex, and training status can have completely different results. However, the two studies
used different intensities of active recovery, even though the recovery protocol was specific to the exercise (e.g., swimmers swam at a lighter intensity and the cyclists cycled at a lower intensity) suggesting that further research is needed to determine the exact intensity needed to optimally clear lactate. Interestingly, another study using percentage of maximal oxygen uptake as a measure of active recovery intensity (Spierer et al., 2004) found that active recovery at 28% of VO\textsubscript{2} max improved performance in repeated Wingate tests when compared to passive recovery, possibly suggesting that light (e.g., <40% VO\textsubscript{2} max) workloads for active recovery are superior to heavier workloads.

Just as with the question of intersession recovery, intrasession recovery must use uniform measures to test active recovery intensity. Studies have used a scaled down intensity of exercise protocol as the treatment (Toubekis et al, 2006; Connolly, Brennan, & Lauzon 2003), an arbitrary active recovery protocol that the researchers feel fall in line with the research (Draper, Bird, Coleman, & Hodgson 2006), or a percentage of maximal oxygen uptake (Bogdanis et al, 1996; Spierer et al, 2004) without any real consensus or consistency. What is seen much less in intrasession recovery research is the use of a percentage of anaerobic threshold, or lactate threshold, as a way to monitor active recovery intensity. This is surprising since anaerobic threshold is used frequently in intersession recovery literature with good rationale.

**Interset Recovery.** Inter-set recovery is similar to intrasession recovery, yet for the purpose of resistance training (repeated sets of multiple exercises sometimes using the same muscle groups), inter-set recovery examines active recovery strategies in between sets of resistance training or short bouts of anaerobic exercises. Inter-set recovery is very important in anaerobic exercise, and this is particularly true with regards to resistance
training. Powerlifters, weightlifters, and other athletes that value performance in their resistance training workouts, can benefit a great deal in knowing the ideal recovery strategy between sets. This holds true for short distance competitive athletes such as sprinters and swimmers. Manipulating rest interval length is a common practice among resistance exerciser in order to encourage different training effects.

**Rest interval length.** The concept of active recovery as part of an inter-set recovery strategy is not mentioned in the ASCM position stand on resistance training (ACSM, 2009). Rather, the position stand provides guidance for rest interval length or, in other words, time between sets. With regards to rest interval length, the position paper distinguishes the length of rest interval that is optimal depending on the trainable characteristic the exerciser is emphasizing through the workout. For example, if the exerciser is trying to build muscular strength, a higher rest time is needed. If the exerciser is trying to build muscular endurance, a shorter rest time is needed. With considerable emphasis on rest interval length throughout the paper, it should give the reader a clue of the potential impact that rest intervals have on workout performance.

Researchers examined the impact of three different rest intervals on volume of a single training session (Willardson & Burkett, 2005). The study examined one, two, and five minute rest schemes during four sets of an eight repetition maximum load of squat and bench press exercises and found that participants (with a minimum of three years of resistance training experience) who had a five minute rest interval allowed for significantly more repetitions when compared to the one minute and the two minute rest interval. Further, a study (Ahtiainen, Pakarinen, Alen, Kraemer, & Hakkinen, 2005) examining the difference between a two and five minute rest scheme between sets over a
six month training period with 13 male participants (average of 6.6 years training experience) found that there was no difference in chronic strength or hormonal changes between the two rest intervals. Although five minutes allows for more volume over a two minute rest period in a single workout (Willardson & Burkett, 2005), this does not seem to translate to chronic strength changes according to Ahtiainen and colleagues (2005). This is somewhat surprising since the five minute rest period allowed participants to lift an average 14% and 30% more load on the leg press and squat, respectively. However, researchers designed the study with an additional set to the short rest group, which meant that the volume of work was greater in this group. This could have caused a counterbalance effect. If researchers manipulated the study to allow the same amount of sets at the same 1RM percentage, it is likely they would not have had the same results given the findings of Willardson and Burkett’s study (2005). Pincivero et al. (1997) compared 40 seconds and 140 second rest period over a four week lower body training program in 15 untrained college students. The researchers found greater hamstring strength increases in the 140 second rest group. It needs to be noted that the participants of this study were not performing resistance training for six months leading into the study, thus would be considered beginners/untrained and can not necessarily be comparable to the studies utilizing trained participants. Pincivero et al. (2004) produced similar findings with a similar protocol (using untrained participants) except examining knee extension isokinetic strength and peak power through the quadriceps femoris. Researchers compared 40 and 160 second rest times, and the results indicated significant improvements in the longer rest group, while there were no significant changes in the short rest group. Future research needs to investigate the influence of rest period length
between trained vs. untrained individuals. Nevertheless, this study leads to the conclusion to build strength longer rest time is needed as recommended by the ACSM (ACSM, 2009).

Though strength differences associated with a rest interval length of either two or five minute rest interval is debatable, shorter rest periods of one minute or less seems impede strength gains (Pincivero et al, 1997; Pincivero et al, 2004; Willardson & Burkett, 2005). It is important to note that these studies only scratch the surface of rest interval length in the literature. There are many possibilities to manipulate study designs in order to examine different aspects of rest intervals and performance beyond a simple short rest group and long rest group comparison. Potential benefits surrounding the use of short rest intervals need to be examined, as well as, rest intervals in between the two and five minutes discussed previously. Also, there is a possibility that differences could exist between high strength participants and relatively low strength participants since high loads demand greater recovery time (American College of Sport Medicine, 2009).

Ratamess et al., (2012) examined a one, two, and three minute rest interval on acute bench press performance. Interestingly, the researchers separated the participants into two cohorts; one to examine sex differences and another to examine differences between a high load bench press participants and relatively weaker bench press participants. All participants had experience resistance training at the time of the study. Participants performed three sets at 75% of their one repetition maximum (1RM) using differing rest intervals across three workout sessions. Researchers found that women and comparatively weak bench pressers were able to lift for more repetitions at the same percentage of 1RM for one minute and two minute rest interval. For all three groups, the
three minute rest period allowed for more repetitions; however, women were able to lift for more reps across all three rest intervals. The study also showed a strength disparity as the high strength group performance dropped significantly when rest times were cut down to one minute and two minutes in terms of power and velocity of the repetitions and repetitions performed. Not only does this study reinforce the notion that a two to five minute rest interval is ideal for performance, it also suggests that there is a sex difference when it comes to interset recovery. It would seem that women need less rest time than men as they were able to perform more repetition at all given rest intervals.

Even though short rest intervals may impede strength gains, there are still some benefits to the short rest interval. Kraemer, Noble, Clark, & Culver (1987) examined differences in exercisers who typically use a very short rest interval in their workouts and exercisers who typically use long rest intervals. Bodybuilders, who used short rest intervals, and power lifters, who used long rest intervals, completed a ten exercise workout using a 10 repetition maximum with 10 seconds of rest between sets and 30-60 seconds between exercises. The study found that the bodybuilders were able to use a greater percentage of their 1RM; as well as suffer significantly lower incidents of dizziness and nausea when compared to the power lifting group. This study suggests that resistance training with short rest intervals is beneficial to increasing muscular endurance. Studies examining the physiological benefits of circuit resistance training report similar findings. Circuit training with resistance exercises is typically done with minimal rest intervals and high volume (ACSM, 2009). A study examining differences in an aerobic/circuit resistance training group and aerobic/callisthenic group in Navy men (Marcinik, Hodgdon, Mittleman, O’Brien, 1985) found that incorporating circuit
resistance training significantly improved muscular endurance. Another study (Haltom et al., 1999) compared a circuit resistance training workout that utilized 20 and 60 second rest intervals and the impact of energy expenditure during excessive post-exercise oxygen consumption (EPOC). Researchers found greater energy expenditure and a greater EPOC was associated with the 20 second rest interval group, which possibly suggests a higher metabolic cost with short rest intervals. These studies suggest that lower rest time may be ideal for individuals looking to use resistance training for muscular endurance or weight loss.

Considering the literature on the topic of rest interval length, one can conclude that for strength increases a two to five minute rest interval is needed. If absolute strength is a high priority to the exerciser, closer to five minutes of rest is likely to be more beneficial than a rest interval closer to two minutes. Though more research needs to be done to distinguish short rest intervals or high volume and the correlation to muscular endurance, it would appear short rest intervals of less than one minute can be beneficial to increasing muscular endurance. Short rest intervals also appear to lead to a higher metabolic cost when compared to long rest intervals. All of the rest interval strategies used in the cited literature, and included as a rationale for the ACSM position paper (ACSM, 2009), incorporated passive recovery when determining optimal rest interval length. Given the evidence surrounding the possible benefits of active intersession recovery, incorporating active recovery strategies into inter-set recovery might be a successful approach to a recovery strategy and possibly reduce the needed recovery time.

**Active Interset Recovery.** Inferring the results of the previously mentioned active intrasession recovery studies to resistance training is challenging because there is little
literature examining active interset recovery in short duration anaerobic exercise. A study by Corder et al. (2000) study examined two different active recovery strategies, in addition to a passive recovery condition, during a four minutes rest interval within a squat workout. Participants consisted of 15 males (with a minimum of six months of resistance training experience for at least three days per week) and were divided into a passive rest group or an active recovery at 25% and 50% of the onset of blood lactate accumulation (OBLA). Participants performed six sets of barbell back squats at 85% of 10 repetition maximum. Following the six sets, a maximal performance set was done for as many repetitions until failure using 65% of 10 repetition maximum. The researchers found that, although blood lactate increased across all conditions, blood lactate accumulation was significantly less in the 25% OBLA group (compared to passive rest and the 50% OBLA group) by the sixth and maximum performance sets, in addition to being able to perform significantly more repetitions during the maximal performance set. Not only does this study point out that incorporating light intensity exercise in between sets can improve performance, it also suggests that lactate clearance may be more important during inter-set recovery. Another study examining the role of active recovery during a resistance training exercise (Hannie et al., 1995) also found benefits over passive recovery. Researchers had untrained participants perform four sets of maximum repetitions at 65% of 1RM and divided participants either into a passive rest group or active rest at 45% of maximal oxygen uptake. The rest interval length was two minutes. Researchers found that the active recovery group were able to complete an average of four more repetitions over the workout. These results show that active recovery will likely lead to better performance during moderate intensity resistance workout. Based on these results, it is
unclear whether active recovery would increase performance during a high intensity resistance training workout (e.g., a resistance workout that utilized sets of \( \geq 85\% \) of 1RM). Hannie et al. (1995) hypothesized that active recovery is not useful when using heavy loads since the phosphagen system is the primary energy system being trained and lactate is not produced as a by-product.

Based on the two above studies one can conclude there seems to be benefits of incorporating an active recovery strategy during the rest intervals of a resistance training workout that has two to four minutes of rest with moderate to high repetitions per set at a moderate to light intensity load. It is not clear, based on these two studies if active recovery could be beneficial in a circuit resistance workout or a resistance workout with short rest time. A study examining the role of active recovery during eight 6-second power test on a cycle ergometer (Signorile et al., 1993) found benefits to power output when compared to passive rest. Researchers recruited six participants, who were all athletes and four of the participants came from sports that incorporated intense resistance training regiments. The testing protocol consisted of 30 seconds of rest between each 6-second power test that would either be done passively or with active recovery. The active recovery intensity was set to 360 kgm/mm. This intensity was considerably less than the power test and has been used in previous literature (Weltman, Stamford, Moffatt, Katch, 1977). Participants completed each testing condition twice on separate days and the order of condition administered was counterbalanced. Researchers found significant differences in total work performed and power output when participants performed active recovery during the rest interval. Although the testing conditions of this study do not employ resistance training, the conditions mimiced a resistance training workout with short rest.
It is possible to infer these results to a resistance training workout that incorporated active recovery in a 30 seconds rest interval. The results of the study could also be referred to other forms of resistance training that are done in an anaerobic fashion for short duration such as kettlebell and battling rope workouts. Another interesting finding from the study is the potential role of active recovery in training that utilizes the phosphagen system, since the phosphagen system is primarily used for 3 – 15 seconds of maximal effort exercise (Wilmore, Costill, & Kenney, 2008). As noted earlier, lactate is not a metabolic by-product of this energy system. Therefore any potential benefit of lactate clearance should not apply to this workout. However, what we see from literature (Signorile et al., 1993; Boobis et al., 1983) is that as creatine phosphate stores deplete, the anaerobic glycolytic system becomes the primary energy system for adenosine triphosphate resynthesis. As explained earlier when discussing glycogen resynthesis, there is significant lactate accumulation in exercise that primarily uses the anaerobic glycolytic system. Boobis et al. (1983) have shown that a 35% reduction in creatine phosphate stores brought about a 15% decrease in muscle glycogen stores and a threefold increase in lactate concentration. These findings could indicate that an active recovery strategy for athletes and exercisers who use heavy loads, such as powerlifters, could benefit from active inter-set recovery. More research needs to be done to examine the role of active recovery in various resistance training workouts that incorporate differing rest intervals and workloads.

**Conclusion**

Throughout the last century our understanding of exercise physiology has increased greatly, and this includes our understanding of fatigue due to exercise. We
understand that lactate accumulation along with the subsequent rise in muscle acidity contributes to peripheral fatigue (Tesch et al., 1978; Sahlin, 1986), although, it is debated on how large of a role lactate accumulation plays in contributing to fatigue (Cairns, 2006). Regardless, lactate accumulation is a contributor to fatigue, though it is important to recognize the role of creatine phosphate, glycogen, and ATP depletion in anaerobic fatigue as well. Reviews of literature, such as the ACSM position stand on resistance training for healthy adults (ACSM, 2009), attempt to get a full grasp on proper exercise procedures and thereby provide a guide to strength and conditioning professionals to get the most results for their clients and athletes. It is understood that rest interval length during anaerobic training is important in order to maintain performance. In order to build strength and maximize hypertrophy a two to five minute rest interval may be most appropriate (Ahtiainen et al, 2005; Pincivero et al, 1997; Ratamess et al., 2012; Willardson & Burkett, 2005). If the goal of the exerciser is to increase muscular endurance and/or aerobic fitness measures, a rest interval under two minutes is ideal (Haltom et al., 1999; Kraemer et al, 1987; Marcinik et al., 1985). It is also important to understand what recovery strategy is ideal within the rest interval length. Although some research argues the role of intersession active recovery (Barnett, 2006) and even during intrasession recovery (Toubekis et al, 2006), these findings are in the minority. The majority of the findings find that active recovery is beneficial when included during intrasession recovery and interset recovery (Bogdanis et al, 1996; Connolly et al, 2003; Cordor et al., 2000; Hannie et al., 1995; Signorile et al., 1993; Spierer et al, 2004). It is not yet understood the role of active recovery in possibly manipulating the length of the
needed rest interval. It is also important to investigate the role of active recovery in
trained exercisers as well as untrained in order to properly infer guidelines to populations.
REFERENCES


Bamberger, M., & Yaeger, D. (1997). Over the edge: Aware that drug testing is a shame, athletes seem to rely more than ever on banned performance enhancers. *Sports Illustrated, 86*, 60.


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Sahlin, K., Harris, R. C., & Hultman, E. (1979). Resynthesis of creatine phosphate in human muscle after exercise in relation to intramuscular pH and availability of


Appendix A – Consent to Participate in Research

CONSENT TO PARTICIPATE IN RESEARCH

Title of Study: Examining the Influence of Recovery Strategy and Rest Interval Length on Performance in Trained and Untrained Individuals

You are asked to participate in a research study conducted Neil Pettit and Dr. Sarah Woodruff from the Kinesiology Department at the University of Windsor. The results will contribute to a graduate master’s thesis study.

If you have any questions or concerns about the research, please feel to contact Neil Pettit (253 3000 ext 4491) and/or Dr. Sarah Woodruff (253 3000 ext 4982) at anytime.

PURPOSE OF THE STUDY
The purpose of this study is to examine the role of differing recovery strategies and rest interval length on performance in trained and untrained participants. The workout will consist of high intensity interval training (HIIT) with large diameter ropes (1-2 inches) called a battling rope. There is little previous research available on battling ropes and the role of active/passive recovery could have an effect on a battling rope workout. Although active recovery has been researched quite extensively, there is a lack of research involving both trained and untrained individuals. Also, research regarding active recovery and performance enhancement is debatable. This investigation will attempt to determine if there are any differences in performance between an active vs. passive recovery strategy in both trained and untrained groups. The study will also examine the role of rest interval length in order to examine if the recovery strategy takes on more importance during a shorter or longer rest interval. Training will consist of two workouts using the battling ropes and an additional day of testing for participants who are untrained on the battling ropes. Participants can expect to get a greater understanding of the role recovery can play in a workout as well as proper use of a battling rope.

PROCEDURES
If you volunteer to participate in this study, you will be asked to:

Come to the Undergraduate Laboratory in the Human Kinetics building at the University of Windsor where you will be asked to complete the Physical Activity Readiness Questionnaire (PAR-Q) and participant information questionnaire that determine whether you have any known risks that would prevent you from participating in physical exercise. These forms include information such as your date of birth, sex, medications you might be taking and any known history of cardiovascular disease. Participants who are untrained with the battling rope will then be asked to schedule a date for a fitness testing session following a 48 hour exercise and alcohol hiatus and must have fasted for 4 hours pretest to prevent interaction of the thermal effect of food. The trained group and control group will not take part in this testing day. The testing session (45 minutes) will involve:
• A graded Astrand VO2max protocol with an Arm Ergometer. This is designed to measure your aerobic capacity while wearing a Hans Rudolph VO2 mask and a Polar Heart Rate Monitor.

• This arm ergometer protocol is completed in two minute stages until volitional fatigue. Following each 2 minute stage you will be asked to rate your exertion level using the Borg 10 point Rating of Perceived Exertion Scale.

• This information will be used in order to accurately gauge intensity during the recovery protocol

• After five minutes of rest, participants will be asked to complete a maximal push up test

• A brief familiarization of the battling rope and study procedure once participant recovers from push up test. Participant will be asked to complete 30 seconds of the battling rope in both double whip and alternate whip style.

After a minimum of 48 hours rest, the second session (30 minutes) will begin. Participants trained on the battling rope will begin here after a minimum of 48 hours of rest after testing from previous study.

• Participants will be asked to sit quietly for five minutes. After which a single use Medlance blood drop lancet will be used to prick the earlobe and draw a single droplet of blood. This blood will then be analyzed for its lactate concentrations with a Lactate Scout.

• A proper active warmup will take place with simple exercises to make sure that your body is prepared for physical activity

• Participants will perform maximal push ups following the warm up

• Participant will perform maximal sit up test following a five minute rest period

• Begin the interval training protocol with the battling rope. You will wear the Polar Heart Rate Monitor. You will complete 10 workout sets of 30 seconds of battling rope exercises, matched by either 60, or 120 seconds of rest depending on your randomized selection. During this rest time, you will either perform light exercise on the arm ergometer or stand idly, again, depending on your randomized selection. During each workout set you will be asked to rate your exertion level using the Borg 10 point Rating of Perceived Exertion Scale.

• Once all ten workout sets are complete, you will be asked to sit down and blood sample will be taken to measure lactate concentrations as done prior to the workout

• Following the blood sample, five minutes of rest will occur using the assigned recovery strategy (active or passive). Another lactate measurement is taken followed by an additional maximal push up test and maximal sit up test.

• After this, a stretching routine will occur in order to cool down and stretch out the muscle tissue used.

• This protocol will be retested after 48 hours rest with the alternate rest interval length

• Participants are asked to refrain from caffeine or pre-workout supplements 4 hours prior to workout
The control group will only be needed for one day of testing and will also be asked to refrain from caffeine or pre-workout supplements

- Participants will be asked to sit quietly for five minutes. After which a single use Medlance blood drop lancet will be used to prick the earlobe and draw a single droplet of blood. This blood will then be analyzed for its lactate concentrations with a Lactate Scout.

- This lactate measurement is followed by 30 minutes of quiet activity where participants can do homework/study but no physical activity is allowed. Participants must stay in the lab unless they need to leave for an excusable reason (eg. Washroom).

- Lactate measurement is to be taken again followed by an additional push up test

In total there will be one VO_{2}\text{max} and push up testing session for participants untrained on the battling rope, and two battling rope HIIT testing sessions with alternate rest interval. Each testing session will be approximately 45 minutes in duration, while each battling rope HIIT session will be approximately 60 minutes in duration. The total time commitment for the trained participant will be approximately two hours; two hour and 45 minutes for the untrained participants; and the control group will have a time commitment of one hour.

**POTENTIAL RISKS AND DISCOMFORTS**

Delayed onset muscle soreness will likely occur between 24 to 72 hours after your training sessions. With proper rest and avoidance of extra training, recovery will occur. Proper stretching protocols will be administered post training session in order to assist in muscle flexibility post workout.

If an unusual or unexpected discomfort is felt throughout the investigation, the protocol can be stopped. Water and/or juice will be made available to you.

**POTENTIAL BENEFITS TO PARTICIPANTS AND/OR TO SOCIETY**

Participants can expect to gain knowledge of a unique training apparatus, as well a greater understanding of recovery and its importance. This research can lead to changes in strength and conditioning programs in the fitness community with proper administration of recovery strategies in training programs. Battling ropes are currently being used in the field but this investigation will provide useful information as to their appropriate application.

**COMPENSATION FOR PARTICIPATION**

The participants will not receive any financial compensation.

**CONFIDENTIALITY**

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. The confidentiality of participant information will be ensured as each participant will be given a unique code that can only be identify them by name if associated with an initial file. This file will be digitally secure (password) on a personal computer and a hard copy will be kept in an office in a keyed (locked) cabinet.

**PARTICIPATION AND WITHDRAWAL**
The investigator may withdraw you from this research if circumstances arise which warrant doing so. Also, the subject may withdraw at any time. If you have a longer than 5 day interval between sessions, you will be asked to withdraw from the study. It is imperative that you are aware of this and can plan accordingly whether you can participate in the study.

**FEEDBACK OF THE RESULTS OF THIS STUDY TO THE PARTICIPANTS**

The final transcript will be emailed to you upon request, which will contain the research findings.

Your email address: _________________________________________________
Date when results are available:  **August 31st, 2013**

**SUBSEQUENT USE OF DATA**

This data may be used in subsequent studies in publications and in presentations.

**RIGHTS OF RESEARCH PARTICIPANTS**

If you have questions regarding your rights as a research participant, contact: Research Ethics Coordinator, University of Windsor, Windsor, Ontario, N9B 3P4; Telephone: 519-253-3000, ext. 3948; e-mail: ethics@uwindsor.ca

**SIGNATURE OF RESEARCH PARTICIPANT/LEGAL REPRESENTATIVE**

I understand the information provided for the study “Examining the Implications of Recovery Strategy and Rest Interval Length on Performance in Trained and Untrained Participants” as described herein. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

____________________________________
Name of Participant
____________________________________
Signature of Participant                  Date

**SIGNATURE OF INVESTIGATOR**

These are the terms under which I will conduct research.

____________________________________
Signature of Investigator                  Date
Appendix B – Participant Information Sheet

Participant Information Sheet

Name: ___________________________

D.O.B. (mm/yy) ____/____

Height: ______ Weight:______ BMI: _______

Sex: M or F

Participant I.D. #_______

Contact Information:

Phone (cell)#: (     ) __________-__________

Phone (home) #: (     ) __________-__________

E-mail: __________________________________@_____________________________

Emergency Contact (Optional)

Name: ________________________________

Phone #: (     ) ______________-____________

Physical Activity Background:

How many months have you been regularly exercising?
1  2  3+  6+  12+

How many times do you exercise per week?
1  2-3  3-4  4+

Have you ever used a battling rope before? _____

Recent or past injuries:
Appendix C – Physical Activity Readiness Questionnaire

PAR-Q & YOU
(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly. Check YES or NO.

YES NO
1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
2. Do you feel pain in your chest when you do physical activity?
3. In the past month, have you had chest pain when you were not doing physical activity?
4. Do you lose your balance because of dizziness or do you ever lose consciousness?
5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?
6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
7. Do you know of any other reason why you should not do physical activity?

YES to one or more questions
Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.
• You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kind of activities you wish to participate in and follow his/her advice.
• Find out which community programs are safe and helpful for you.

NO to all questions
If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:
• start becoming much more physically active — begin slowly and build up gradually. This is the safest and easiest way to go.
• take part in a fitness appraisal — this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

© Canadian Society for Exercise Physiology; www.csesp.ca/forms

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.
### Appendix D – Control Data Set

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<th>ID</th>
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</tbody>
</table>

*Notes.* According to paired samples t-test, no significant differences existed in either pre- or post-test push up or sit up performance.
Appendix E – Performance Measures

**Push ups.** Figure A shows participant places hand slightly wider than shoulder width and toes on the floor. Figure B participant lowers until chin touches the floor then raises to starting position. Protocol followed for baseline testing. Female participants perform push up test from kneeling position (Figure C) and lowers chin to floor (Figure D) then raises to starting position.

**Sit ups.** Figure A shows starting position. Figure B shows finishing position. Participant flexes at hip and elbows must touch thighs without leaving side of head, with researcher holding feet in anchored position.
Appendix F – Arm Ergometer VO$_2$ max Test

VO$_2$ max test. Figure A illustrates the starting position of the arm ergometer VO$_2$ max test. The axel of the arm ergometer is adjusted so it is in line with the participant’s shoulder joint. Figure B illustrates half of a full rotation where participant’s arm is able to reach adequate extension. Participant is fitted with Hans Rudolph mask and follows Astrand Protocol.
Appendix G – Lactate Measure

**Lactate Measure.** Lactate measured using Lactate Scout Analyzer (A), Autolancet and Medlance 1.8mm which were used to obtain single blood droplet and analyzed for blood lactate concentration. Participant is seated and earlobe is cleaned with alcohol swab (B). Researcher then holds medlance against earlobe (C) until device clicks (D) and device is disposed of in clearly marked biohazard container (E). Blood is then analyzed by Lactate Scout for blood lactate concentration.
Appendix H – Data Collection Form

Battling Rope Rest Interval Recovery Strategy Data Collection Form

Participant Name: ____________________
Participant ID: _______________________

1. Par Q+ Complete
2. Participant Information Questionnaire Complete
3. Letter of Consent Given
4. Consent Form Filled Out
5. Date of Birth
6. Exercise at least 2x a week for 6 months?

7. Group
   Trained
   Untrained
   Passive
   Active

Testing Session (Untrained only)
8. 48 hour exercise and alcohol hiatus?
9. 12 hour caffeine hiatus?

YMCA Bent-Knee Sit Up Test
9. Knees bent with investigator holding feet
10. Hands behind head
11. Elbows touch knees for one rep
12. 1 minute for maximal reps
13. Total

**Astrand VO2max Test**
14. Put on HR monitor
15. Put on Hans Rudolph Mask
16. Head of humerus at axle
17. Set distance that allows appropriate extension
18. Demonstrate RPE scale
19. Allow warm up for few minutes
20. Set up digital display
21. Begin at 60 RPM
22. Initial workout at 10W
23. Allow few minute warm up at 10W
24. Ask RPE at end of each stage

<table>
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<th>Rd 1</th>
<th>Rd 2</th>
<th>Rd 3</th>
<th>Rd 4</th>
<th>Rd 5</th>
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<th>Rd 7</th>
<th>Rd 8</th>
<th>Rd 9</th>
<th>Rd 10</th>
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</thead>
</table>
25. Final Stage
26. Final Time
27. Final Workload
28. Sterilize equipment
29. 10 minute break

**ACSM Push Up Test**
30. Hands shoulder width apart
31. Females from knees/males from toes
32. Chin must touch the ground
33. Full extension of arms
34. Total

35. Rope Familiarization
   - Double whip
   - Alternate whip

36. Minimum of 36 hours of rest maximum 5 days

**30:60 Work to Rest Session**
1. sit for 5 minutes
2. Draw blood lactate value from ear
3. Put on HR monitor
4. **Warm Up**
   - 20 jumping jacks
   - 10 Forward shoulder circles: 10 backward shoulder circles

**Date:**
10 Wall stick ups
10 Alternate lunges
10 push ups

5. 3 minute break
6. **Maximal Push Up Test**
   Hands shoulder width apart
   Females from knees/males from toes
   Chin must touch the ground
   Full extension of arms

7. Total
8. 5 minute break
9. **YMCA Bent-Knee Sit Up Test**
   Knees bent with investigator holding feet
   Hands behind head
   Elbows touch knees for one rep
   1 minute for maximal reps

10. Total
11. 5 minute break

12. **30:60 Battling Rope Protocol**

<table>
<thead>
<tr>
<th>Active</th>
<th>Passive</th>
</tr>
</thead>
</table>

**For Active Recovery**
13. Have arm ergometer ready
14. Explain quick transition to active recovery
15. Have 30% of VO\textsubscript{2max} determined

\begin{tabular}{|c|c|}
\hline
\textbf{V02max} & \textbf{30\%VO2} \\
\hline
\end{tabular}

16. Explain value to participant
17. Demostrate quick transition

For Passive Recovery
18. Explain importance of minimized movements

20. Record HR immediately after round (Post HR) and before (Pre HR)

\begin{tabular}{|c|c|c|}
\hline
\textbf{Round 1: Double Whip} & \textbf{Post HR} & \textbf{RPE} \\
\textbf{Round 2: Alternate Whip} & & \\
\textbf{Round 3: Double Whip} & & \\
\textbf{Round 4: Alternate Whip} & & \\
\textbf{Round 5: Double Whip} & & \\
\textbf{Round 6: Alternate Whip} & & \\
\textbf{Round 7: Double Whip} & & \\
\textbf{Round 8: Alternate Whip} & & \\
\textbf{Round 9: Double Whip} & & \\
\textbf{Round 10: Alternate Whip} & & \\
\hline
\end{tabular}

21. Draw blood Lactate immediately
22. 5 min rest with appropriate recovery strategy

\begin{tabular}{|c|c|}
\hline
\textbf{Active} & \textbf{Passive} \\
\hline
\end{tabular}

23. Draw blood Lactate

24. Maximal Push Up Test

- Hands shoulder width apart
- Females from knees/males from toes
- Chin must touch the ground
25. Total

26. **Maximal Sit Up Test**
   - Knees bent with investigator holding feet
   - Hands behind head
   - Elbows touch knees for one rep
   - 1 minute for maximal reps

30. Total

31. **Stretches (20 seconds each)**
   - Seated Twist
   - Reach back and turn
   - Pole reach
   - Wrist flexion
   - Wrist extension

Full extension of arms
30:120 Work to Rest Session

1. Sit for 5 minutes
2. Draw blood lactate value from ear
3. Put on HR monitor
4. Warm Up
   - 20 jumping jacks
   - 10 Forward shoulder circles: 10 backward shoulder circles
   - 10 Wall stick ups
   - 10 Alternate lunges
   - 10 push ups
5. 3 minute break
6. Maximal Push Up Test
   - Hands shoulder width apart
   - Females from knees/males from toes
   - Chin must touch the ground
   - Full extension of arms
7. Total
8. 5 minute break
9. YMCA Bent-Knee Sit Up Test
   - Knees bent with investigator holding feet
   - Hands behind head
   - Elbows touch knees for one rep
   - 1 minute for maximal reps
10. Total
11. 5 minute break
12. **30:120 Battling Rope Protocol**

For Active Recovery
13. Have arm ergometer ready
14. Explain quick transition to active recovery
15. Have 30% of VO2max determined
16. Explain value to participant
17. Demostrate quick transition

For Passive Recovery
18. Explain importance of minimized movements
20. Record HR immediately after round (Post HR) and before (Pre HR)
   - Round 1: Double Whip
   - Round 2: Alternate Whip
   - Round 3: Double Whip
   - Round 4: Alternate Whip
   - Round 5: Double Whip
   - Round 6: Alternate Whip
   - Round 7: Double Whip
   - Round 8: Alternate Whip
   - Round 9: Double Whip
   - Round 10: Alternate Whip

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</table>
21. Draw blood Lactate immediately
22. 5 min rest with appropriate recovery strategy
23. Draw blood Lactate
24. **Maximal Push Up Test**
   - Hands shoulder width apart
   - Females from knees/males from toes
   - Chin must touch the ground
   - Full extension of arms
25. Total
26. **Maximal Sit Up Test**
   - Knees bent with investigator holding feet
   - Hands behind head
   - Elbows touch knees for one rep
   - 1 minute for maximal reps
30. Total
31. **Stretches (20 seconds each)**
   - Seated Twist
   - Reach back and turn
   - Pole reach
   - Wrist flexion
   - Wrist extension
Appendix I – Emergency Action Plan

Laboratory Emergency Action Plan (EAP)

For Medical Emergencies during Exercise Testing

STEP 1: REMAIN CALM.
CONTROL and ASSESS the situation.
DESIGNATE a person to CALL and meet EMERGENCY PERSONNEL:

911 OR Campus Police EXT. 4444
(they will dispatch required authorities)

OUR ADDRESS/DIRECTIONS:

The University of Windsor
Human Kinetics Building
2555 College Ave.
Main Entrance off College Ave.
Room# 202 (uppermost floor)

Directions: Enter the HK building at the North entrance and head up the staircase on the left. Take your first right and Room 202 is on your right.

OUR PHONE#

519-253-3000 ext 2431

STEP 2: PERFORM all measures (CPR/First Aid) to ensure safety of subject.
ATTEND to subject until replaced by emergency personnel.

STEP 3: CREATE a Department of Kinesiology Incident Report.
Appendix J – Warm up Protocol

Jumping jacks. Figure A shows starting position where participant stands in anatomical position. Figure B follows as participant abducts at the hip and shoulder joints in a hoping motion before returning to starting position.

Arm circles. Participant circumducts at both shoulder joints through full range of motion. Participant then repeats exercise circumducting the other direction.
Lunge. Figure A shows starting position where participant is standing upright followed by Figure B where participant takes large step forward and flexes at knee and hip. Participant returns to starting position and alternates between right and left leg.

Stick ups. Figure A shows starting position where participant places back flush against wall while keeping upper arm as tight as possible to side and elbows in flexed position. Figure B shows finishing position where participants laterally abducts at the shoulder while extending at the elbow joint all while staying flush to wall.
Push ups. Figure A shows participant places hand slightly wider than shoulder width and toes on the floor. Figure B participant lowers until chin touches the floor than raises to starting position. Protocol followed for baseline testing. Female participants perform from the kneeling position (Figure C and D)
### Appendix K – Rating of Perceived Exertion

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Appendix L – Battling Rope Protocol

**Alternate whip.** Figure A shows starting position while figure B shows finishing position. In a quick movement, participant flexes at one shoulder while extending at the other shoulder. Participant then alternates. This is continued for the working interval.

**Double whip.** Figure A shows starting position. Once participant is instructed, shoulders are rapidly flexed (figure B) followed by quick extension of the shoulder. This is continued as quickly as the participant can for the working interval.
Appendix M – Active Recovery

**Active recovery.** Participant is seated at arm ergometer with seat positioned so the axle of ergometer is in line with shoulder joint of participant. Participant performs exercise at 20% of maximum wattage determined during baseline testing with a cadence of 60 rotations per minute and is maintained for the duration of the recovery interval.
# Appendix N – Arm Ergometer VO\textsubscript{2} max Data

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Notes. MHR refers to age predicted maximum heart rate. Max W refers to maximum wattage obtained during the VO\textsubscript{2} max test. HR@ VO\textsubscript{2} max refers to heart rate obtained by last stage of VO\textsubscript{2} max test. 20% W is wattage used for active recovery protocol. HR refers to heart rate of 20%W from beginning of stage to last stage. *indicates malfunctioning heart rate monitor.
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**Notes.** MHR refers to age predicted maximum heart rate. Max W refers to maximum wattage obtained during the VO₂ max test. HR @ VO₂ max refers to heart rate obtained by last stage of VO₂ max test. 20% W is wattage used for active recovery protocol. HR refers to heart rate of 20% W from beginning of stage to last stage. * indicates malfunctioning heart rate monitor.
VITA AUCTORIS

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