ASSESSMENT OF LACTATE RESPONSE
AFTER THE COMPLETION OF THREE DIFFERENT
VOLUME PATTERNS OF POWER CLEAN

by

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ABSTRACT

The ability of continuous lactate clearance and the inflection points of the lactate curve are two important determinants of performance of competitive field athletes. Current training practices for improving lactate tolerance such as high intensity aerobic activities and the combination of aerobic and resistance training seem to have undesired physiological adaptations (e.g. muscle loss, change in fiber types). The Role of Explosive power movements in lactate accumulation has not been studied properly. Hence, the purpose of this study was to assess lactate response after the completion of three different volume patterns of the power clean movement. Ten male recreational athletes (age 18-30 years) participated in the study. Volume patterns consisted of 3 sets* 3RM (I), 3 sets* 6RM (II) and 3 sets*9 RM (III) with identical rest periods of 2 minutes. Forty eight hours of rest observed between performances of each pattern. Blood samples were collected at the beginning and at the end of each volume pattern. The volume pattern of 3 sets * 9RM showed greatest post activity lactate response (7.43 mmol/l ±2.94mmol/l) as opposed to 4.03 mmol/l ± 1.78mmol/l and 5.27 mmol/l ±2.48mmol/ in patterns I and II respectively. Mean relative increase in lactate response was highest in volume III (356.34%). Findings indicate that lactate response in power cleans is largely associated with volume as determined by Number of repetitions, load, and rest interval. Explosive movements; if performed over a prolonged period can impose greater glycolytic and oxidative demands. This study presents the enticing proposition of evaluating the role of explosive power movements in improving lactate tolerance.

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CHAPTER 1: INTRODUCTION

The quality of human performance is dependent on the body's ability to optimally utilize all available energy resources and maintain homeostasis throughout the process. The primary function of the various energy producing metabolic pathways is to transfer energy from exergonic reactions (energy releasing reactions/catabolic reactions) through the intermediate molecule adenosine tri phosphate (ATP) to endergonic reactions (reactions that require energy/anabolic reactions) (Brooks, Fahey, & Baldwin, 2005). ATP stores a large amount of readily available energy in chemical bonds. The breaking of these chemical bonds produces mechanical and thermal energy (Bridges, Clark, Hammond, & Stephenson, 1991). The human body requires a constant supply of energy to perform a range of tasks from simple biological functions such as digestion and respiration to athletic performance. However, basic storage of ATP in the body is limited; therefore energy producing metabolic pathways function to provide a constant supply of ATP to working muscles (Baechle & Earle, 2008).

Metabolic Pathways

The phosphagen, glycolytic and oxidative pathways are the three metabolic systems at work in human muscles. The phosphagen system is the preferred pathway at the initiation of all activities. Rapid acting enzymes such as myosin ATPase and creatine kinase are the catalysts of this pathway. Myosin ATPase catalyzes the hydrolysis of ATP to quickly release energy; creatine kinase catalyzes the synthesis of ATP from creatine phosphate (CP) and adenosine diphosphate (ADP) (Baechle & Earle, 2008). The phosphagen system provides the energy at a rapid rate; however, the duration is short due to the limited storage of ATP and CP in muscles (Cerreteli, Rennie, & Pendergast, 1980).

The second system is known as glycolysis, which means the breakdown of muscle or liver glycogen and blood glucose to produce pyruvate. This system functions in two ways which are known as fast glycolysis and slow glycolysis. In slow glycolysis, pyruvate enters the mitochondria for aerobic metabolism. Energy contribution of fast and slow glycolysis is dependent on energy requirements of the activity and the availability of oxygen. Typically, fast glycolysis occurs in high intensity exercise, during the periods of reduced availability of oxygen (Brooks et al., 2005). In fast glycolysis, pyruvate is converted to lactic acid in order to generate ATP. This process leads to the accumulation of blood lactate.

Accumulation of Lactate

Accumulation of blood lactate is associated with a corresponding increase in hydrogen ion (H^+) concentration in skeletal muscles, which inhibits glycolytic reactions and interferes with muscle excitation-contraction coupling (Nakamura & Schwartz, 1972). Such interference may result in limitations to muscular contractions through reduced availability of calcium (Baechle & Earle, 2008). In addition, inhibition of glycolytic reactions may result in reduced availability of ATP (Brooks et al., 2005). Therefore, lactate accumulation, and the associated accumulation of H^+ is generally associated with muscular fatigue.

Previous researches have shown that lactate production occurs more in type II muscle fibers than type I; and is greater in high intensity, intermittent activities than low intensity, continuous activities. Type I muscle fibers are characterized by large number of mitochondria, high aerobic capacity and dense capillary concentration whereas type II muscle fibers are characterized by low mitochondria, low aerobic but high anaerobic capacity and higher force production (Lexell, Henriksson-Larsen, Wimblod, & Sjostrom, 1983). Thus, the type I muscle fibers are predominant in aerobic activities, while type II muscle fibers play an important role in short duration, explosive power events and/or resistance training. Moreover, it has been observed that the muscle fibers of intermediate and large motor units, which are used in explosive power and resistance events, produce more lactate than small motor units (Jones & Ehrsam, 1982).

Lactate Curve

Studies in the past have shown a specific pattern of lactate accumulation. It has been observed that, when compared to exercise intensity, increases in blood lactate are non-linear. This non-linear representation of the relationship between blood lactate and exercise intensity is known as the lactate curve (Davis, Frank, Whipp, & Wasserman, 1979). There are specific points on this curve which are associated with abrupt increase in blood lactate above the baseline concentration (Davis et al., 1979).

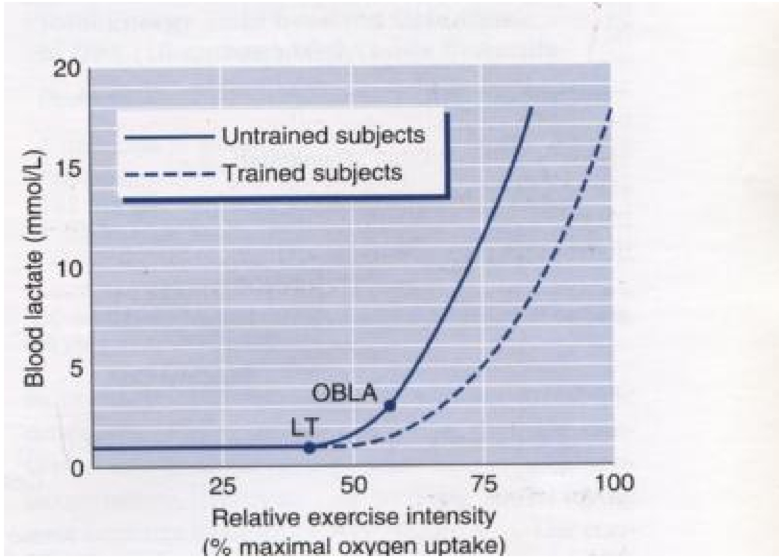

Figure 1 Lactate Threshold Curve (Baechle & Earle, 2008).

Figure 1 shows the concentration of blood lactate in response to the increase in intensity in terms of percentage of maximum oxygen uptake ($\dot{V}O_2max$) (Baechle & Earle, 2008). The first point at which the blood lactate begins an abrupt increase is known as lactate threshold (LT), while the second point of abrupt increase is known as onset of blood lactate accumulation (OBLA) (Sjodin & Jacobs, 1981). Previous studies have observed that LT occurs at 50% to 60% of $\dot{V}O_2max$ in untrained individuals and at 70% to 80% of $\dot{V}O_2max$ in trained individuals. OBLA is associated with blood lactate accumulation over 4mmol/l (Cerretelli, Ambrosoli, & Fumagalli, 1975). From the previous discussion, it should be understood that, LT and OBLA are typically associated with reduced availability of oxygen, gradual shift from oxidative energy substrates to non-oxidative energy substrates and muscular fatigue.

Lactate Tolerance

Due to this chain of events, and the rise in the lactate production, the ability to quickly clear and utilize blood lactate is of immense importance. Continuous and concurrent lactate utilization ensures that the concentration of blood lactate and the associated H^+, at any given point, does not exceed utilization and buffering capacities of muscle, heart, liver, kidneys, blood and lungs.

Previous studies of how to shift LT and OBLA to higher intensities have observed that training at intensities near LT and OBLA results in rightward shift of lactate curve (shown as dotted line in the Figure1) (Davis et al., 1979). The rightward shift means that LT and OBLA will occur at relatively and absolutely higher exercise intensities (percentage of $\dot{V}O_2max$ in this case) which facilitate higher quality of human performance and delay in muscle fatigue.

The ability of continuous lactate clearance and the inflection points of the lactate curve are two important determinants of performance of competitive athletes in sports like soccer, basketball and tennis, among others, where the intense and repetitive nature of these activities places high demands on metabolic systems, often resulting in lactate accumulation (Eniseler, 2005). The dynamic and explosive nature of these events, coupled with the long duration, requires an athlete to repetitively perform a range of activities from power jumping (dunk in basketball) to long sprints (soccer). Therefore, the ability to oxidize lactate for a longer duration, thus called lactate tolerance is important to improve athletic performance.

Significance of the Study

It is important to understand that lactate production and lactate utilization are two different processes. Typically, lactate production takes place in the presence of anaerobic energy production while lactate utilization requires oxygen (Bridges et al., 1991; Brooks, 1986). Hence, training for improvement in lactate tolerance typically includes activities which facilitate enough stimuli for concurrent lactate production and utilization.

Current training practices for improving lactate tolerance in athletes are highly influenced by aerobic activities and the combination of aerobic and resistance training (Dudley & Fleck, 1987). The prevalence of aerobic activities in such training is due to its metabolic requirement which enhances lactate clearance; however, the intensity of such training is kept very high in order to initiate sufficient lactate production. These training regimens are generally found to be effective; however, certain drawbacks prevail due to its nature of using very high intensity for longer duration (Hickson, 1980). Constantly working at a particular intensity proves difficult due to the limitations of current practice of monitoring intensity in aerobic training through heart rate (HR) while working at lactate threshold. Thus, the risk of muscle loss is greater when aerobic training is used as a tool for improving lactate tolerance (Eniseler, 2005). This obstacle can be avoided if resistance training is modified and used as an intermittent activity to enhance concurrent lactate production and clearance, without exposing an athlete to the negative effects of excessive aerobic training.

A study was conducted to evaluate the effects of high intensity resistance training on the performance of distance runners (Hamilton, Paton, & Hopkins, 2006). The participants were divided in to two groups. In this 5-week long study, the control group performed their usual competitive-phase training while the experimental group replaced part of their training with explosive jumps and short treadmill sprints. This study observed an improvement in 1500 m speed; 800 m speed, 5 km outdoor time trial speed and lactate threshold speed without compromising baseline muscle strength.

It is necessary to recite that, lactate production is higher in type II muscle fibers and during the recruitment of large to intermediate motor units (Jones & Ehrsam, 1982), as can occur in the Olympic style weight lifting techniques such as the clean and jerk, power cleans and the snatch. Thus, the possibility of using explosive power activities to improve lactate tolerance needs to be evaluated. Working at the intensity which facilitates significant lactate is important to improve lactate tolerance; therefore, the use of explosive training is consistent with the training goal in question.

Current scientific literature provides mixed results in this regard. A study conducted by Paton & Hopkins (2005) provides information about relationship between explosive power movements and lactate accumulation; however, the study does not indicate the mechanism behind the response. Similarly, a study conducted by Pierce, Rozenek, & Stone (1993) evaluated the effects of resistance training on increased lactate accumulation without indicating the mechanism behind the process. Both studies have been reviewed further in the present study.

The mixed results of the aforementioned studies demand further research in this area. Few studies have evaluated the effects of weight training on lactate at given power output (Stone et al., 1987). In addition, the effects of high volume explosive training on lactate tolerance have yet to be evaluated. In order to close the gap between research and application, it is important to evaluate the effects of high volume explosive training on lactate production as a prelude to the evaluation of high volume explosive training on lactate tolerance during continuous intermittent activities.

Statement of Problem

The Olympic style lifts are popular explosive training tools in current conditioning practices for nearly all athletic events. However, little is known about actual effects of Olympic style lifts on lactate production. A study was conducted on weightlifters to evaluate the effects of different patterns of volume and the Olympic style lifts mode on lactate concentration (Gupta & Goswami, 2001). Participants performed three sessions with various volume patterns for the clean and jerk and the snatch. It was observed that lactate concentration was highest in the multiple set sessions and more in the clean and jerk than in the snatch. However, the study focused on the difference between two modes of Olympic style lifts training and not on difference between volumes patterns of the same mode.

Therefore, the purpose of this study is to evaluate the effects of different volume patterns of Olympic style lifts training on lactate accumulation. Power cleans was the specific activity selected for this study. The review of the literature further explains the reasoning behind selecting power cleans.

Hypotheses

The following hypothesis was tested in the study:

Null Hypothesis – There is no difference in pre and post exercise blood lactate levels and, increase in blood lactate levels is not higher with higher volumes.

Alternative Hypothesis – Because of the greater metabolic demands of high volume power cleans; there is a difference in pre and post-exercise blood lactate levels, and increase in blood lactate levels is higher with higher volumes.

Limitations

The following limitations are present in this study

1. This study was limited to the small sample of resistance trained males aged between 18 and 30 years so results may not be generalized to other populations.
2. No biomechanical tools were used to evaluate technique breakdown thus the association of technique with volume and lactate response cannot be determined.
3. Participants were not limited to individuals with specific conditioning profile or sports

   background so results of this study cannot be generalized with specific group of population (e.g. Women or athletes of specific sports).

Delimitations

The following delimitations are present in this study

1. All participants were volunteers from the Treasure Valley area.
2. All participants complied with the scientifically verified procedures and postures of Olympic style lifts.

3. All participants were restricted from participation in any other form of exercise during the period of the study.
4. Participants were limited to males between the age of 18 and 30.
5. Participants with no prior resistance training experience or currently untrained participants were not used for this study.
6. Participants who suffer from hypertension, cardiac health problems, musculo-skeletal injuries or other potential health problems with a potential hindrance to successful participation in resistance training activities were not used for this study.

Definition of Terms

ATP (Adenosine triphosphate) – Common chemical intermediate used to power muscle contractions and other forms of cellular work (Bridges et al., 1991).

Explosive power movements – Movements generating maximal force in very short duration (Baechle & Earle, 2008)

Glycolysis – The process of breakdown of carbohydrates in the form of muscle glycogen of glucose to resynthesize ATP (Brooks et al., 2005).

Lactate – Anion of lactic acid which is formed when Pyruvate is catalyzed by the enzyme called lactate dehydrogenase in glycolysis (Brooks et al., 2005; Baechle & Earle, 2008).

Lactate threshold – The first point on blood lactate curve at which blood lactate begins an abrupt increase (Sjodin & Jacobs, 1981).

Lactate Tolerance – Ability to maintain the balance in lactate production and lactate utilization (Dudely & Fleck, 1987).

Metabolism – The sum of catabolic and anabolic reactions in a biological system (Brooks et al., 2005).

CHAPTER 2: REVIEW OF LITERATURE

The interaction between fast and slow glycolysis is a major determinant of human performance during prolonged and/or strenuous activities. Metabolic reactions required to provide energy during such activities create acidic conditions due to the production of lactic acid and associated increase in H^+ (Gollnick, Bayla, & Hodgson, 1986; Brooks, 1986). It is these H^+ that play a significant role in fatigue and limit activity (Bergeron, 1991).

Glycolysis

Glycolysis is the conversion of glucose to pyruvate in order to generate ATP. The process primarily occurs in the cytosol, where glycolytic enzymes are in abundance. Sixteen steps of this process have been identified and the primary enzymes involved in this process are phosphofrucktokinase (PFK), phosphate dehydrogenase, and lactate dehydrogenase (LDH) (Brooks et al., 2005). Glucose is converted to glucose-6-phosphate and later to fructose-6-phosphate with the help of catalyst such as hexokinase. Fructose-6-phosphate is later converted to fructose-1, 6-phosphate, this process consumes ATP and generates ADP and H^+. Fructose-1,6-phosphate is then converted to glyceraldehyde-3-phosphate. Phosphate dehydrogenase catalyses next step of conversion of glyceraldehyde-3-phosphate to 1,3 diphosphoglycerate. This process requires mitochondrial necotinamide adenine dinucleotide (NAD^+) and additional phosphate and leads to the production of reduced form of necotinamide adenine dinucleotide (NADH) and additional H^{+}. The process continues further and leads to the production of ATP through conversion of phsphoenolpyruvate to pyruvate with the help of pyruvate kinase. However, during the periods of reduced mitochondrial oxygen, availability of NAD^{+} required for the said reactions diminishes. Hence, pyruvate gets converted to lactate (Gollnick et al., 1986; Brooks et al., 2005). Figure 2 further explains the process of glycolysis.

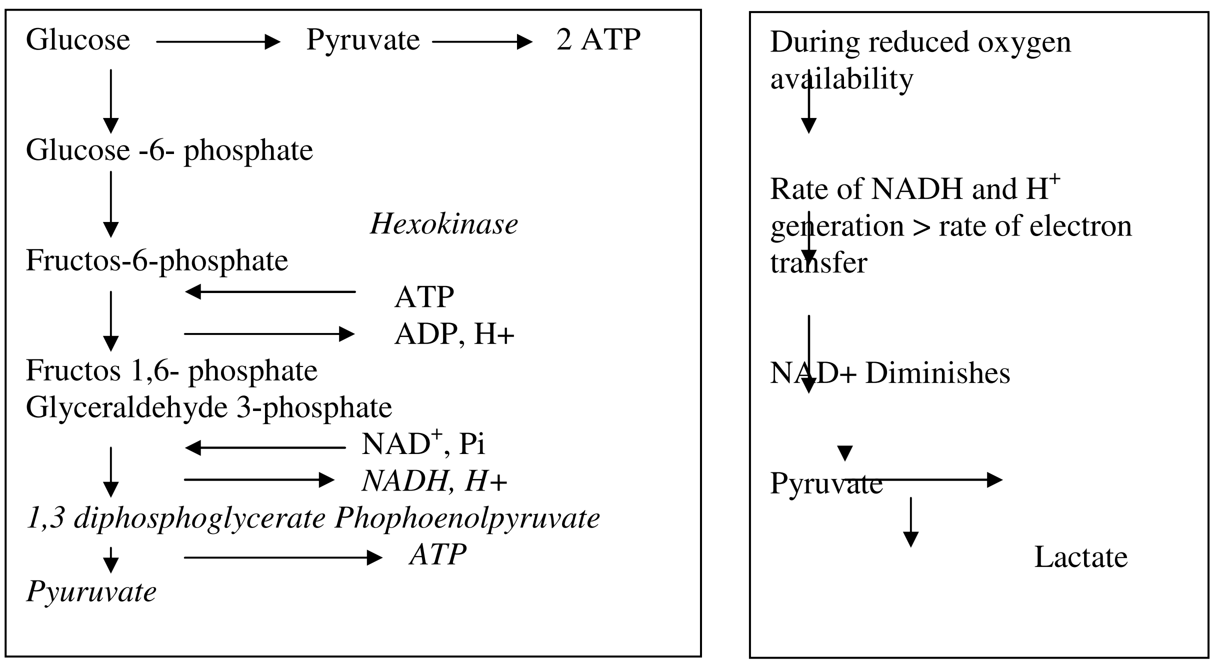

Figure 2 – Glycolysis and accumulation of lactate.

Thus, glycolysis results in the formation of pyruvate, NADH, H^{+}, and ATP. ATP can be utilized for muscle contraction and the pyruvate, NADH and H^{+} further processed in the mitochondria. This is key because NADH and H^{+} can pass electrons across the mitochondrial membrane to NAD^{+}. These NADH and H^{+}, in addition to those formed in the Kreb's cycle; provide electrons to oxygen through the electron transport chain to generate additional ATP and water (Bergeron, 1991).

One fate of pyruvate is oxidation that can yield additional ATP. This process also takes place in the mitochondria, where pyruvate is converted to acetyl CoA. Acetyl CoA enters Kreb's cycle to be oxidized to carbon dioxide. Eventually, ATP is formed as electrons are transferred to oxygen. This process is known as aerobic respiration (Bergeron, 1991).

Another fate of pyruvate, that occurs when NADH and H^+ begins to accumulate in the cytosol faster than the electrons can be transferred across the mitochondrial membrane; such as during long and intense activities which can affect availability of oxygen. Under very high energy demands, the NADH and H^+ must be converted to NAD^+ to allow glycolysis to continue. In this situation the available pyruvate is reduced to lactate to facilitate the rapid regeneration of NAD^+ and the continued rapid prodcution of ATP via glycolysis. This process facilitates continuous glycolysis but results in less ATP generation and increased lactate production (Wassermann, Beaver, & Whipp, 1986).

The Fate of Lactate

The fate of lactate is characterized by the shuttling of lactate and H^+ out of the muscle cell, which in turn, decreases blood ph. This process is known as intracellular lactate shuttle (Brooks et al., 2005). The intracellular lactate shuttle permits NADH, H^+ and a substrate for oxidation to gain entry in the mitochondria. This transport mechanism is important as NADH, H^+ and other substrates for oxidation are poorly defused across the mitochondrial membrane. Thus, lactate formed as the result of fast glycolysis functions as a carrier and gets oxidized to produce energy. However, during the periods of reduced availability of oxygen, lactate and H^+ accumulate. As previously discussed, these acidic conditions result in muscle fatigue and limit performance. Many athletic events include long and/or strenuous activities and are limited by lactate and ph induced fatigue.

Necessity of Resistance Training for Improvement in Lactate Tolerance

A previous study conducted using soccer players indicates that lactate tolerance or anaerobic threshold is a better determinant of training status than $\dot{V}O_2max$ (Clark, & Edwards, 2004). Training status refers to the physical ability of athlete to cope with the energy demands of an activity. In this study, twelve professional soccer players were tested on three occasions for $\dot{V}O_2max$ and lactate threshold. Tests were conducted during the off-season, following five weeks of conditioning and at the end of the season. There was no significant difference found in the $\dot{V}O_2max$ between the two tests (from 63.3 ml.kg.min to 62.1 ml.kg.min); however, inflection points on lactate curve shifted upwards when compared to the $\dot{V}O_2max$. This indicates that, lactate tolerance was significantly increased which was due to the training and actual performance during the season. There were no actual changes in the aerobic capacity; however the duration of lactate tolerance at the aerobic capacity was increased significantly, suggesting that lactate tolerance is the better indicator of training status of athletes. The study also indicates that lactate tolerance can be improved with game practice and actual performance during the season which consists of aerobic as well as anaerobic activities that occur during soccer.

However, such improvement in lactate tolerance may have subsequent physiological adaptations, which can be detrimental to other important conditioning parameters such as power. Increased aerobic training can have negative implications on muscle girth and size. Decrements in the size and girth of a muscle diminish the muscular strength as well as potential for power production (Dudley & Djamil, 1985). Such chain reactions eventually affect athletic performance in field sports. It has been observed that excess aerobic training during the season, coupled with regular participation in an athletic event leads to the loss of lean muscle mass and decrease in $\dot{V}O_2max$ (Miller et al., 2007). In this study, 26 division I women soccer players were examined for body composition and aerobic capacity on three different occasions during the season. Participants were tested in April (after a 15 week strength and conditioning program), in August (after 12 weeks of summer strength and conditioning program) and in December (at the end of the regular season). The results of the study showed no significant differences in the body composition and aerobic capacity between April and August. However, there was a significant increase in the fat mass at the end of the season (18.78%) as compared to the readings at the beginning of the season (16.24%). Subsequent to changes in the body composition, aerobic capacity also decreased (absolute by 4% and relative by 22%). There was little change in relative $\dot{V}O_2max$ due to the observed decrease in the body weight despite the increase in fat mass. This is a clear indication of a loss of muscle mass which has resulted in an apparent increase in the fat mass percentage and decrease in the aerobic capacity. Primary reasons for these negative effects include lack of resistance training during the season due to the time constraints and the practice of taper. The study concludes that, the lack of resistance training may not be compensated for by increased aerobic activity in practice and during the actual play. This holds true for non-starters and beginners as well.

A complete lack of resistance training, coupled with increased amounts of aerobic activities may lead to undesirable physiological adaptations such as those observed in the study by Miller et al. (2007). In addition, any loss of muscle mass may result in muscle imbalance; which in turn, could lead to musculo-skeletal injury and loss of power (Fry et al., 1994). Sports like soccer impose significant aerobic activities during the course of the game. Modifications in the exercise regimen are necessary in order to compensate for the undesired physiological adaptations imposed by the nature of the game. Thus, it is important to continue resistance training during the season, coupled with alteration of intense aerobic exercises.

A study indicated that excess aerobic training may have detrimental effects on strength gains and power production (Nelson, Arnaal, Loy, Silvester, & Conlee, 1990). In this study, 14 untrained men were divided in three groups. Group one performed isometric leg extensions four days a week. Training consisted of 3 sets of 6 maximal repetitions (reps). A second group performed endurance activity on a leg ergo meter. A third group performed a combination of both activities with resistance training always preceding endurance training. Training duration remained the same for all groups. The results indicated that torque power had a non significant increase of 10% in the endurance training group as compared to the increases of 64% and 28% in resistance training and combination groups respectively. In addition, the endurance training group observed subsequent hypertrophy in type I muscle fibers as compared to type II muscle fibers which are efficient in power production. In the light of such findings regarding physiological adaptations of various training modes, it is important to evaluate training practices that can facilitate improvements in lactate tolerance with minimum undesired physiological adaptations associated with current practices. Observations of previous studies indicate that resistance training and explosive power movements can be used for this purpose.

Role of Resistance Training and Explosive Power Movements in Lactate Production and Clearance

Several studies have evaluated the effects of resistance training on lactate production. Studies conducted by Brown, Thompson, Bailey, Johnson, & Wood (1990), Pierce et al. (1993), and Zajac, Waskiewicz, & Pilis (2001) have observed significant increase in the lactate production following various modes of resistance training. A study conducted by Paton el al. (2005) indicates the efficacy of combining explosive and resistance training to improve lactate tolerance. However, little is known about the effects of explosive training alone on actual lactate production.

A study was conducted to evaluate the effects of resistance training on lactate production in weight trained and endurance trained men (Brown et al., 1990). Participants (n=15) with different exercise history were divided in to three groups of untrained, weight trained and endurance trained athletes and they participated in three sets of leg presses until exhaustion at 60%, 70% and 80% of one rep max (1RM). The results showed that weight trained men have blood lactate levels of 10mmol/l at 80% as compared to 6mmol/l and 5.5mmol/l of blood lactate in untrained and endurance trained men respectively. The trend was similar at the other workloads. This result indicates that specific adaptations to weight training include improved capacity of working at high intensity. It is possible that conversion of type IIA muscle fibers to type IIB is the mechanism responsible for the process. Type IIB muscle fibers have shown greater glycolytic enzyme activity and hence, greater ability to produce more lactate (Jones & Ehrsam, 1982). However, further research is required.

Results also indicated higher lactate tolerance in the endurance group during the $\dot{V}O_2max$ test. This was possibly due to the higher lactate clearance rate imposed by endurance training. However, the difference in lactate levels in the two groups of trained participants; when adjusted for relative aerobic capacity was non-significant. This indicates that resistance training with enhanced lactate production coupled with an aerobic activity to increase lactate clearance may work to enhance lactate tolerance. However, further research is required to determine the efficacy of resistance-only training to improve lactate tolerance.

One study has reported reduced lactate levels at similar intensity following eight weeks of resistance training (Pierce et al., 1993). The study was conducted on 23 untrained male participants who were divided into two groups. One group served as a control group while the second group underwent eight weeks of resistance training comprised of contemporary resistance exercises such as bench press, squats, shoulder press and leg curls among others. The protocol was performed twice in a week. The volume patterns included 3 sets of 10 RM for the first three weeks, 3 sets of 5 RM for the next three weeks and 2 sets of 10 RM for the last two weeks. Peak lactate levels dropped significantly from 11.9mmol/l in pre-training test to 5.1mmol/l in post-training test in the experimental group. The change in peak lactate level was insignificant in the control group. It was observed that, resistance training may facilitate changes in blood lactate levels at similar intensity. However, further research is required to evaluate whether such changes are due to the decreased lactate production or improved lactate clearance.

Another study conducted on 10 male bodybuilders corroborates the association of weight training with greater lactate response (Zajac et al., 2001). In this study, participants underwent 10 sets of squats and 10 sets of bench press, designed in a progressive volume pattern (volume increased with every set). Lactate levels were significantly higher at the end of the training session. However, lactate levels of lower limbs showed greater increases (from 2.11mmol/l to 15.28mmol/l) compared to increases in the lactate levels of upper limbs (from 1.96mmol/l to 5.99mmol/l). The results of this study indicate that larger muscle groups and compound movements contribute more in lactate production. This result supports the notion of the use of compound movements of explosive power training to produce higher lactate levels as a contributor to the training regimen aimed at improving lactate tolerance.

Another study indicates that a combination of explosive training and high-resistance training may assist in improving lactate tolerance (Paton & Hopkins, 2005). Cyclists (n=18) were divided into two groups. One group served as a control group and performed a routine in-season exercise regimen. The experimental group replaced part of its normal routine with a 30 minute explosive session comprised of 3 sets of 20 single leg jumps (each leg) and 3 sets of high resistance cycling sprints for 5 to 30 seconds. The exercise routine lasted for 12 weeks. Data collected during a two stage sub maximal test indicates that power production at LT increased in experimental group (from 1.7% to 5.5%) when compared with little increase in aerobic capacity. However, no effects on actual lactate concentration were reported; hence, the mechanism behind the increase in the lactate cannot be determined.

Lack of sufficient data and discrepancies in the previous studies warrant further research in this area, especially the effects of explosive power training on lactate production, with a view to improve lactate tolerance. Olympic style weight lifting movements are commonly used explosive training performed in an athletic setting. However, few studies have evaluated whether the physiological adaptations to these movements are identical to resistance training for enhanced lactate production (Gupta & Goswami, 2001). Five male weight lifters performed three different volume patterns of clean and jerk and snatch on three different days. Pattern one comprised of one set of 1RM, performed on the first day. Pattern two comprised of multiple sets sessions in one day. Multiple sets (6) of both exercises at 50% of 1RM for 6 reps, 60% of 1RM for 5 reps, 70% of 1RM for 4 reps, 80% of 1RM for 3 reps, 90% of 1RM for 2 reps and 100% of 1RM for 1 rep. The rest period between each set was constant at 3 minutes. The third volume pattern comprised loads and numbers of reps similar to that of volume pattern two; however, exercise at each workload was performed on separate but successive days. Blood lactate levels were tested at 2-3 minutes after the completion of each set. Lactate levels were highest at the midpoint (70% to 80% of 1RM) of the multiple set patterns (18.11mmol/l to 19.8mmol/l) as compared to the other two volume patterns (11.6mmol/l in third pattern and 3.05mmol/l in the first pattern). In addition, using the clean and jerk led to greater lactate accumulation than the snatch in all volume patterns. The results of this study indicate that Olympic style weight lifting can stimulate sufficient lactate production in order to overload the lactate clearance mechanism. However, the limited numbers of participants in this study limit the validity of the results. Moreover, the effects of different volume patterns with similar rest periods on lactate production are yet to be evaluated.

Olympic Style Lifts Training

The common movements in Olympic style weight lifting training include the clean and jerk, cleans, the snatch, the push jerk and the clean pulls (Baechle & Earle, 2008). Previous study has observed more lactate production in the clean and jerk than in the snatch (Gupta & Goswami., 2001). Similarly, it can be hypothesized that cleans would produce greater lactate than snatch.   This can be due to the complexity of the movement of the clean and jerk, and clean and also due to the fact that more weight can be lifted in the clean and jerk, and clean than in the snatch. Little is done to evaluate the effects of other Olympic style lifts on lactate production. The variations in the clean and jerk, clean and the snatch include power movements (Movement is initiated by lifting the dead bar on the floor) and hang movements (movement is initiated by moving the bar from the knee height). The power clean is more common than any other form of Olympic style lifts in training practices of athletes. In addition, it is a subjective observation that maintaining the correct form and technique is easier in the power clean than in the snatch or in other types of Olympic lifts training. This is key as incorrect form may lead to undesired or deceiving physiological responses such as reduced lactate production due to little use of large muscle groups. Moreover; incorrect form, coupled with high numbers of reps may lead to musculo- skeletal injuries. Hence, the power clean is the preferred Olympic style weight lifting activity for this study.

Table 1 Review of studies on role of resistance training and explosive power movements in lactate production and clearance.

Authors	***Year Published***	***Participant***	***Methods***	***Results***	***Significance***
Brown et al.	1990	15 males with different exercise history such as untrained, weight trained and endurance trained	Participants divided in three groups (untrained, weight trained and endurance trained). Performed 3 set of various resistance training exercises until exhaustion at 60%, 70% and 80% of 1RM	Blood lactate levels at 80% protocol – Weight trained – 10mmol/l Untrained- 6 mmol/l Endurance trained – 5.5 mmol/l	Adaptations to weight training Improved capacity to work at high intensity. Endurance trained athletes may have greater lactate tolerance.

Pierce et al.	1993	23 untrained males divided in experimental and control group.	Untrained participants performed strength training for 3 weeks. Volume patterns – 3sets * 10RM, 2*5 RM, 2*10RM	Exp group – Peak lactate levels – Pre training- 11.9mmol/l Post training- 5.1mmol/l Control group- No change.	Strength training may alter blood lactate levels at similar intensity. Mechanism behind change is unclear.
Zajac et al.	2001	10 male bodybuilders	Bodybuilders completed 10 sets of squats and 10 sets of bench press (Designed in progressive pattern)	Lactatelevels Lower limb Pre – 2.11mmol/l Post- 15.28mmol/l Upper limb Pre- 1.96mmol/l Post- 5.99mmol/l	Larger muscle groups and compound movements generate greater lactate.

Paton & Hopkins	2005	18 male cyclists divided in control and experimental groups.	Control- regular in season exercises Experimental- 30 mins of explosive session (Replaced)	Lactate power profile increased by 1.7% to 5.5 % (Experimental group)	Insignificant effects on actual lactate concentration No change in aerobic capacity Mechanism unclear
Gupta & Goswami	2001	Five male weight lifters	Participants performed three different volume patterns of clean and jerk and snatch	Lactate levels highest in pattern 2 (18.1 mmol/l	Olympic style weightlifting can generate

		Pattern 1 – 1set*1RM Pattern2- 6sets* 6,5,4,3,2 and 1 reps for 50%,60%,70%,80%,90% and 100% of 1RM respectively; 3 minutes rest intervals. Pattern 3- Similar volumes with 24 hours of rest interval between each load percentage.	to 19.8mmol/l) Compared to other two pattern (9.5mmol/l and 3.5mmol/l respectively)	sufficient lactate to overload lactate clearance mechanism.

CHAPTER 3: METHODS

The purpose of this study was to evaluate the effects of different volume patterns of power clean on lactate production. This may serve as a prelude to the study evaluating the effects of Olympic style weight lifting for improving lactate tolerance.

Subjects

Olympic style lifts require specific set of techniques. Moreover, Olympic style lifts are a common practice in a competitive as well as recreational athletic population. Hence, an athletic population (recreational as well as competitive) was deemed to be more familiar with the skill set required for Olympic style lifts. In addition, use of untrained participants or trained participants with little experience of Olympic style lifts may have generated questionable results either due to inefficiency of movement due to lack of familiarity or due to the overwhelming physiological adaptations of completely unfamiliar training. Little is done to evaluate the effects of Olympic style lifts in female athletes. Hence, due to the lack of referring literature, this study utilized only male athletes as participants.

The design of this study required participants to perform high volume of power clean (9 reps). Such high volume is not consistent with current Olympic style lift training practices for competitive athletes. Thus, trained male recreational athletes (N=10) between the ages of 18 and 30 years (24.22 years ±1.39) volunteered for this study. All participants were screened for the study contraindications. Qualified participants signed a consent form prior to participation (Appendix C). All participants were recruited through word of mouth, and advertizing flyers posted on bulletin boards of Boise State University. The Boise State University Institutional Review Board for the protection of human participants in research approved this study (BM 103-09-014).

Compliance with Technique

The technique and form of the power clean was monitored according to the guidelines of the National strength and conditioning association (NSCA) (Baechle & Earle, 2008). The movement of the power clean consisted of quickly and forcefully pulling the bar from the floor to the front of the shoulders in one explosive movement with the help of the extension at ankles knees and hips. At the beginning position, participants stood with feet hip width apart and their toes pointing slightly outward. Participants, then squatted down, keeping their hips below the shoulders and held the bar in a pronated grip. The distance between two hands was monitored to be slightly wider than the shoulder length of the participants. Up to this point, participants were instructed to keep their elbows fully extended. Participants maintained following body positions during this phase.

1. Flat back
2. Shoulders square and above the bar
3. Knees above the bar
4. Shins close to the bar, Toes directly underneath the bar and facing slightly outwards.

During the upward movement phase; also known as the first pull, participants lifted the bar off the floor while extending their knees and hips. It was monitored that participants maintained a flat back position without extending their hips before raising the shoulders. In addition, participants were instructed to keep the bar as close to their shins as possible. The next phase is known as transition phase or scoop. In this, participants raised the bar just above the knees while keeping the elbows fully extended and pointing outwards; and their back flat or slightly arched. The next phase which was followed is known as the second pull. During this phase, participants explosively extended ankles, knees and hips while keeping the bar as close to the body as possible with elbows fully extended and facing outwards and head in line with the vertebral column. After the complete extension of lower body joints, participants forcefully shrugged the shoulders without flexing the elbows. After the complete elevation of shoulders, participants abducted the arms to pull the elbows as high as possible and flexed the elbows while pulling the body underneath the bar. During the last phase of the movement; known as the catch, participants pulled their body under the bar and rotated their arms around and under the bar. Participants were monitored such that they maintained following body positions at the end of the movement.

1. The hips and knees are flexed in to a quarter squat positions.
2. Upper arms are parallel to the floor
3. The bar is racked across the front of clavicles and anterior deltoids.

Figure 3 shows the accurate movement of power clean.

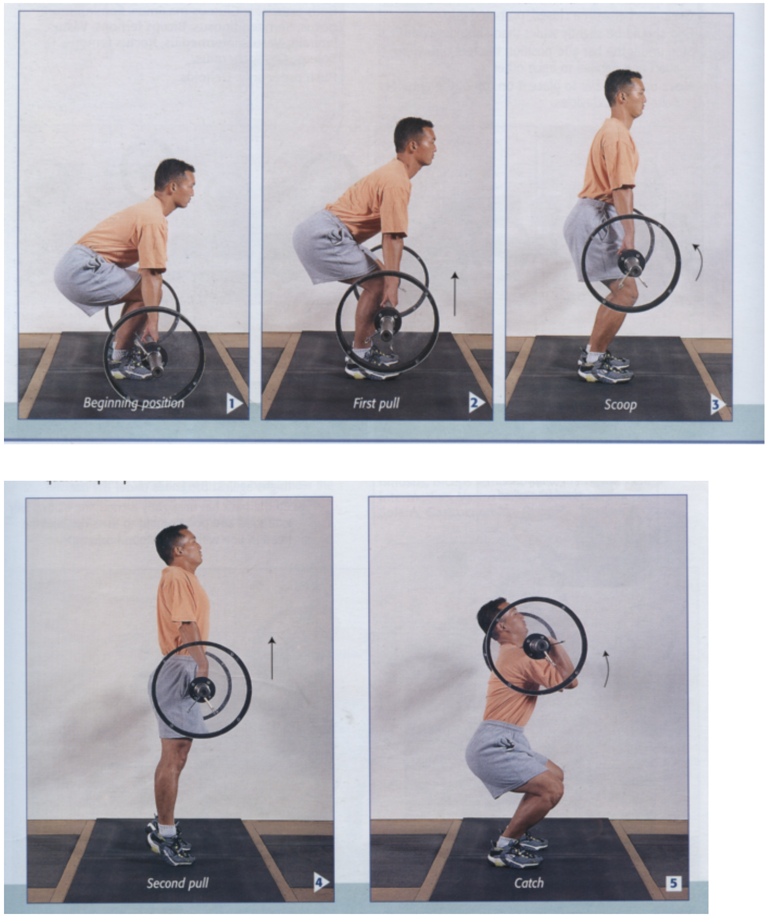

Figure 3 – Movement of Power Clean (Baechle & Earle, 2008)

Volume Patterns

As mentioned before, the common practice of Olympic lifts training in athletic settings incorporates volume patterns which do not go beyond the repetition range of 3-6. This is due to the belief that it is difficult to maintain correct technique during high reps Olympic style weight lifting. However, no study has examined this philosophy in detail. In addition, no study has evaluated the effects of Olympic style lifts training with the repetition range of 6-9 on lactate production. Hence, this study incorporated three different repetition ranges of three, six and nine reps of the power clean movement. Three sets were performed for each repetition range. The numbers of sets were determined according to the common norm and guidelines of current athletic practices (Fleck & Kraemer, 1988; Fleck, 1999).

The relationship between load, reps, sets and the rest period was important in determining volume. Previous authors have stated the importance of RM in determining the intensity of the resistance training activity (Kramer et al., 1997). Data derived from studies conducted by Lander (1984), Brzycki (1993) and Chapman, Whitehead, & Binkert (1998) have been used to determine the association between specific numbers of reps and the percent of 1 RM. These estimations propose approximate association of 93%, 85% and 77% of 1 RMs with three, six and nine reps respectively (Baechle, & Earle, 2008). However, different studies point out that in power lifts; maximal power is reached at intermediate velocities and with moderate loads. (Knuttgen & Kraemer, 1987; Newton, Kraemer, Hakkinen, Humphries, & Murphy, 1996). Therefore, load percentages for power exercise will be less than previously identified for the same number of reps in conventional resistance exercises.

In this study, a more practical approach was taken in determining load-reps component of volume. Participants were evaluated for 3RM and the loads for six and nine reps were determined according to the performance during the 3RM set. The performance was evaluated on the basis of ability to maintain the technique and subjective symptoms of excess fatigue such as heavy breathing and muscle pain. In order to comply with the volume patterns, it was important to successfully perform the specified numbers of reps. In Olympic style lifts; the quality of performance is influenced by the level of technique (Hedrick & Wada, 2008). Subjective observation of athletes who performed high repetition ranges of power cleans; coupled with discussions with the experts in the industry (e.g. Mr. Mike Conroy, Olympic weight lifting Coach, USOC) indicated that uniform load percentage for all participants, irrespective of the skill level of the participant would increase the possibility of failed sets and a subsequent risk of injury. Therefore, percent loads in all volume schemes were subject to individual skill levels and ability to successfully complete the set.

The rest period was an important parameter to ensure optimum performance due to its role in determining energy pathway. Current guidelines indicate the rest periods of 2-3 minutes between the sets of 3-4 reps of explosive power movements (Baechle & Earle, 2008). Thus, the rest period between each set for all volume patterns was maintained at 2 minutes.

Lactate Analysis

Blood lactate was analyzed at the beginning and at the end of every session using a digital lactate analyzer (Lactate plus, Nova Biomedical, Waltham, MA). The device required only 0.7 micro liters of blood. Researchers have determined that the Lactate plus device meets current clinical standards (Ridenour, Gada, Brost, & Karon, 2008). The blood was drawn from the tip of the index finger.

Previous researchers have determined resting blood lactate levels to typically be at or below 2.5 mmol/l (Cerretelli et al., 1975). Efforts were made to maintain pre-exercise blood lactate at resting levels; however, administrative limitations coupled with inter participant's variability in readings generated the necessity of calculating relative increase in blood lactate levels (Relative increase = [Post activity lactate – Pre activity lactate / Pre activity lactate]*100).

Procedure

Olympic style lifts training session and subsequent blood lactate analysis were conducted at the Bronco Weight room and at Boise State Campus Recreation Center located on Boise state University Campus. Participants performed one volume pattern on each day. Three total days were required for each participant to complete the study. A rest period of 48 hours was observed between the training days. Participants refrained from participating in any physical activity within 24 hours of the training day.

Standard procedure on a typical testing day was as follows:

1. Participants arrived at the designated testing place (Bronco Weight room or Boise state University recreation center).
2. Five minutes of passive rest was followed by collection of resting blood lactate levels.
3. Participants participated in a 5 minutes of warm up activity of their choice. Typically, this activity consisted of dynamic stretching and low intensity resistance training exercises.
4. Participants performed three sets of power clean complying with the stipulated volume pattern of the day.
5. Immediately after the cessation of exercise, Post activity blood lactate levels were measured.
6. Participants were instructed to perform cool down activities consisting of static stretching. Participants were closely monitored for any signs of discomfort.
7. At the completion of cool down activities, testing procedures were concluded.

Statistical Analysis

Statistical analysis was performed with SPSS version 17.0 (SPSS Inc, Chicago). Repeated measure ANOVA was used to test the hypothesis. In the present study; volume pattern was the independent categorical variable which had three different groups in form of three volume patterns, thus, use of the test of ANOVA to test the hypothesis of this study is justified. Previous studies with similar hypothesis and sample size have used the alpha level of 0.05 (Hamilton et al., 2006). Therefore, the alpha level for the data analysis was determined at 0.05 levels. The degree of freedom used for the analysis was 2. Linear correlation was run between weight lifted by participants and relative increase in blood lactate. In addition, multiple regression was run to examine the effect of interaction between Load, reps and sets as volume on Lactate response.

CHAPTER 4: RESULTS

This study primarily focused on effects of exercise volume on lactate response. Since, exercise volume determines the degree of physiological demand, it was hypothesized that blood lactate response will increase for each increase in volume pattern.

Ten healthy male recreational athletes (24.2 yr ±1.39, range 21 – 29) from the population of Boise State University participated in the study. The mean weight lifted (±sd) for three reps was 82.67 Kg ±15.72 Kg (Table 2). The mean weight lifted for six reps was 69.8 Kg ± 11.65 Kg. The mean weight lifted for nine reps was 60.3 Kg ± 10.28Kg. In addition, the total volume of each volume pattern was calculated (Volume = Sets*load*reps). The mean volume for volume pattern I was 744.03kg ±141.53kg. The mean volume for volume pattern II was 1256.4kg ±209.87kg. The mean volume for volume pattern III was 1628.1kg ±277.64kg. (Appendix A, Table 4).

According to the scientific literature, 3RM for the resistance training exercises is estimated to be 93% of 1RM while 6RM and 9RM are at 85% and 77% respectively (Baechle, & Earle, 2008). However, it has been suggested that the Olympic style lifts require a lower relative RM due to the relationship between force and velocity (Knuttgen & Kraemer, 1987; Newton et al., 1996). This was validated here by associating the mean load lifted for 6RM and 9RM in this study with the approximate load percentage of 80% and 70% of 3RM respectively.

The average blood lactate levels (±sd) for volume pattern I was 2.04 mmol/l ±0.84mmol/l prior to exercise and 4.03 mmol/l ± 1.78mmol/l after the completion of three sets of three reps (Table 2 and appendix A, Table 5). The average blood lactate levels for volume pattern II was 2.37 mmol/l ±1.40mmol/l prior to exercise and 5.27 mmol/l ±2.48mmol/l after the completion of three sets of six reps. The mean blood lactate levels for volume pattern III was 1.96 mmol/l ±1.36mmol/l prior to the exercise and 7.43 mmol/l ±2.94mmol/l after the completion (Figure 4). In addition, when the relative increase was analyzed; it was observed that higher volume is associated with higher lactate response as volume pattern III showed mean relative increase of 356.34% as opposed to mean relative increase of 110.42% and 153.51% in volume pattern I and II respectively (Figure 5 and Appendix A, Table 6). From figure 5, it can be seen that there is a significant difference in relative blood lactate increase in all volume patterns.

Linear correlation was run to evaluate how the training statuses of participants influenced the lactate response. Insignificant correlation was found between weight lifted in volume patterns I & II and the subsequent relative blood lactate increase (r= 0.1), (r= -0.34) respectively. However, there was a significant correlation between weight lifted in volume pattern III and subsequent relative blood lactate increase (r=0.55). Statistical power for this study was observed to be at 0.24.

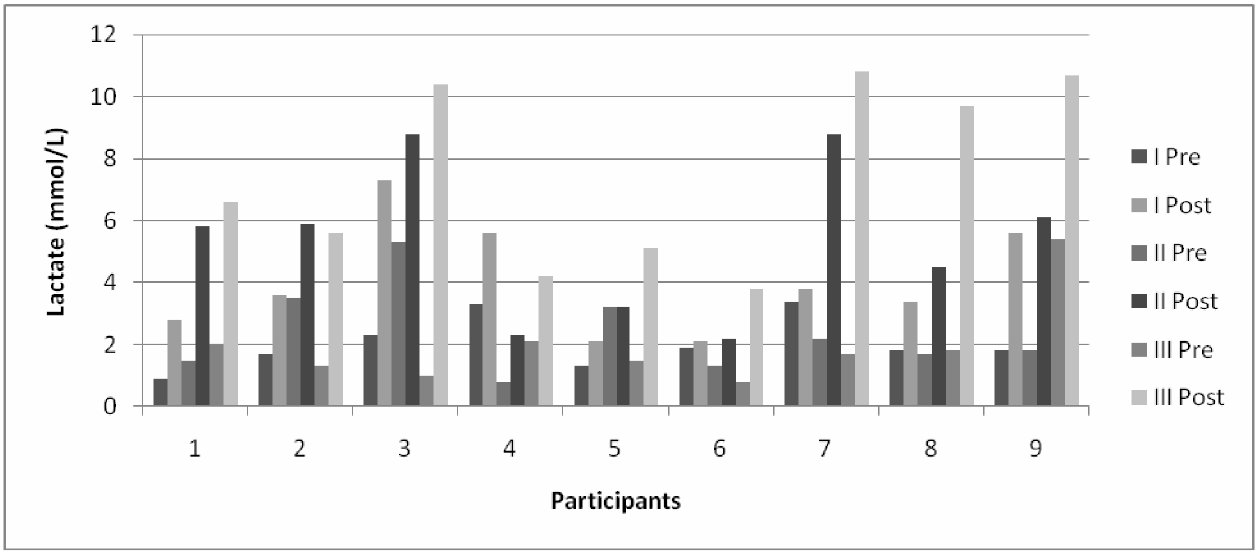

Figure 4 Lactate Response of Each Participant for All Volume patterns

I pre	Pre-exercise lactate level for volume pattern I
I Post	Post-exercise lactate level for volume pattern I
II pre	Pre-exercise lactate level for volume pattern II
II Post	Post-exercise lactate level for volume pattern II
III Pre	Pre-exercise lactate level for volume pattern III
III Post	Post-exercise lactate level for volume pattern III

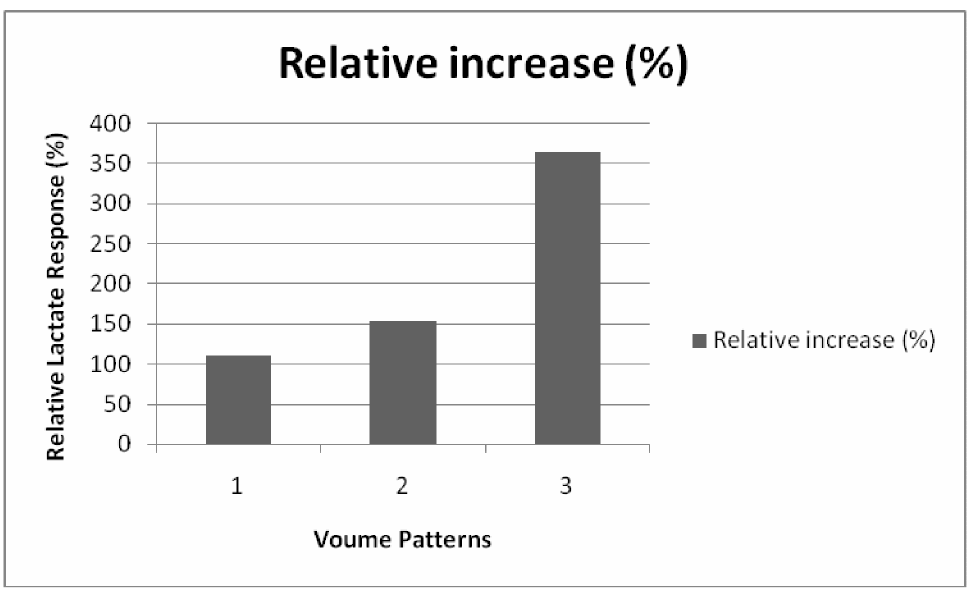

Figure 5 Mean Relative Increases in Blood Lactate Levels in All Volume Patterns

Table 2 provides Pooled data of mean load, mean volume, mean blood lactate levels and mean relative increase in all volume patterns.

Volume Pattern	**Mean (± sd)**		**Blood lactate levels**		
	Load	Volume	Pre (±sd)	Post (±sd)	Relative increase (%) (± sd)
I	82.67(±15.72)	744.03(±141.53)	2.04(±0.84)	4.03(±1.78)	110.42 (± 83.62)
II	69.8 (± 11.65)	1256.4(±209.87)	2.37 (± 1.4)	5.27(±2.48)	153.51 (± 108)
III	60.3 (± 10.28)	1628.1(±277.64)	1.96(±1.36)	7.43(±2.94)	365.34 (± 260.2)

Pre- Pre-exercise blood lactate levels
Post- Post-exercise blood lactate levels
Volume- Load*reps*sets

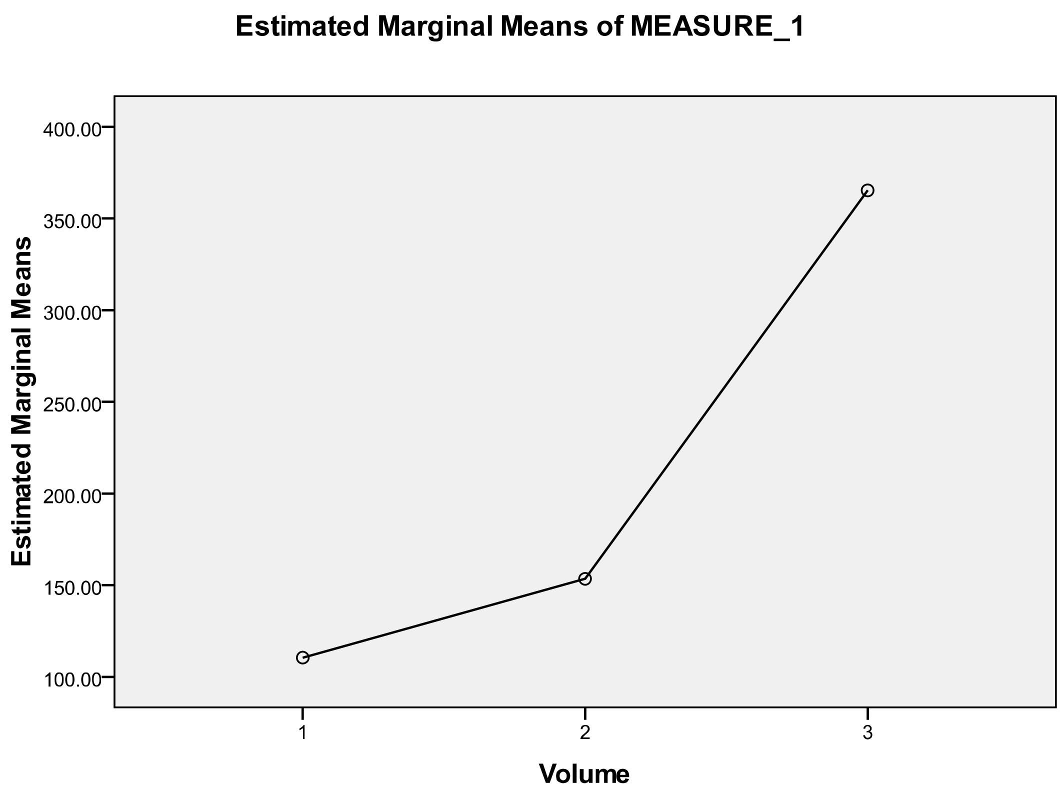

Figure 6 – Interaction between volume patterns and relative percent increase in lactate response.

Notes-
X Axis – Volume patterns
Y Axis – Percent increase in mean blood lactate response

Compliance with Hypothesis

It is important to determine the assumption of sphericity before the use of repeated measure ANOVA. Table 7 in Appendix A shows the Mauchley's test of sphericity. Since, $p< 0.05$, it is verified that Assumption of sphericity is violated. Table 8 in Appendix A shows the test of within subject effects conducted as per the test of repeated measure ANOVA. Since, $p < 0.05$, the null hypothesis is rejected.

Multiple regression was run to evaluate how the interaction between load, reps and sets; as a volume, influence the lactate response. It was observed that, changes in load and reps significantly and positively influenced the lactate response ($p<0.05$); indicating that increase in volume as an interaction between load and reps positively influence lactate response, as set was considered as a constant variable. The slope (β) for load and reps was observed at 2.52 and 51.89 respectively (Appendix A, Table 9).

Therefore, the results of the study are that; there is a difference in pre and post-exercise blood lactate levels after the completion of three different volume patterns of power clean and that this difference is greater with greater volume.

CHAPTER 5: DISCUSSION

This study was designed with the primary purpose of analyzing difference in blood lactate response following the completion of three different volume patterns of power clean exercise. Two key findings of this study are 1) the difference observed in lactate response to different volumes and 2) the association observed between higher volume and higher lactate response.

Prior to analyzing the possible explanations for the findings, it is necessary to contemplate the study design. The volume of the exercise was the influential variable in measuring the lactate response. Various factors such as load, reps, time under tension and bar displacement among others influence the volume (Pauletto, 1986; Pauletto, 1985). The volume, in this study was measured as Load*Sets*Reps. After quantifying four different methods of calculating volume; which consisted of the volume- load method (Load*reps), maximum dynamic strength method, time under tension method and total work method; McBride et al. (2009) observed that the volume-load method can have flaws in accurately measuring volume when no external resistance is used (McBride et al., 2009). However, methods like time under tension cannot be used accurately in power movements as the time spent in movement is considerably less than other forms of resistance training. Thus, when compared to other methods, the simplicity of calculating volume through the volume- load equation was considered more practical for this study.

It was necessary to understand the volume design of this study as differing results have been observed in this study when compared to previous studies. As discussed earlier, the percent load of estimated 1RM was less when associated with higher number of reps. In addition, Multiple regression observed greater slope (β) associated with reps (51.89) as compared to load (2.52). Therefore, this study observed that lactate response is largely dependent on volume as determined by the load-volume method. This is in contrast with propositions put forward by Reynolds. Frye & Sforzo,. (1997) who analyzed long term effects of resistance training on lactate response and proposed that blood lactate response is largely dependent on percentage of 1RM.To corroborate the association between higher lactate response and load; Robergs et al. (1991) concluded that the rate of glycogenolysis was twofold greater during leg extension at 70% of 1RM than 50% of 1RM, possibly due to the greater involvement of type II muscle fibers (Robergs et al., 1991). While findings of these studies give clear indications that lactate response in resistance exercise is largely dependent on load, observations made in the present study, coupled with observations by Abernethy & Wehr (1997), Gupta & Goswami (2001), and Rozenek, Rosenau, Rosenau & Stone (1993) observe that lactate response in resistance training is determined by volume.

Rozenek et al. (1993) observed that, in bench press exercise; when numbers of reps are constant; there is an association between elevated lactate response and higher volume. This study analyzed the volume of bench press exercise performed for 10 reps at 50% and 70% of 1RM. Mean 1RM for this study was at 87.4 kg. Therefore, 10 reps performed at 70% of 1RM measured the volume of 611.8 kg. Mean blood lactate response generated at this volume was 9.5mmol/l which is higher than mean lactate response generated at 50% of 1RM (2.5mmol/l). These observations are similar to the present study in which type III volume pattern with highest number of reps (9) but smallest amount of load percentage has yielded greatest volume and lactate response.

In addition, Abernethy & Wehr (1997) observed three times higher blood lactate response in three sets of 15RM leg press exercise with the volume of 3210 kg when compared to 5RM protocol with the volume of 1275kg. Gupta & Goswami (2001) observed up to 14mmol/l of blood lactate response to the volume of 6 reps of clean and jerk at 50% of 1RM, which is significantly higher than the 9.3mmol/l of blood lactate response reported for the volume of 3 reps at 80% of 1RM.

The literature indicates that lactate production occurs more in type II muscle fibers and in larger muscle groups (Jones & Ehrsam, 1982; Robergs et al., 1991). In addition, Shimano et al. (2006) reported that larger muscle groups can perform more reps for the given intensity when compared to smaller muscle. Previous studies with similar findings to the present study have used conventional resistance training exercises such as bench press and leg press (Abernethy & Wehr, 1997; Rozenek et al., 1993).These studies have shown similar pattern in lactate response; however, relative increase in lactate response remain higher in the present study. The greater number of reps performed in this study at relatively similar volumes can be accounted for the greater use of larger muscle groups and increased use of type II muscle fibers in power movements compared to the conventional resistance training exercises. Therefore, the differences in findings can be attributed to the more dynamic nature of power clean movements which uses large muscle groups and greater contributions from Type II muscle fibers.

Another explanation could be found in the fact that higher power output is generated at lower percentage of RM in power movements when compared to standard resistance exercises (Knuttgen & Kraemer, 1987; Newton et al., 1996). Kawamori et al. (2005) reported that, in hang power clean, maximal power output can be achieved at sub maximal load of 70% of 1RM (Kawamori et al., 2005). This is possibly due to the decreased speed of movement associated with higher loads. This load pattern is similar to the one used for nine reps volume scheme in the present study which has generated highest lactate response, thus lactate response may be associated with higher power output.

The large influence of volume on lactate response is further illustrated by the second key finding of this study. Mean percent increase was recorded at 110.42% (±83.62), 153.51 (± 108) and 365.34% (± 260.2) for volume patterns I, II and III respectively. Abernethy & Wehr (1997), Gupta & Goswami (2001), and Rozenek et al. (1993) have also reported similar increases in lactate response to higher volume exercises with larger muscles groups. Therefore, it may be possible that high volume exercise with large muscle groups generate greater lactate response.

In regards to the aforementioned findings, it is important to revisit the process of energy production through glycolysis. Bergeron (1991) reported that glycolysis results in the formation of pyruvate, $NADH^+$, H^+ and ATP. While ATP is used for energy production; pyruvate, $NADH^+$ and H^+ is further processed through aerobic respiration and electron transfer chain, respectively. When the rate of energy requirement exceeds electron diffusion, pyruvate is converted to lactate. However, in intense exercise and continued energy demand, the rate of lactate production exceeds oxidation and lactate accumulates (Bergeron, 1991).

Thus, this study confirms that lactate accumulation is closely associated with increased energy demand. It is possible that the higher volume patterns in this study overwhelmed the aerobic capacity, which may have resulted in exceedingly higher blood lactate response.

Greater time spent while performing higher volume patterns may be another determinant contributing to the elevated lactate response in volume patterns performing greater reps. Gollnick et al. (1986), and Stone et al. (1987) have reported that peak lactate levels are achieved at 2 to 3 minutes after completion of short burst activity. This phenomenon is attributed to the process of lactate diffusion from muscle to blood. This delay in lactate appearance in systemic circulation can be key to the higher lactate response with higher volume, as time spent in performing three sets of nine reps was considerably higher than time spent in performing three sets of three reps. In the light of this observation, it would be interesting to see the lactate response after a specific time frame as opposed to the lactate response at the cessation of exercise. Delayed lactate evaluation may result in greater lactate response; however, it is possible that basic differences in lactate response to different volume patterns remain the same. Coelho, Hamar, & Araujo, (2003) also reported higher lactate response to continuous exercises with moderate intensity as compared to discontinuous exercises. This finding can be important in athletic settings as most field sports such as soccer and tennis feature continuous, intense activity which can elicit a greater lactate response. Therefore, ability to produce high power output and optimal use of oxidative capacity are key to the improved performance. These fitness components can be improved with the help of higher volume power movements.

To further corroborate the findings, the study conducted by Brown et al. (1990) can be examined. They reported that; lactate response to the resistance training exercise with same intensity is higher by 30% in weight trained men than endurance trained men. Additionally; it was also observed that lactate levels in recovery phase remain significantly higher in weight trained men as compared to endurance trained men, which possibly means that higher aerobic capacity in endurance trained men facilitates greater ability to clear lactate during recovery. This could be one of the possible reasons for the individual differences in lactate response in this study.

In another study, Naclerio, Colado, Rhea, Bunker, & Triplett, (2009) reported that maximum strength and power are positively related to muscle endurance performance ($r=0.71$) and resistance training performance ($r=0.64$). In this study, it was observed through subjective as well as statistical evaluation that highest lactate levels were reported in individuals who performed at greater volume ($r = 0.55$ in volume III) and accurate technique. In power cleans; large loads cannot be lifted without accurate technique and sufficient training status (Hedrick & Wada, 2008). Therefore; in this study, load was considered as the sign of better trained status and better technique competence. This may indicate that better trained individuals tend to apply better technique, lift greater volumes and generate greater lactate responses. In the present study, the accuracy of technique was evaluated on the basis of NSCA guidelines with the help of subjective observation of key elements such as accurate positions of all the joints prior to the beginning of the movement, triple extension, ability to keep extended elbows throughout the initial phase, the depth of the catch and landing patterns among others (Baechle & Earle, 2008).

Rest interval is another important determinant of volume (Pauletto, 1985). The length of the rest interval can determine the performance in oncoming sets, thereby affecting the volume. In addition, it also affects the total time spent to complete the performance. As discussed previously, lactate diffusion from muscles to systemic circulation results in the delay of lactate accumulation (Gollnick et al., 1986).Therefore, the length of the rest interval may play a vital role in determining blood lactate levels. Longer rest intervals may generate higher volume and subsequent greater lactate levels at the onset of next set, however, it may also result in improved availability of oxygen which, in turn may facilitate greater lactate utilization during the next set. On the other hand, shorter rest intervals may overwhelm the oxidative capacity. Willardson, & Burkett, (2008) reported that higher volume is associated with longer rest periods. Thus, higher volumes at similar rest periods will account for greater physiological responses than lower volumes. Hence, the uniform rest interval of two minutes for all volume patterns in this study may have resulted in reduced availability of oxygen at the onset of next set; which in turn, may have elicited greater lactate at higher volume.

Limitations

Despite the novel findings reported, this study is not without limitations. The sample size used for this study was relatively small; thus, findings of this study cannot be generalized to larger groups with specialized features such as athletic population of specific event, female athletes or older individuals.

This can affect the practical implications of the findings as physiological responses can vary among different populations. Bellezza, Hall, Miller, & Bixby (2009) reported mean lactate difference of 6 mmol/l among men and women in response to resistance training. In addition, various sport activities impose different physiological adaptations including lactate production and clearance (Baechle & Earle, 2008; Bellezza et al., 2009).

This study used non-contemporary volume pattern of nine reps for the power clean exercise. Serious doubts were expressed about the ability of participants to maintain the technique. However, due to the unique volume pattern design of this study, the technique breakdown was minimal and it was observed that greater physiological responses are associated with accurate technique and greater absolute load. However, no efforts were made to objectively and biomechanically evaluate the technique.

Lack of uniformity in the base line lactate among participants was another limitation of this study. However, it was countered by calculating relative increase in blood lactate after the completion of activity.

Future Research Recommendations

The ability to clear lactate continuously is a vital fitness component among most athletes and it is important to determine training tools which can generate greater results with minimal unwanted physiological adaptations. In the light of this, the findings of this study can be used to further investigate the efficacy of explosive power movements in improving lactate tolerance.

The basic ideology here is to incorporate active recovery phases along with actual high volume power movements thereby maximizing the ability to utilize the greater blood lactate quantity produced during power lifts. Studies in the past have examined this ideology. Corder, Potteiger, Nau, Figoni, & Hershberger, (2000) reported that sub maximal active recovery is the most effective tool to clear blood lactate accumulated after strenuous activity. The highest blood lactate levels reported in this study were similar to the findings of the present study (9.5mmol/l vs. 10.8mmol/l). In addition, Navalata & Hrncir Jr, (2007) reported that performance of core stabilization exercises during the recovery phase after completion of high intensity cycling can further improve lactate clearance. As discussed previously, power movements are more dynamic in nature compared to standard resistance or cardio vascular exercise. In addition, power movements utilize more large muscle groups than typical resistance training exercise. Therefore; it is possible that, extensive use of posterior kinetic chain coupled with explosive multi joint and large muscle group movements in Olympic style lifts may induce greater physiological and neuro-muscular fatigue. Hence; it will be interesting to see the effects of additional fatigue associated with higher volume explosive power movements, during the performance of active recovery phase.

This study did not report heart rate responses of participants to different volume patterns. Larson reported that the heart rate responses at blood lactate threshold differ in different modes of roller skating activity (Larson, 2006). Similar findings were reported by Stone et al. (1987) in a study involving rowers. In the light of these findings, it would have been interesting to observe the association between the heart rate and blood lactate in power movements. Examining the HR responses is important as this study aims to direct the efforts in determining the efficacy of power movements in improving lactate tolerance. The comparison between efficacy of aerobic activities and power movements in improving lactate tolerance is a topic worth of future consideration. The intensity of aerobic activities is primarily calculated through HR. Therefore association of heart rate and blood lactate during power movements can be enticing future proposition.

Lack of evaluation of technique breakdown with the help of biomechanical tools is one of the limitations of this study. Higher volume power movements are not common in current athletic practices and schools of thought. Therefore, to corroborate the findings of this study and to clear the prejudices about the higher volume power movements, the future study is recommended in regards with biomechanical evaluation of technique breakdown in high volume power movements. This study also observed associated mean load percentages of 80% and 70% of the 3RM load with successful performance in 6RM and 9RM protocol respectively. Future studies about high reps power clean can refer to the suggested loads.

Finally, it is important to design a study which can be used for larger and diverse population. Thus, a scientific study on high volume power movements; incorporating considerable sample size and diverse population groups such as women, non athletic or specific athletic population (athletes from particular sport or sports of similar physiological demands) is the need of the future. The power observed for this study was 0.24. This was primarily due to the small sample size. The acceptable statistical power is considered to be at or above .80 (Cohen, 1992). Therefore, the effect size for the future studies with similar study design would be 30.

Conclusion

In conclusion, this study indicates that blood lactate response in power clean movement is largely associated with volume as determined by number of reps, load and rest interval. The power output can be another determinant of blood lactate response to power cleans; however, further study is required to support this observation.

It is important to consider these different determinants of physiological demands as most field sport activities and high volume power movements share common physiological components such as explosive, intense and continuous nature of activity. Thus, power movements can be used in a more effective way to generate greater physiological adaptations and improve performance.

This study also concludes that, explosive movements, if performed over a prolonged period, can impose greater demands on glycolytic and oxidative capacity. Therefore, prolonged explosive activities can be used for greater improvement in energy substrate utilization.

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APPENDIX A

Statistical tables

Data - Assessment of blood lactate accumulation following the completion of three different volume patterns of power clean												
ID	Load (Kg)			Blood Lactate (Pre / Post) in mmol								
	I	II	III	I			II			III		
[redacted]				Pre	Post	% increase	Pre	Post	% increase	Pre	Post	% increase
1	77.28	70.45	61.36	0.9	2.8	211.11111	1.5	5.8	286.66667	2	6.6	230
2	86.36	75	61.36	1.7	3.6	111.76471	3.5	5.9	68.571429	1.3	5.6	330.76923
3	102.27	84.09	75	2.3	7.3	217.3913	5.3	8.8	66.037736	1	10.4	940
4	52.27	47.72	43.18	3.3	5.6	69.69697	0.8	2.3	187.5	2.1	4.2	100
5	95.45	80	75	1.3	2.1	61.538462	3.2	3.2	0	1.5	5.1	240
7	80	60	50	1.9	2.1	10.526316	1.3	2.2	69.230769	0.8	3.8	375
8	80	69.09	60	3.4	3.8	11.764706	2.2	8.8	300	1.7	10.8	535.29412
9	100	80	60	1.8	3.4	88.888889	1.7	4.5	164.70588	1.8	9.7	438.88889
10	70.45	61.82	56.82	1.8	5.6	211.11111	1.8	6.1	238.88889	5.4	10.7	98.148148
Average	82.67	69.8	60.3	2.04	4.03	110.42	2.37	5.27	153.51	1.96	7.43	356.34
SD	15.72	11.65	10.28	0.84	1.78	83.62	1.4	2.48	108	1.36	2.94	260.2
SE				0.28	0.59	27.87	0.48	0.83	35.99	0.45	0.98	86.73

Table A3 Combined data

Notes-

- I- Volume pattern I consisting of 3 sets of 3 reps
- II- Volume pattern II consisting of 3 sets of 6 reps
- III- Volume pattern III consisting of 3 sets of 9 reps
- Pre- Pre-exercise data
- Post- post- exercise data
- % increase – Relative increase
- SD- Standard Deviation

SE- Standard error of mean
§

Table A4- Loads lifted by participants during the performance of power clean for each volume pattern (including total volume)

ID	Age	Load and Volume (Kg)					
		I		II		III	
		Load	Volume	Load	Volume	Load	Volume
1	25	77.28	695.52	70.45	1268.1	61.36	1656.72
2	24	86.36	777.24	75	1350	61.36	1656.72
3	21	102.27	920.43	84.09	1513.62	75	2025
4	24	52.27	470.43	47.72	858.96	43.18	1165.86
5	25	95.45	859.05	80	1440	75	2025
7	24	80	720	60	1080	50	1350
8	24	80	720	69.09	1243.62	60	1620
9	26	100	900	80	1440	60	1620
10	25	70.45	634.05	61.82	1112.76	56.82	1534.14
Average	24.22	82.67	744.03	69.8	1256.4	60.3	1628.1
SD	1.39	15.72	141.53	11.65	209.87	10.28	277.64

Notes-
SD- Standard Deviation
I – Volume pattern I consisting of 3 sets * 3 repetitions
II - Volume pattern II consisting of 3 sets * 6 repetitions
III – Volume pattern III consisting of 3 sets * 9 repetitions

Table A5- Blood lactate response of participant before and after the performance of power clean for three volume patterns

ID	Load (Kg)			Repetitions			Blood Lactate (Pre / Post) in mmol					
	I	II	III	I	II	III	I		II		III	
							Pre	Post	Pre	Post	Pre	Post
1	77.28	70.45	61.36	3	6	9	0.9	2.8	1.5	5.8	2	6.6
2	86.36	75	61.36	3	6	9	1.7	3.6	3.5	5.9	1.3	5.6
3	102.27	84.09	75	3	6	9	2.3	7.3	5.3	8.8	1	10.4
4	52.27	47.72	43.18	3	6	9	3.3	5.6	0.8	2.3	2.1	4.2
5	95.45	80	75	3	6	9	1.3	2.1	3.2	3.2	1.5	5.1
7	80	60	50	3	6	9	1.9	2.1	1.3	2.2	0.8	3.8
8	80	69.09	60	3	6	9	3.4	3.8	2.2	8.8	1.7	10.8
9	100	80	60	3	6	9	1.8	3.4	1.7	4.5	1.8	9.7
10	70.45	61.82	56.82	3	6	9	1.8	5.6	1.8	6.1	5.4	10.7
Average	82.67	69.8	60.3				2.04	4.03	2.37	5.27	1.96	7.43
SD	15.72	11.65	10.28				0.84	1.78	1.4	2.48	1.36	2.94

Note.
Pre- blood lactate levels prior to the beginning of exercise
Post- blood lactate levels after the completion of exercise.

Table A6 - Relative increase in blood lactate response to all volume patterns

ID	Load (Kg)			Repetitions			Percent increase (%)		
	I	II	III	I	II	III	[redacted]		
[redacted]									
1	77.28	70.45	61.36	3	6	9	211.11	286.67	230
2	86.36	75	61.36	3	6	9	111.76	68.57	330.76
3	102.27	84.09	75	3	6	9	217.39	66.03	940
4	52.27	47.72	43.18	3	6	9	69.7	187.5	100
5	95.45	80	75	3	6	9	61.54	0	240
7	80	60	50	3	6	9	10.53	69.23	375
8	80	69.09	60	3	6	9	11.76	300	535.29
9	100	80	60	3	6	9	88.89	164.71	438.89
10	70.45	61.82	56.82	3	6	9	211.11	238.89	98.15
Average	82.67	69.8	60.3				110.42	153.51	365.34
SD	15.72	11.65	10.28				83.62	108	260.2

Note -

% - Relative Percent increase in blood lactate levels after the completion of each volume pattern

Table A7 - Mauchley's test of sphericity

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Volume	.407	6.290	2	.043	.628	.689	.500

Notes-
Df- Degree of Freedom
Sig- Significant value

Table A8 -

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Volume	Sphericity Assumed	335147.301	2	167573.650	5.640	.014
	Greenhouse-Geisser	335147.301	1.256	266921.943	5.640	.033
	Huynh-Feldt	335147.301	1.379	243039.700	5.640	.029
	Lower-bound	335147.301	1.000	335147.301	5.640	.045
Error(Volume)	Sphericity Assumed	475350.867	16	29709.429		
	Greenhouse-Geisser	475350.867	10.045	47323.064		
	Huynh-Feldt	475350.867	11.032	43088.939		
	Lower-bound	475350.867	8.000	59418.858		

Notes-

Df- Degree of Freedom

Sig – Significant (p) value

Table A9 – Data of the test of Multiple Regression

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	-280.578	270.309		-1.038	.310	-838.468	277.312		
	Load	2.523	2.741	.196	.920	.366	-3.135	8.181	.636	1.573
	Reps	51.896	16.933	.652	3.065	.005	16.947	86.845	.636	1.573

a. Dependent Variable: Response

b. Independent Variables : Load, Reps

c. Constant Variable : Sets

APPENDIX B

Standard techniques and guidelines of Power clean

BEGINNING POSITION

- Participants will stand with the feet placed hip-width apart and tows pointing slightly outward
- Participants will squat down with the hips lower than shoulders and grasp the bar with closed, pronated grip.
- Hands will be shoulder width apart, with elbows fully extended.
- Feet will be flat on the floor; bar will be close to shins and directly over the balls of feet.

BODY POSITIONS

- Back will be flat or slightly arched
- Chest will be held up and out
- Scapula will be retracted
- Head will be in line with the vertebral column or slightly hyper extended
- Shoulders will be over the bar

UPWARD MOVEMENT PHASE

- Participants will lift the bar off the floor by forcefully extending knees and hips.
- Participants will not let the hips rise before the shoulders and maintain the flat back position.
- Participants will keep the elbows fully extended and bar as close to the body as possible.

TRANSITION PHASE

- As soon as the bar rose above the knee, participants will thrust the hips forward and slightly re-flex the knees and move thighs and knees under the bar.
- Participants will maintain flat back position with elbows fully extended.

SECOND PULL

- Participants will quickly and forcefully extend hips, knees and plantar-flex ankles.
- The bar will be kept near or in contact with the front of the thighs.
- Back will remain flat, elbows will be pointing outwards and remain extended as long as possible.
- As soon as the lower body joints reach full extension, participants will rapidly shrug shoulders without flexing the elbows.
- As soon as the shoulders reach highest elevation, participants will flex and pull elbows as high as possible and pull the body under the bar.

- The torso will be erect or slightly hyper extended.

<u>CATCH</u>

- As soon as the body goes under the bar, participants will rotate the arms around and under the bar while simultaneously flexing the knees and hips in quarter squat position.
- Arms will be parallel to floor and bar will be racked across the front of clavicles and deltoids.

<u>DOWNWARD PHASE</u>

- Participants will lower the bar by gradually reducing the muscular tension and will allow a controlled descent of the bar toward the thighs.
- Participants will flex knees and hips to cushion the impact on the thighs
- To conclude the movement, participants will squat down and with fully extended elbows until the bar touches the floor.

APPENDIX C

CONSENT TO BE A RESEARCH PARTICIPANT
BOISE STATE UNIVERSITY

A. PURPOSE AND BACKGROUND

Anand Date and Dr. Shawn Simonson, Ed.d in the Department of Kinesiology at Boise State University are conducting a research study entitled "Assessment of lactate accumulation following the completion of three different volume patterns of power clean." The purpose of this study is to evaluate the effects of explosive power exercises of different volumes on lactate production; with a view of potential use of explosive power exercises in training for improvement of lactate tolerance.

B. PROCEDURES

If you agree to be in the study, the following will occur:

1. You will participate in the 3 repetition max (RM) testing of power clean.

2. You will participate in the three day training regime (spread throughout the week) which will consist of warm up exercises, followed by three different volume patterns of power clean exercise. Volume pattern will be consist of
   A. 3 sets * 3RM
   B. 3 sets * 6RM
   C. 3 sets * 9RM
3. You will volunteer for the blood lactate test to be conducted at the beginning and at the end of every session. The test will require a drop of blood from the fingertip of the index finger.

These procedures will be done at BSU recreation center. Each session will last for approximately 45 minutes. The gap between two sessions will be no less than 48 hours. (Note- First session may require longer duration due to the RM test).

C. RISKS/DISCOMFORTS

1. Muscular sprain or muscle soreness may occur as a result of the activity.

2. Blood lactate analysis will require a small pinch at the lateral surface of the tip of the index finger.

3. A drop of blood will be drawn two times in every session. Lactate analysis will be conducted on six occasions during the entire course of study.

D. BENEFITS

You will be able to learn or revise the skill set required for advanced explosive movement such as power clean. The data of lactate response to different volumes will be beneficial knowledge for designing of a training program. In addition, the results of this study will contribute in the body of knowledge of athletic strength and conditioning.

E. COSTS

There will be no costs to you as a result of taking part in this study, other than the time spent to participate.

F. QUESTIONS

If you have any questions or concerns about participation in this study, you should first contact the investigator. Investigator can be reached at anandshriramdate@u.boisestate.edu. You can also call Dr. Shawn Simonson at 208-426-3973 during the day time on weekdays. If for some reason you do not wish to do this, you may contact the Institutional Review Board, which is concerned with the protection of volunteers in research projects. You may reach the board office between 8:00 AM and 5:00 PM, Monday through Friday, by calling (208) 426-5401 or by writing: Institutional Review Board, Office of Research Compliance, Boise State University, 1910 University Dr., Boise, ID 83725-1138.

Should you feel discomfort due to participation in this research and you are a BSU student, you may contact the Boise State University Health and Wellness Center for counseling services at (208) 426-1601. If you are not a BSU student and you feel discomfort, you should contact your own health care provider.

H. CONSENT

You will be given a copy of this consent form to keep.

PARTICIPATION IN RESEARCH IS VOLUNTARY. You are free to decline to be in this study, or to withdraw from it at any point. Your decision as to whether or not to participate in this study will have no influence on you present or future status as a student of Boise State University or as a member of Boise state Recreation Center.

I give my consent that I do not suffer with following health issues:

Hypertension Yes/No

Cardiac Health Problems Yes/No

Current/ Past Musculo-skeletal injuries Yes/No

If yes,
Details______________________________

Arthritis Yes/No

________________________________ ________________

Signature of Study Participant Date

I give my consent to participate in this study:

________________________________ ________________

Signature of Study Participant Date

____________________________________ ____________________
Signature of Person Obtaining Consent Date

THE BOISE STATE UNIVERSITY INTSTITUTIONAL REVIEW BOARD HAS REVIEWED THIS PROJECT FOR THE PROTECTION OF HUMAN PARTICPANTS IN RESEARCH.

APPENDIX D

Procedure for the use of Lactate Analyzer

This study will use digital lactate analysis device manufactured by Nova Biomedical. The device name is lactate plus and it requires approximately 0.7 micro liters of blood to be drawn from the fingertip.

The location to draw the blood will be the lateral surface area of the fingertip of the index finger. This area is selected to ensure convenience in drawing the blood. It will also ensure minimum hindrance to strength of the grip on the bar.

Blood lactate analysis will be recorded at the beginning and at the end of every session. Hence, three sessions of three different volume patterns warrant for the lactate analysis on six occasions throughout the course of the study.

Following steps will be followed while performing blood lactate analysis through digital lactate analyzer.

1. The entire fingertip of the index finger of the right hand of the participant will be cleaned with the help of cotton balls and a drop of isopropyl rubbing alcohol.
2. The fingertip will be cleaned dry with another cotton ball.
3. Lactate analyzer will be made ready by fixing the lactate reader strip at the top of the device.
4. Capped lactate strip (Lancet) will be drawn from the box and will be fixed on lactate needle pen (acu-check soft clix product).
5. Needle pen will be used to pinch at the lateral surface of the finger tip of the index finger of the participant.
6. Needle will be taken out, capped and thrown away.
7. Participant will be instructed to put a drop of blood on the top of the lactate reader strip.

8. As soon as the device receives sufficient blood to completely fill the lactate reader strip, the blood lactate levels will be shown on the screen of the device.
9. Upon completion of the test, participant will be instructed to keep the fresh cotton ball on the wound for at least 2 to 3 minutes.
10. It will be ensured that there is no continuous blood loss from the fingertip.
11. Lactate analysis test will be concluded.

Note – Researcher will wear gloves while performing such test. Separate trash bag will be used to dispose of the unwanted material.

APPENDIX E

Flyer

Time requirements: - ONLY 20mins/day for 3 days spread over a week's period.

Still a chance to work on your power cleans

Hello everybody, This is Anand again. Thanks for your great response to the study on power clean.

You can still participate in this unique study and polish your power clean skills while contributing to the science of strength training. All you have to do is shoot an email to ananddate2411@gmail.com or give a call on 917-603-2665. This study will now go on till the beginning of the fall semester.

Highlights

- Use this great opportunity to learn/revise the skill set required for power cleans.
- Gather valuable information which can be used in your next work out design.
- Contribute in the body of science of athletic strength and conditioning.

Prerequisites for the participation

- Male
- Aged between 18 and 30
- Minimum of 2 years of training age (should be doing resistance training for at least 2 years)
- Experience in performing Olympic lifts training preferred.
- Should not be suffering from any musculo skeletal injury, cardiac illness, hypertension or arthritis.