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# The Effect of Selected Rest Intervals on Total Work Volume and Blood Lactate Levels during High Intensity Elbow Flexion Exercise at a Fixed Relative Resistance

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B.Sc., University of Ottawa, 1987

Thesis

Submitted to the School of Graduate Studies
in partial fulfilment of the requirements
for the degree of Master of Science in Kinanthropology
in the School of Human Kinetics,
University of Ottawa, 1990

ISBN 0-315-79989-7

UNIVERSITÉ D'OTTAWA
UNIVERSITY OF OTTAWA

**ACKNOWLEDGEMENTS**

I would like to thank Drs. Cotton, Thoden and Pete Stothart for their suggestions and encouragement towards the completion of this document.

I would like to thank Dr. Al Reed for his support and guidance and tireless patience throughout.

I would like to thank my friends and fellow students, Jeff Fitzgerald, Pierre Gaudet, Robert Seguin for their assistance with this study and their belief in me. Our departure has surely marked the end of an era in the history of Montpetit Hall.

I would especially like to thank Martha for pushing me to achieve my goal but mostly for always being there.

Mostly I would like thank my Mom for her love and understanding in the pursuit of my goal.

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**ABSTRACT**

A group of male subjects (N=8) were used to examine the effects of two selected rest intervals on total work volume and blood lactate during a maximal effort elbow flexion resistance exercise performed at a fixed relative resistance (70% 1RM). The rest intervals were set at 30 seconds ($R_{30}$) and 180 seconds ($R_{180}$) and were based on the half and full recovery times respectively of the high energy creatine phosphate (CP) system. The exercise continued until a computerized light sensor system detected a movement speed decrease to a pre-determined level of fatigue. The fatigue point was set when the speed of arm movement had slowed by 25% compared to the speed of the first repetition of that set. The number of sets would continue until the first repetition of a set was 25% slower than the first repetition of the first set. The computer signalled the end of a set and the end of the exercise by an auditory beep. $R_{180}$ resulted in a significantly greater volume of work (247%) achieved without a statistically significant increase in blood lactate (10%) compared to $R_{30}$. It was concluded that a rest interval between repeats of elbow flexion exercise of 180 seconds versus 30 seconds significantly increased the ability to do work without a significant increase in the contribution of the anaerobic lactic system.

## INTRODUCTION

The past ten years have seen a great increase in the use and acceptance of resistance training by many people such as athletes, fitness enthusiasts, students and patients. Strength training cycles are being incorporated in a great variety of sports into the yearly macrocycles of many athletes by their coaches (Fleck and Kraemer, 1987). At present, there are many different classifications for strength training methods. These methods can be classified by the load used (maximal strength method), by the particular effect they have on the individual (speed-strength method), or by the people who use them (bodybuilding method) (Schmidtbleicher , 1984).

In various types of strength training programs it has been agreed that resistance training should be performed at the same velocity as is used in the actual sporting event (Fleck et al., 1987). As a result, the training velocities will be high for many sports. This method of training has been classified as speed-strength training. The literature which outlines the principles of speed-strength training seems to vary in choice of intensity, number of sets and repetitions, and rest interval between sets.(Schmidtbleicher , 1984; Fleck et al., 1987; Poliquin, 1988).

Another important factor to consider in strength training is the understanding of the characteristics of human skeletal muscle. It has been observed that fast twitch fibres are able to develop more force through greater velocities of shortening compared to slow twitch fibres and that fast twitch fibres can develop force more rapidly, making the correlation between fast twitch fibres and strength increasingly higher as strength is measured at increasing velocities (Coyle et al., 1979; Faulkner et al., 1986).

It has been shown that muscle with a higher percentage of fast twitch fibres fatigued more quickly during maximal effort exercise (Thorstensson and Karlsson, 1976) and that fatigue, defined as the failure to maintain a required or expected force (Edwards, 1981), may be due to the increase in hydrogen ion concentration together with an increase in lactate production.

Thus it would seem important to investigate fatigue problems in human skeletal muscle during a speed-strength exercise at a selected intensity and rest interval to observe the amount of work that can be performed before fatigue, and to examine whether or not lactate is related to the development of fatigue. Additionally, a drop in creatine phosphate (CP) and a subsequent increase in inorganic phosphate and it's ionized forms have also been identified as important factors for a depressed force output (Boobis et al. 1982; Hirvonen et al. 1987; Miller et al. 1988; Tesch et al. 1989).

In order to maintain a required high force output, the training stimulus to achieve such a result should ideally be free from any premature fatigue that would result in a lower volume of optimal performance. Thus, the purpose of this study was to examine the effect of selected rest intervals on total exercise volume, as measured by the number of sets completed, and blood lactate levels during elbow flexion exercise at a fixed relative resistance. Of additional interest was the effect of the rest intervals on the time required to reach the fatigue criterion as reflected by the mean time per set.

## METHODOLOGY

The subjects in this study were all competitive athletes who were experienced weightlifters. These were eight male volunteers ranging in age from 20 to 28 years. The group consisted of 4 varsity, 2 semi pro, 1 provincial, and 1 national athlete. All subjects gave their informed consent before participating in the study.

The equipment used in this study involved a Scott Curl bench, installed at an angle of 45 degrees to the floor; a dumbbell in which weight could be varied; two Honeywell FE7C-RCGG retroreflective switches with reflectors; an IBM X/T personal computer and LABMASTER Board along with custom software programs for recording speed of movement between the two light gates.

The speed of limb movement was determined during elbow flexion-extension by the arm passing through two infra-red retroreflective photoelectric cells which were positioned at selected angles (see text below) relative to the face of the Scott Curl Bench. Analog to digital (A-D) conversion of the switch signals was accomplished by the LABMASTER installed in the IBM X/T microcomputer. Custom software was developed to retrieve the time values between switch signals and instantaneously calculate changes in the time values.

The testing protocol extended over a period of eleven days. On day 1, 3, and 5 of the protocol each subject's one repetition maximum (1RM) in elbow flexion of the dominant arm was determined. The 1RM test was performed three times to ensure a reliable measure of maximum ($r = 0.99$). Days two, four, six, seven, nine, and ten were rest days in which the subjects were told to resume normal activity but abstain from any arm exercises. On days eight and eleven the subjects performed sets of elbow flexion and extension repetitions with 70% of their 1RM (Table 1).

Table 1

Exercise Protocol

| DAY 1/3/5 | DAY 6/7 | DAY 8 | DAY 9/10 | DAY 11 |
|---|---|---|---|---|
| Determination of 1 RM | O F F | - Elbow flexion at 70% 1RM<br>- Rest between sets; half group 30 sec, half group 180 sec,<br>- Post lactates at 0, 1, 2 min | O F F | - Elbow flexion at 70% 1RM<br>- Rest between sets; half group 30 sec, half group 180 sec,<br>- Post lactates at 0, 1, 2 min |

They were instructed to execute the repetitions as fast as possible while still maintaining control and full range of motion. Each set lasted until fatigue occurred. Fatigue was measured by the computer software program, which calculated the speed of arm movement in the concentric phase, through the two photoelectric gates which were positioned at angles of 40 and 90 degrees relative to the face of the Scott Curl bench. The full range of motion was between 0 and 130 degrees with the midpoint being at 65 degrees.

The positioning of the gates at 40 and 90 degrees were chosen because they represented an area around the midpoint where the arm would be considered to be travelling at its maximum velocity (Appendix B, Figure 1). When the speed of arm movement had slowed by 25% compared to the speed of the first repetition of that set, the computer signalled the end of the set by an auditory beep. Rest time between sets was predetermined at either 30 seconds or 180 seconds. The number of sets would continue until the first repetition of a set was 25% slower than the first repetition of the first set. At this time the exercise for the subject was completed for that day. The number of sets and repetitions were counted and recorded for the $R_{30}$ and $R_{180}$ conditions. Repetition data was taken for future reference as this is a traditional parameter in weight training. No analyses of the repetition data was intended or done as the thrust of the present study was to measure time not repetitions. Total work time for each set was determined by stopwatch measurement of the time from the start of exercise until the fatigue criterion was reached. Mean time per set (XTIME) was calculated as the total work time divided by the number of sets. Dominant hand fingertip blood samples were then taken from the subject at zero, one, and two minutes following the last completed repetition. These sample times were chosen based on pilot work which showed blood lactate peaking within the first two minutes post exercise. The blood samples were analyzed with a Kontron 640 Medical Lactate Analyzer to determine lactate concentration. All subjects performed the exercise using both 30 second and 180 second

rest intervals. The order of these treatments were randomized equally among the eight subjects. The rest intervals of 30 and 180 seconds were based on physiological landmarks of half and full CP recovery respectively, in the anaerobic alactic energy system (Hultman et al., 1967). Three one-way analyses of variance (ANOVA) with repeated measures were used to analyze the collected data where the rest interval was the independent variable and number of sets, blood lactate concentration, and mean time per set served as the dependant variables.

## RESULTS

The subjects used in the study were all experienced weightlifters however the measurements indicated that their strength levels varied considerably (Table 2). Approximately 2.3 times more weight was lifted by the strongest subject compared to the subject with the lowest 1RM. It was important to note that no controls were made on choice of subjects according to their strength levels, only on their experience in weightlifting. The group of eight subjects consisted of 4 varsity, 2 semi pro, 1 provincial, and 1 national level athlete. The between subject variability in the number of sets completed and the mean time per set can be seen in Table 3 for both the $R_{30}$ and $R_{180}$ exercise protocols (raw data in Appendix A). However, the focus of this study was to look at the effect that different rest intervals had on work volume within the same subject.

Table 2

Means and Standard Deviation of Some Results Descriptive of the Subjects.

| Variable | N | Mean | S.D. | Minimum Value | Maximum Value |
|---|---|---|---|---|---|
| Age of subjects(yrs) | 8 | 23.50 | 3.16 | 20.00 | 28.00 |
| Experience (yrs) | 8 | 4.13 | 1.46 | 3.00 | 7.00 |
| Max. 1RM (lbs) | 8 | 45.79 | 45.79 | 28.80 | 68.00 |
| 70% 1RM (lbs) | 8 | 32.06 | 8.76 | 20.50 | 48.00 |

Table 3

Number of Sets Completed and Means and Standard Deviation of the Subject's Time Per Set for the 30 Second and 180 Second Rest Interval Exercise Protocols.

| | | $R_{30}$ | | | $R_{180}$ | | |
|---|---|---|---|---|---|---|---|
| Subject | Sets | Mean | S.D. | Sets | Mean | S.D. | Ranking |
| 1 | 6 | 18.59 | 4.13 | 9 | 20.81 | 4.35 | SP |
| 2 | 3 | 15.13 | 2.71 | 14 | 13.58 | 3.08 | V |
| 3 | 3 | 14.45 | 2.96 | 7 | 12.84 | 2.00 | V |
| 4 | 6 | 12.97 | 5.84 | 8 | 12.87 | 2.26 | N |
| 5 | 2 | 12.19 | 0.28 | 12 | 13.62 | 6.01 | SP |
| 6 | 3 | 12.53 | 3.66 | 6 | 13.52 | 2.80 | V |
| 7 | 6 | 11.66 | 4.9 | 13 | 12.45 | 5.20 | P |
| 8 | 4 | 11.60 | 3.4 | 15 | 12.25 | 1.44 | V |

Ranking definitions:

V = Varsity

P = Provincial

SP = Semi pro

N = National

A comparison between the two rest intervals of $R_{30}$ and $R_{180}$ showed that the mean number of sets (SETS) increased nearly 2.5 times with the minimum SETS completed increasing 2 fold and the maximum SETS completed increasing 2.5 fold(Table 4). Mean peak blood lactate (PEAKBLa) also increased from $R_{30}$ to $R_{180}$ but only by 10%. This change was relatively small when compared to the increases in work volume that were attained with the longer rest interval. Mean time per set (XTIME) reflects the time taken for the subject to perform a set before fatigue occurred. When comparing $R_{30}$ to $R_{180}$ the XTIME increased by only 2%. The relatively small change showed that the subjects were fatiguing at similar times in both protocols.

Table 4

Means and Standard Deviation of Number of Sets, Mean Time Per Set, and Peak Blood Lactate.

| Variable | N | Mean | S.D. | Minimum Value | Maximum Value |
|---|---|---|---|---|---|
| Rest = 30 sec | | | | | |
| Number of Sets | 8 | 4.25 | 1.49 | 3.00 | 6.00 |
| Mean Time per Set (sec) | 8 | 13.64 | 2.37 | 11.61 | 18.60 |
| Peak Blood Lactate (mMol) | 8 | 3.01 | 0.89 | 1.74 | 4.32 |
| Rest = 180 sec | | | | | |
| Number of Sets | 8 | 10.50 | 3.42 | 6.00 | 15.00 |
| Mean Time per Set (sec) | 8 | 13.99 | 2.80 | 12.25 | 20.81 |
| Peak Blood Lactate (mMol) | 8 | 3.32 | 1.12 | 2.00 | 5.12 |

Table 5 showed the correlations among the variables. No statistically significant correlations were found to exist between the amount of weight lifted by the subjects and the number of sets completed, the mean time per set, and the peak blood lactate. Thus the varying strength levels of the subjects created no dependence among the variables analyzed. There was no significant correlation between the selected rest intervals, XTIME, and PEAKBLa indicating that the length of rest between sets did not affect the work time

before fatigue per set or the PEAKBLa. However, the rest interval was strongly positively correlated with the SETS ($r = 0.78$, $p < 0.0003$).

Table 5

Pearson Correlation Coefficients and Levels of Significance for the Variables Investigated (n = 8).

| | WEIGHT | REST | SETS | XTIME | PEAKBLa |
|---|---|---|---|---|---|
| WEIGHT | X | r=0.00 | r=0.18 | r=0.14 | r=0.07 |
| | | p<1.00 | p<0.50 | p<0.59 | p<0.81 |
| REST | | X | r=0.78 | r=0.07 | r=0.16 |
| | | | p<0.0003 | p<0.79 | p<0.55 |
| SETS | | | X | r=0.01 | r=0.13 |
| | | | | p<0.96 | p<0.63 |
| XTIME | | | | X | r=0.14 |
| | | | | | p<0.62 |
| PEAKBLa | | | | | X |

WEIGHT = Amount of weight lifted in pounds

REST = Rest interval between sets in seconds

SETS = Number of sets completed

XTIME = Mean time per set in seconds

PEAKBLa = Peak blood lactate in Mm.

The ANOVA (Table 6) yielded no statistically significant difference ( $ = 0.05) between the effect of the two rest intervals on the two dependant variables observed ( PEAKBLa, XTIME). However, the SETS were significantly different ($ = 0.0003) between the two rest intervals. These results have shown that a rest interval of 180 seconds versus 30 seconds significantly increased work volume as reflected by the number of sets without a significant increase in blood lactate or a change in the time at which fatigue occurred as reflected by mean time per set.

Table 6

One Way Analysis of Variance for Effect of Rest Interval.

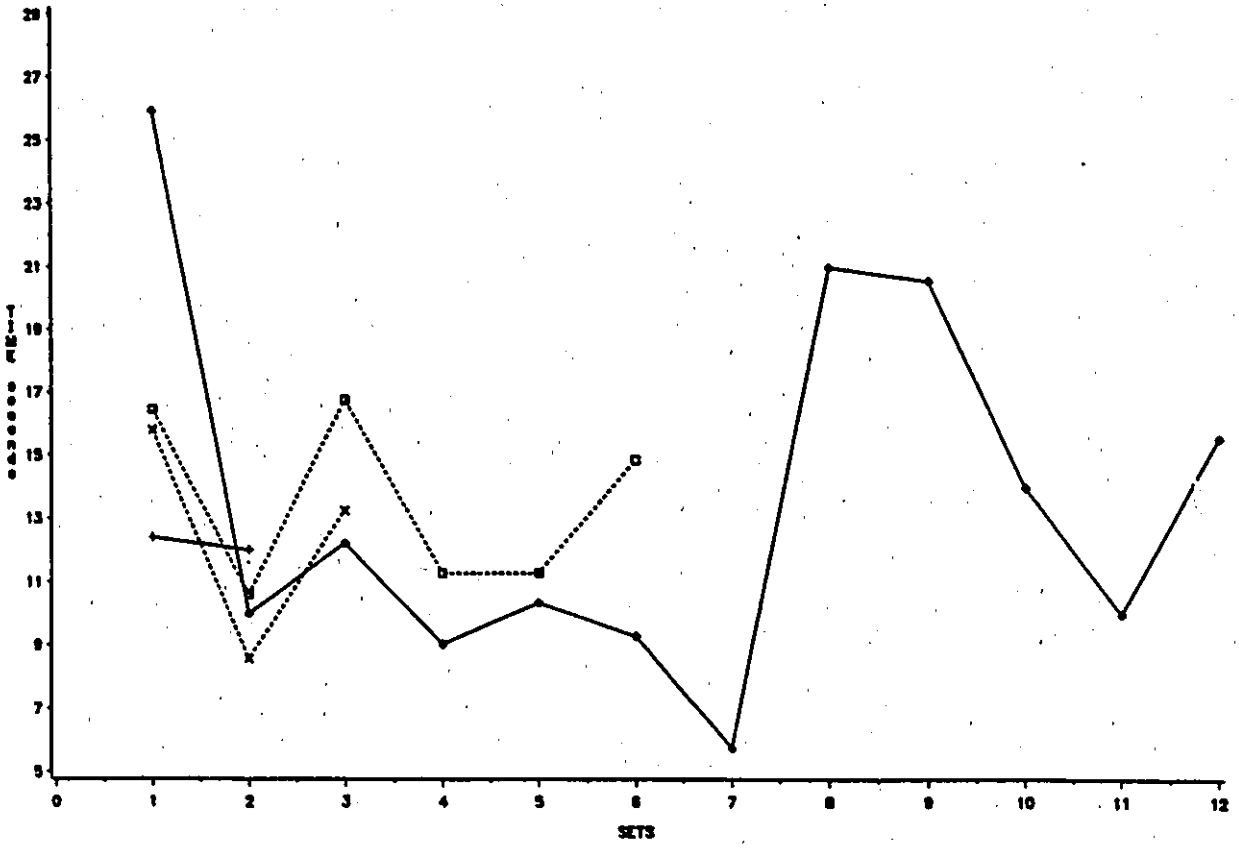
| Source | Sum of squares | Degrees of Freedom | Mean Square | F value |
|---|---|---|---|---|
| No. of Sets | 253.75 | 15 | 6.96 | 22.44 * |
| XTime per set | 94.80 | 15 | 6.74 | 0.07 |
| PEAKBLa | 14.69 | 15 | 1.02 | 0.37 |

* Significantly different at p<0.0003.

Figure 2 showed the time per set of two of the subjects (5 & 6) and the number of sets completed by each subject until fatigue. These values were graphed for both protocols $R_{30}$ and $R_{180}$. The figure has illustrated a definite variation between the exercise patterns of the two subjects but the design of the study was intended to look at the variance within subjects between the $R_{30}$ and $R_{180}$.

Figure 2

Time Per Set of Subjects 5 & 6




**Legend**

Subject 5: Plus = $R_{30}$, Diamond = $R_{180}$

Subject 6: X = $R_{30}$, Square = $R_{180}$

## DISCUSSION

The main purpose of the present study was to examine the effect that selected rest intervals had on total work volume and blood lactate levels in a maximal effort exercise. It was found that by manipulating the rest interval between sets of a maximal effort exercise the total work volume increased significantly by 247% while blood lactate levels increased by a non-significant 10%. The rest intervals used were 30 seconds and 180 seconds and were based on the half and full recovery times respectively of the CP system. This system has also been referred to as the Anaerobic Alactic Energy System (Green, 1982; Hultman et al., 1967).

A similar effect was seen by Margaria et al. (1969). Strenuous work bouts lasting ten seconds were separated by selected rest intervals. As the rest interval was increased the total work volume also increased. It was stated that when rest intervals were longer than 25 seconds the phosphagen source would give adequate energy supply without reliance on anaerobic glycolysis and the work could be carried out indefinitely. Wootton and Williams (1982) also looked at the effects of different rest intervals on the ability to perform repeated bouts of maximal dynamic exercise. A comparison between a 30 second and 60 second rest interval was made using a work interval of 6 seconds. The longer rest interval allowed a higher force output to be maintained. However, neither rest interval allowed adequate time for full CP replenishment.

This caused lactate levels to rise considerably in both protocols with the highest lactate levels after only 30 second rest intervals. The present study has shown similar effects to these investigations. However, what is of physiological importance here is that the selected rest intervals allowed for a statistically significant increase in work volume with no statistically significant change in blood lactate.

It seemed reasonable to assume that fast twitch fibres were the major contributors to force output due to the nature of the exercise protocol in this study (Gollnick et al., 1974; Thorstensson & Karlsson, 1976; Jacobs et al., 1981; Faulkner et al., 1986) and that fast twitch fibres have the physiological capacity to form lactic acid (Essen et al., 1975; Karlsson, 1979; Tesch, 1978; Tesch et al., 1978). Gollnick et al. (1974) showed in their results that during intermittent exercise the muscle lactate produced was small at all tensions. It was also stated that during sustained contractions when tension was at 20% or more of MVC major increases in muscle lactate were observed. The length of time that these tensions were applied was not stated but Jacobs et al. (1983) have indicated muscle lactate levels rising significantly in supramaximal work lasting only ten seconds. These were muscle lactate values and although the present study is looking at blood lactate and not intramuscular values, the dramatic increase in work volume without a large increase in PEAKBLa might suggest that the work being done could be primarily due to regeneration of CP stores

during the rest intervals without a heavy dependence on anaerobic glycolysis to produce ATP. The reason for this being that the CP stores were allowed to fully recover with the 180 second rest interval (Hultman et al., 1967).

Other factors may have also influenced the absolute level of lactate observed in the present study. The subjects in the present study rested passively between sets and this has been shown to be the least efficient way to remove lactate (Hermansen & Stensvold, 1972; Bonen & Belcastro, 1976; McGrail et al., 1978; Dodd et al., 1984), although, there has been evidence to suggest that nonexercising muscle plays an important role in the removal of lactate during exercise (Ahlborg et al., 1975). The amount of muscle mass employed could also have had an effect on lactate levels as values 4 to 5 times higher have been found in subjects performing anaerobic work using larger muscle groups (Margaria et al., 1971; Fujitsuka et al., 1982). Therefore, the absolute values of lactate reported in the present study which were associated with fatigue may not compare with similar values using exercise involving larger muscle groups.

The levels of lactate found in the present study which used a relatively small muscle mass might suggest that lactic acid was a fatigue factor. However, the significant increase in work volume without a significant increase in lactate levels across the two exercise protocols does support such a conclusion.

Fatigue has been defined as a failure to maintain a required or expected force (Edwards, 1981). The criteria for the termination of a set and subsequently the complete exercise bout in the present study was based upon this concept of fatigue. The value of a 25% decrease in speed of contraction, which was related to the initial decrease in force output, was derived from a study by Stark et al. (1987) on the Canadian National Alpine Ski team and from work done on energy delivery systems by Green (1982). By terminating the exercise in the present study when the subject's speed of contraction decreased by 25%, it was intended that the work being done would be related to an objective indicator of the initial fatigue response. The average work times per set between the two exercise protocols were similar with less than 0.5 seconds separating the two. These average work times fell in the range of values that maximal voluntary dynamic work can be achieved with the ATP-CP system being the major energy system recruited. (Green,1982; Margaria et al.1969; Wootton and Williams 1982). The results from the present investigation seem to indicate that this type of energy utilisation might be occurring as shown by the non-significant difference in blood lactate levels with very significant changes in work volume between the exercise protocols.

It was concluded that the alactic strength training strategy used in the present study, in which the manipulation of the rest interval was based on physiological landmarks of CP recovery, may have had the effect of significantly increasing total work volume

without a consequent increase on blood lactate production. The metabolic explanation for the fatigue in this study could have been due to the decreased energy supply from the high energy phosphate stores and that lactate may not be the primary cause of depressed force output when work was stopped at the fatigue level chosen for the present study.

These conclusions were made with the understanding that intramuscular observations are needed to further explain the data collected in the present study and to give a clearer explanation of the metabolic processes that are at work.

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# APPENDIX A

## Descriptive Results

Gender = Male

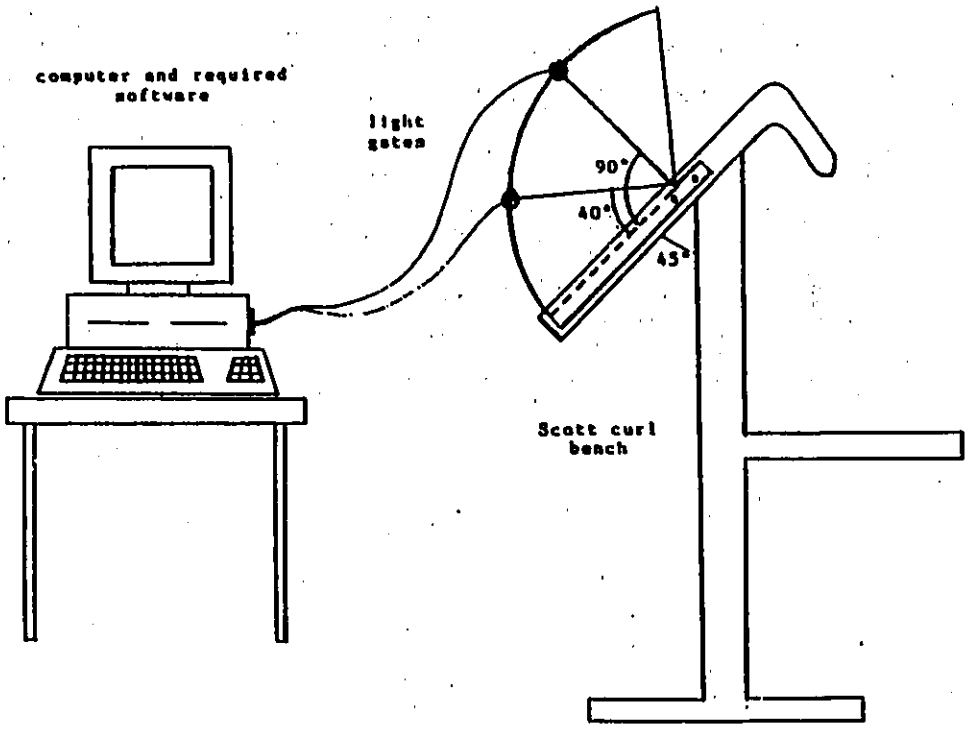
### Subjects

| Variables | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Age (yrs) | 24 | 21 | 21 | 21 | 20 | 27 | 26 | 28 |
| WEIGHT (1RM, lbs) | | | | | | | | |
| DAY 1 | 55.5 | 40.5 | 28.0 | 68.0 | 45.5 | 33.0 | 43.0 | 50.5 |
| DAY 3 | 53.5 | 40.5 | 30.5 | 68.0 | 45.5 | 33.0 | 45.5 | 53.0 |
| DAY 5 | 53.5 | 40.5 | 28.0 | 68.0 | 45.5 | 33.0 | 43.0 | 53.0 |
| WEIGHT (70% 1RM, lbs) | 38.0 | 28.0 | 20.5 | 48.0 | 33.0 | 23.0 | 30.5 | 35.5 |
| EXPERIENCE (yrs) | 6 | 3 | 3 | 3 | 4 | 2 | 5 | 7 |
| # OF SETS 30' | 6 | 3 | 3 | 6 | 3 | 3 | 6 | 4 |
| # OF SETS 180' | 9 | 14 | 7 | 8 | 12 | 6 | 13 | 15 |
| BLOODLa (30') | | | | | | | | |
| POST 0" | 2.72 | 2.74 | 2.24 | 4.10 | 1.74 | 4.32 | 3.36 | 2.48 |
| POST 1" | 3.02 | 2.36 | 2.20 | 3.54 | 1.58 | 3.26 | 2.66 | 2.54 |
| POST 2" | 2.54 | 2.22 | 2.46 | 3.34 | -.-- | 1.84 | 2.16 | 2.54 |
| BLOODLa (180') | | | | | | | | |
| POST 0" | 2.84 | 2.96 | 3.04 | 3.38 | 2.34 | 4.88 | 3.36 | 2.48 |
| POST 1' | 2.64 | 2.08 | 2.70 | 2.64 | 2.34 | 1.96 | 2.66 | 2.54 |
| POST 2" | 2.56 | 1.98 | 2.72 | 2.52 | 2.26 | 2.08 | 2.16 | 2.54 |
| TIME PER SET 30' sec | | | | | | | | |
| SET 1 | 22.12 | 16.21 | 11.04 | 23.08 | 12.39 | 15.79 | 21.31 | 16.67 |
| SET 2 | 21.24 | 12.04 | 16.29 | 9.61 | 12.00 | 8.57 | 9.80 | 9.63 |
| SET 3 | 19.41 | 17.13 | 16.03 | 10.37 | | 13.24 | 8.08 | 9.62 |
| SET 4 | 13.26 | | | 8.72 | | | 10.20 | 10.50 |
| SET 5 | 13.56 | | | 8.99 | | | 8.76 | |
| SET 6 | 21.97 | | | 17.03 | | | 11.82 | |
| TIME PER SET 180' sec | | | | | | | | |
| SET 1 | 26.51 | 18.31 | 12.53 | 12.82 | 25.91 | 16.43 | 26.62 | 12.02 |
| SET 2 | 20.13 | 14.84 | 13.38 | 14.76 | 9.99 | 10.61 | 16.05 | 13.13 |
| SET 3 | 13.52 | 12.88 | 11.68 | 15.81 | 12.20 | 16.74 | 7.60 | 13.36 |
| SET 4 | 23.84 | 14.28 | 13.33 | 12.47 | 9.02 | 11.27 | 7.31 | 12.52 |
| SET 5 | 22.81 | 20.57 | 12.09 | 8.73 | 10.33 | 11.27 | 11.08 | 12.84 |
| SET 6 | 15.4 | 12.84 | 10.20 | 13.09 | 9.27 | 14.83 | 9.29 | 10.58 |
| SET 7 | 25.04 | 10.31 | 16.64 | 10.91 | 5.74 | | 7.84 | 14.71 |
| SET 8 | 18.72 | 14.19 | | 14.40 | 20.96 | | 9.82 | 10.20 |
| SET 9 | 21.33 | 14.57 | | | 20.51 | | 15.38 | 12.46 |
| SET 10 | | 10.69 | | | 13.96 | | 15.62 | 12.21 |
| SET 11 | | 13.02 | | | 9.98 | | 11.59 | 14.70 |
| SET 12 | | 13.77 | | | 15.52 | | 11.49 | 12.86 |
| SET 13 | | 9.03 | | | | | 12.13 | 10.59 |
| SET 14 | | 10.88 | | | | | | 10.48 |
| SET 15 | | | | | | | | 11.07 |

# APPENDIX B

Figure 1

DIAGRAM REPRESENTING EXERCISE TESTING APPARATUS



## APPENDIX C

## TRADITIONAL FIRST THREE CHAPTERS

# The Effect of Selected Rest Intervals on Total Work Volume And Blood Lactate Levels during High Intensity Elbow Flexion Exercise at a Fixed Relative Resistance

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A thesis proposal
presented to the University of Ottawa
in partial fulfilment of the
thesis requirement for the degree of
Master of Science
in
Kinanthropology

Ottawa, Ontario, Canada, 1990

## CHAPTER ONE

## INTRODUCTION

The past ten years have seen a great increase in the use and acceptance of resistance training by many people such as athletes, fitness enthusiasts, students and patients. (Fleck and Kraemer, 1987) Strength training cycles are being incorporated in a great variety of sports into the yearly macrocycles of many athletes by their coaches. Because of the increased popularity of weight training among athletes and other individuals the methods have become quite diverse in order to meet the different strength needs of various activities (Fleck and Kraemer, 1987).

At present, there are many different classifications for the strength training methods. These methods can be classified by the load used (maximal strength method), by the particular effect they have on the individual (speed-strength method), or by the people who use them (bodybuilding method) (Schmidtbleicher , 1984).

In various types of strength training programs it has been agreed that resistance training should be performed at the same velocity as is used in the actual sporting event (Fleck et al., 1987). As a result the training velocities will vary from sport to sport. This method of training has been classified as speed-strength training (Schmidtbleicher , 1984; Fleck et al.,

1987; Poliquin, 1988).

The literature which outlines the principles of speed-strength training, along with other methods of resistance training, seems to vary in choice of intensity, number of sets and repetitions, and the rest interval between the sets. For example, Schmidtbleicher (1984) referred to intensities of 35-50% of one maximum repetition (1RM) with rest intervals varying from three to five minutes. Poliquin (1988), talked of loads varying from 50-95% of 1RM with rest intervals from three to ten minutes. Ajan et al. (1988) referred to percentages of 65-80% when developing speed strength with the number of repetitions being from three to five and rest intervals between sets being on average one to three minutes which they recommend for all types of strength training. It is evident that the above papers do not support each other in the time required for rest between sets during speed strength training.

Another important factor to consider when developing a strength program is to have a general understanding of the characteristics of human skeletal muscle.

There are two different types of fibres which make up human skeletal muscle. These are fast twitch fibres, which are further divided into type IIA and type IIB fibres, and slow twitch fibres

or type I fibres (Brooke & Kaiser, 1970). It has been observed that fast twitch fibres are able to develop more power through greater velocities of shortening compared to slow twitch fibres making the correlation between fast twitch fibres and strength increasingly higher as strength is measured at increasing velocities (Coyle et al., 1979; Faulkner et al., 1986).

Gollnick et al. (1974), in looking at selective glycogen depletion in human skeletal muscle while performing maximal voluntary contractions (MVC) concluded that at an MVC greater than 20% there was a primary dependence on fast twitch fibres.

When prescribing resistance training programs in order to improve the strength and speed of muscle contraction it stands to reason that different loads placed on the muscle along with different rates of contraction will cause the muscle to fatigue at different times, where fatigue can be defined as failure to maintain a required or expected force (Edwards, 1981).

Thorstensson and Karlsson (1976), in looking at fatigue of the quadriceps muscle during maximal knee-extension at a fast velocity concluded that muscles with a higher percentage of fast twitch fibres fatigued more quickly. Hermanson and Stensvold (1972), while looking at the effect of metabolic changes on force during maximal exercise hypothesized that one of the reasons for a reduction in force development or fatigue may be due to the increase in hydrogen

ion concentration together with an increased lactate production.

Thus it would seem important to investigate fatigue problems in human skeletal muscle during a speed-strength exercise at a selected intensity and rest interval to observe the amount of work that can be performed before fatigue, and to examine whether or not lactate is related to the development of fatigue.

**RATIONALE**

In reviewing the current literature on designing and implementing strength training programs it appears that there is little rationale presented behind the choice of number of sets, repetitions and length of rest intervals when performing weight training exercises at selected intensities.

There has however been extensive research into muscle physiology which has indicated the different muscle fiber types, their force outputs and duration, the type of fuel used, and the rates of fatigue.

Thus it would be interesting to look at the amount of work that can be performed in a maximal effort exercise with a selected intensity in which the rest intervals between the exercise sets are based on physiological landmarks that allow energy repletion back into the muscle.

## STATEMENT OF THE PROBLEM

The purpose of this study was to examine the effect of selected rest intervals on total exercise volume, expressed as the number of sets completed, and blood lactate levels during elbow flexion exercise at a fixed relative resistance. Of additional interest was the effect of the rest intervals on the time required to reach the fatigue criterion as reflected by the mean time per set.

## HYPOTHESIS

It was hypothesized that the length of rest interval between bouts of isotonic contractions at 70% of 1RM will have a statistically significant effect on the total work volume and blood lactate levels.

## LIMITATIONS

The subjects involved in this study were all males between the ages of 20 to 28 years. The subjects were all competitive athletes from various sports whose strength training has been directly supervised by this researcher for no less than one year. Subjects of this nature were used to help control for the learning response that may take place with subjects that have less experience. The results of this study should not be applied to males out of this

age bracket, or with less weight training experience. This is because recruitment patterns in other age groups may vary, and those with less experience may still be adapting neurally to muscle recruitment pattern and therefore may not reach true muscular fatigue (Moritani et al., 1979). This study looks at fatigue in an elbow flexion exercise with the arm at 45 degrees to the floor. Therefore, it may not be plausible to apply the results of this study to other musculature and their involvement in different types of resistance exercise.

**ABBREVIATIONS**

| | |
|---|---|
| ATP | Adenosine triphosphate |
| CP | Creatine phosphate |
| CPK | Creatine phosphokinase (EC 2.7.3.2) |
| FT | Fast twitch glycolytic muscle fiber (IIb) |
| H&'sup(+) | Hydrogen ion |
| LA | Lactic acid |
| LDH | Lactate dehydrogenase (EC 1.1.1.27) |
| MK | Myosinkinase (EC 3.6.1.3) |
| MVC | Maximum voluntary contraction |
| PFK | Phosphofructokinase (EC 2.7.1.11) |
| ST | Slow twitch oxidative muscle fiber (Ia) |
| Total work volume | Total number of sets completed |
| 1RM | The maximum weight that can be lifted for one repetition |

# CHAPTER TWO

# REVIEW OF LITERATURE

## Introduction

The following review of literature has focused on: 1) the role of muscle fiber types in high intensity high speed limb movements, 2)the physiological characteristics of the fiber types that are involved in these movements, 3) Lactic acid metabolism during exercise, 4) rest intervals and fatigue, 5) the effect of lactate accumulation and phosphagen depletion on muscle fatigue.

## ROLE OF MUSCLE FIBER TYPES IN HIGH INTENSITY, HIGH SPEED LIMB MOVEMENTS

In looking at the power output of fast and slow human muscle fibres, Faulkner et al. (1986) measured the contraction time, maximum isometric tetanic force development, and velocity of shortening at 12 to 15 different afterloads on bundles of fibres which were suspended in a muscle bath containing buffered mammalian Ringer's solution at 37 degrees Celsius. The purpose of this study was to collect data on the force-velocity characteristics of bundles of fast and slow fibres, calculate the power curves, and

model the contribution of both fast and slow fibres to the composite power curve for a mixed muscle.

The results showed that the power developed by fast fibres was greater than that developed by slow fibres at all speeds of contraction and that the peak power developed by the fast fiber was up to four times greater than that of the slow fiber (see Figure 1, p. 6).

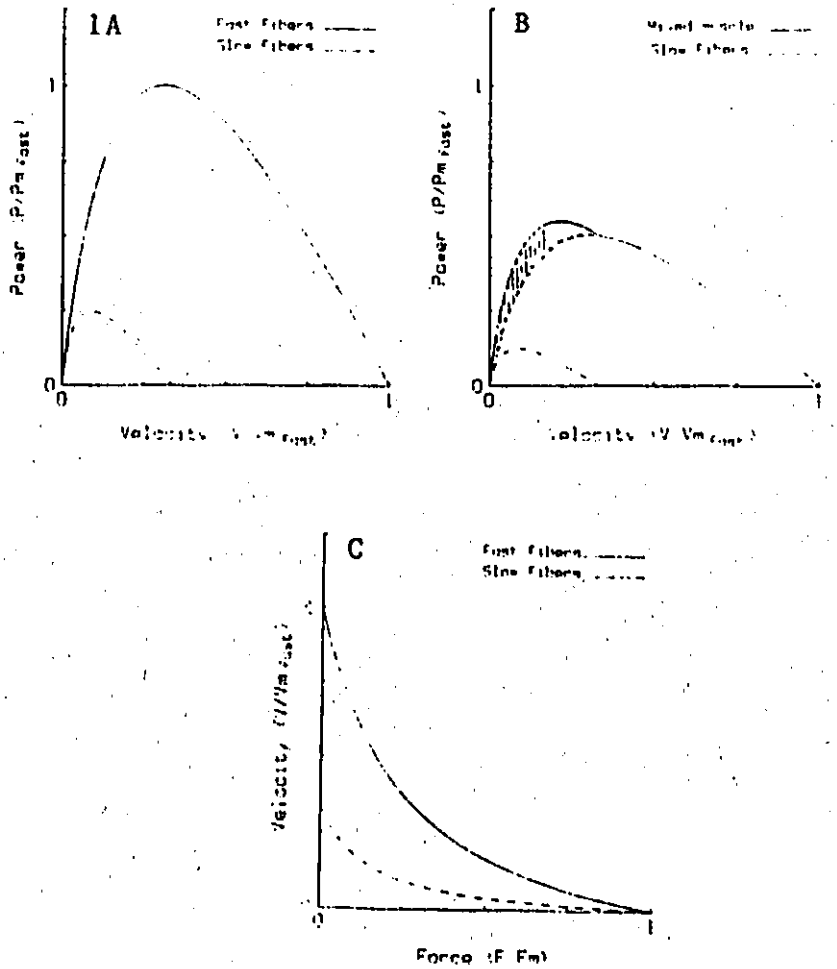


Figure 1A. Velocity of shortening as a function of force for fast and slow fibres. B. Power curves for pure fast and pure slow muscle fibres. C. Power output of a mixed muscle (50% fast and 50% slow fibres) and of the slow fibres of the mixed muscle. From

Human Muscle Power: Power output of fast and slow fibres from human skeletal muscle. (pp. 84-85) by J. A. Faulkner, D. R. Clafin, & K. K. McCully,1986, Human Kinetics Publishers, Inc.

The Faulkner et al. (1986) mixed muscle model showed that at low velocities the power output of slow fibres was almost as much as the fast fiber but at high velocities the contribution by the slow fibres was negligible. They also confirmed that fast fibres will contribute most of the power development when the subjects are performing the movement at high velocities.

Another study that also helps to confirm fiber type recruitment was done by Thorstensson and Karlsson (1976). They investigated the development of fatigue and its relation to fiber composition with repeated fast maximal isokinetic contraction in human quadriceps muscle. The fatiguability was determined as the decline in maximal force with repeated isokinetic knee-extensions on a CYBEX II dynamometer at an angular velocity of 3.14 radians per second. It was concluded that fatigue while performing rapid maximal voluntary isokinetic contractions was greater in muscles with a higher percentage of fast fibres.

Jacobs et al. (1981) looked at muscle strength and fatigue after selective glycogen depletion in human skeletal fibres. The purpose of their study was to investigate the effects of two distinct exercise protocols on performance of an isokinetic short-time, maximal strength test. Tesch (1980) has previously shown this test to be directly related to fast fiber recruitment and distribution in the involved musculature. One group of subjects performed a group of exercises that would deplete both

main muscle fiber types of their glycogen: running for 75 minutes, cycling at 70% of MVO2 for 30 minutes, and three bouts of maximal knee extensions at a velocity of 180 degrees per second. The second group ran the Stockholm marathon, an event which was to deplete the glycogen in mainly slow fibres (Costill et al., 1973, in Jacobs et al., 1981). Within 1 to 2 hours after the exercise protocols all subjects performed 50 maximal knee extensions on a CYBEX II dynamometer at a velocity of 180 degrees per second. Muscle biopsies both before and within 1 hour after the exercise protocols determined glycogen content in the fiber types. It was concluded that glycogen exhaustion in both fast and slow fibres impaired muscular torque in a single maximal dynamic contraction, whereas when glycogen fatigue occurred in only slow fibres, there was no observed impairment in maximal muscular torque. These papers strongly support the assumption that fast fibres will be the major contributor to force development in high speed limb movements.

Gollnick et al. (1974) also support the recruitment of fast fibres at higher intensities with their study on selective glycogen depletion in skeletal muscle fibres of man following sustained contractions. The subjects were asked to perform repeated isometric contractions of knee-extension until exhaustion with varying forces ranging from 10 to 40% of the maximum voluntary contraction (MVC). They also performed sustained isometric contractions at 40 and 50% of their MVC for 20 seconds with 40 second rest periods. Muscle biopsies were taken before and during

the testing for histochemical analysis. The results showed that during intermittent exercise the muscle lactate produced was small at all tensions. However, during sustained contractions when the tension was at 20% or more of MVC, there were major increases in muscle lactate. In looking at glycogen content of the fibres, it was observed that at exercise tensions greater than 20% of MVC, the fast fibres showed a greater depletion of glycogen. When the exercise tension reached 40% of MVC, all the fast fibres showed glycogen depletion, whereas the slow fibres did not differ significantly from their pre-exercise appearance. It was suggested that fast fiber recruitment may be due to the fact that in supramaximal dynamic exercise or in isometric exercise blood flow may be restricted or occluded. However, in very intense bicycle exercise the slow fibres were depleted as expected (Gollnick et al., 1974), so it seems that in a cyclic exercise such as repeated elbow flexion-extension, both fast and slow fibres may be recruited but because of the greater power output by fast fibres (Faulkner et al., 1986), once the fast fibres began to fatigue it would seem plausible that there would be a noticeable decrease in speed of contraction.

**PHYSIOLOGICAL CHARACTERISTICS OF MUSCLE FIBER TYPES**

A look at the physiological and metabolic characteristics of both fast and slow fiber types would give a better understanding of the role these fibres play in high intensity, high speed limb movements.

One of the purposes of a study by Essen et al. (1975) was to describe some biochemical characteristics of the different fiber types in human skeletal muscle using a technique whereby an individual fiber of each type was dissected. From this qualitative biochemical measurements were based on either single or pooled fibres.

Approximately 150 samples obtained by a needle biopsy-technique, and some through surgical procedure, were obtained from 35 healthy males and five healthy females, who ranged in age from 20-39 years of age. The muscle samples were taken at rest from the lateral portion of the thigh, the deltoid, gastrocnemius and soleus muscle. The samples were histochemically stained for myofibrillar ATPase and NADH-dehydrogenase which showed that these samples contained the two major fiber types in human skeletal muscle. These fiber types were named Type I and Type II.

The results showed that the Type II or fast fiber had 2.2-2.5 times higher ATPase activity levels than in the Type I or slow fibres. The glycogen content did not differ greatly between the two fiber types. However there was a wide variation in the values and it was suggested that the histochemical stain for glycogen was not sensitive enough. There was a significant difference in triglyceride concentration with a nearly three times higher level in Type I compared to Type II fibres. The only glycolytic enzyme studied was phosphofructokinase (PFK) which was shown to be

significantly higher in the Type II fibres. A further comparison of the subgroups of Type II fibres showed higher PFK activity in the Type IIB fibres. With respect to the present study Essen et al. (1975) have shown that there exists higher levels of ATPase and PFK in the Type II fiber which has been shown to be the fiber type primarily responsible for high power movements in the human body.

Karlsson (1979), in his review on localized muscular fatigue, has also looked at the metabolic profiles of both fast-twitch and slow-twitch fibres (see Table 1).

**Table 1.** A comparison of the functional properties of slow twitch and fast twitch fibres and the subgroups of the fast twitch fibres in human skeletal muscle.

| Property | Slow Twitch Fiber | Fast Twitch Fiber (FT or type II) | | |
|---|---|---|---|---|
| | | FTa | FTb | FTc |
| Mitochondrial enzyme activities, i.e.,oxidative potential | High | Intermediate | low | high |
| Activities of enzymes involved in contraction (e.g., actomyosin ATPase, MK, CPK); | Low | | High | |
| Glycogenolytic enzyme activities, i.e., Glycogenolytic potential | Low | Intermediate | High | Intermediate |
| Phosphagen content | | | | |
| ATP | High | Low? | Low? | Low? |
| CP | Low? | High? | High? | High? |
| Glycogen content | Low? | High? | High? | High? |
| Triglyceride content | High | Low | Low | Low |
| Fatigability with short-time explosive activities (< 30 sec) | Small | | Large | |
| Fatigability with prolonged muscle activity (> 10 min) | Large | | Small (if recruited) | |

Adapted from "Localized Muscular Fatigue: Role of muscle metabolism and substrate depletion" by J. Karlsson, 1979, Exercise and sport science reviews, vol 7, p.10.

Karlsson (1979) has stated that the slow-twitch fiber has a higher oxidative capacity due to greater activity of mitochondrial enzymes such as pyruvate dehydrogenase, and 3-hydroxyacylCoA dehydrogenase. The slow-twitch fiber also has more lactate dehydrogenase (LDH) isozymes that are rich in H units which give the fiber a greater potential for utilization of lactate as a fuel over the fast-twitch fiber.

The fast-twitch fibres have greater actomyosin ATPase, myokinase(MK), and creatine phosphokinase (CPK) activity. They also show greater activity of phosphorylase, PFK, and LDH, which are enzymes in the glycogenolytic pathway. The higher glycogenolytic activity by the fast-twitch fibres indicates greater ATP resynthesis through anaerobic processes, which means an increase in production of acidic metabolites such as pyruvic and lactic acids. Tesch et al. (1978) studied the relationship between lactate accumulation, fiber type distribution and LDH characteristics in human skeletal muscle. Muscle biopsies were taken from the vastus lateralis of male subjects after performing intense leg extensions on a Cybex II dynamometer. The results of the investigation showed that fast twitch (FT) fibres averaged significantly higher lactate concentration compared to slow twitch (ST) fibres. Total LDH activity as well as M-LDH activity was also significantly higher in FT fibres over ST fibres. The M-LDH isozymes are known to be more involved in the formation of lactate compared to the H-LDH isozymes.

These characteristics are in agreement with another study by Tesch (1978) in which his findings indicated a higher anaerobic capacity in FT fibres and that within one and the same muscle FT fibres form more lactate compared to ST fibres.

When looking at the phosphagen content in both fast and slow fibres of human skeletal muscle, Karlsson (1979) stated that the CP content is higher in the FT fibres when compared to the ST fibres. However, Rehunen and Harkonen(1980) in their analysis of high energy phosphate compounds found that there was no significant difference in the concentrations between fast and slow twitch fibres. They did find however that in women the high energy phosphate concentrations were significantly higher in slow twitch than in fast twitch fibres.

Thus, in looking at the metabolic profiles of the two main fiber types in human skeletal muscle it is evident that fast twitch muscle fibres are better at forming lactate than slow twitch fibres. The comparison between CP content of fast and slow twitch muscle fiber cannot be as clearly defined.

## LACTATE METABOLISM DURING EXERCISE

### Lactate production

The mechanism for the metabolism of glycogen occurs along the glycolytic pathway which is common to both aerobic and anaerobic processes. In glycolysis, 3 ATP molecules are produced by the reduction of G-6-P to 2 pyruvate molecules.

During strenuous exercise which would involve anaerobic metabolism and probably the involvement of FT fibres (Gollnick et al, 1974; Jacobs et al., 1981; Thorstensson and Karlsson, 1976) the NAD+ demands of glycolysis outgrow the amount that can be regenerated via the malate shuttle. FT fibres compared to ST fibres have lower levels of malate-aspartate shuttle enzymes (Schantz, 1986). In the presence of the enzyme lactic dehydrogenase (LDH), more NAD+ is formed by the reduction of pyruvate to lactic acid. The FT fiber has more LDH isozymes rich in M units which favour a formation of pyruvate to lactic acid (Karlsson, 1979).

### Lactate in blood

Lactic acid (LA) has a pK value of 3.86 and can be almost completely ionized in the body. Undissociated LA is lipid insoluble and therefore can only permeate across cell membranes in

an ionized form. This would indicate that the permeation rate of both the LA anion and H+ can become rate limiting (Hirche et al., 1973). The lactate produced during anaerobic glycolysis once it has diffused from the muscle may accumulate in the blood where it can be measured to serve as an indicator of the anaerobic processes being activated during a workout. The peak blood lactate levels can vary anywhere from one to ten minutes post exercise (McGrail et al., 1977). Jorfeldt et al. (1978) looked at the release of lactate in relation to muscle lactate concentration and found that lactate release rose approximately linearly up to about five mmol/minute but then levelled off. Their results suggested a maximal level for lactate release from muscle with a translocation limitation for lactate within the muscle.

Lactate removal

The process of lactate removal from blood during exercise has been of much interest to many investigators. There are many sites in the body which can assist in the removal of blood lactate with some sites being more effective than others. In his review McGrail et al. (1977), spoke of the heart, kidney, skeletal muscle, brain, and liver as being some of the removal sites for blood lactate.

During exercise the heart is responsible for removing approximately ten percent of the lactate found in the blood. The kidneys and brain have minor contributions to the removal of

lactate during exercise and are considered negligible.

The liver was considered to be the primary site for lactate removal during both rest and exercise. Rowell et al. (1966), in their findings determined that approximately 50 percent of the estimated total lactate produced was removed by the splanchnic organs with the other 50 percent being taken up by the heart, skeletal muscle, and kidneys. However, a more recent investigation by Hermansen and Stensvold (1972), in using the values for liver blood flow and the highest arterio-venous lactate difference, taken from a later study by Rowell, calculated that the liver was responsible for removing about 3-4 percent of the lactate produced during exercise. Thus Hermansen and Stensvold (1972), suggested that if their calculations were correct the importance of the liver in removing lactate during exercise can be regarded as insignificant. As a result it was also stated in their conclusions that human skeletal muscle rather than the liver may be regarded as the main site for lactate removal during exercise.

It has been shown that human skeletal muscle can oxidize lactate under several different conditions. Hermansen and Stensvold (1972), found that the average maximal rate of lactate removal was at 63 percent of the individual's VO2 max. during treadmill exercise. They also showed that lactate removal was on average significantly higher at the highest workload (i.e. 80% VO2 max.), than at rest.

Belcastro and Bonen (1975), also found comparable results in lactic acid removal rates after a standardized 6 minute bicycle ergometer exercise. Lactic acid removal was most effective at 29.7 and 45.3 percent of VO2 max as well as during the free recovery conditions with a failure to see effective lactic acid removal at rest. Thus it was suggested that lactic acid removal should occur most effectively during moderate exercise recovery intensities. It was also stated that in a competitive situation requiring repeated maximal performances lactic acid removal may be most effective when the athlete recovers at will.

Another similar study by Bonen and Belcastro (1976) indicated that a self-selected intermittent recovery, most commonly used by athletes, was more rapid than at rest but not as rapid as during a continuous self-selected recovery exercise at removing lactic acid. They also found that these recovery conditions were significantly faster in trained runners compared to the untrained subjects in their previous study (Belcastro & Bonen, 1975). It was suggested that these differences may be due to a greater percentage of ST fibres in the trained subjects and a greater relative activity of the heart-specific isozymes of LDH. Later studies have also shown that lactate can be metabolized in skeletal muscle and that the rate of lactate disappearance was significantly greater during active recovery versus passive recovery (Dodd et al.,1984; McGrail et al., 1978).

There has also been evidence to suggest that nonexercising muscle plays an important role in the removal of lactate during exercise (Ahlborg et al., 1975).

**REST INTERVALS AND FATIGUE**

In repeated heavy resistance exercise such as that seen in weightlifting, the recovery time between the sets of exercises is important in that it be adequate enough to allow repeated bouts of quality work. Yates et al. (1987) looked at recovery of dynamic muscular endurance in an attempt to understand the ability to continue in a submaximal isotonic activity. The subjects performed dynamic elbow flexion exercise to failure using 1/6 of their MVC. The test was done on an arm lever ergometer in which weight could be added. The range of motion was limited by blocks from 170 to 70 degrees. The subjects performed the exercise to a prerecorded tape with a cadence of 38 repetitions/minute. When the subject fell four beats behind the exercise was terminated. The subjects were split into two groups and were randomly assigned recovery intervals which were 5, 15, 45, 135, 405, and 1215 seconds for group one, and 10, 30, 90, 270, 810, 2550 seconds for group two. The results showed that recovery progressed rapidly in the first 30 seconds to about 35%, 50% recovery was reached by 2 minutes 15 seconds, 75% recovery by 7 minutes, and 90% recovery after 20 minutes. It must be noted that this was a muscular endurance exercise because the load used yielded an initial endurance time of 2-4 minutes. 1/6 of

MVC is a relatively low load placed on the muscle, but 38 repetitions per minute is a rate of
work that requires a relatively high velocity, therefore it can be assumed that fast fibres were involved in the contractions (Faulkner et al., 1986). Yates et al. (1987) suggested that the early rapid recovery in the first 15 seconds could relate to resynthesis of ATP and CP.

Weltman et al. (1979) looked at recovery from maximal effort exercise under four different recovery modes. The purpose of their investigation was to determine the effectiveness of different recovery protocols in regard to blood lactate removal and further maximal effort exercise. The subjects performed two maximal 5 minute work tests on four different occasions on the Monark friction-type bicycle ergometer. The work rate used was based on the subject's VO2 max which was determined earlier. The two tests were separated by a 20 minute recovery. The recovery patterns were; a) passive recovery (PR) sitting on a chair, b) active recovery (AR) below anaerobic threshold (AR AT), c) active recovery (AR) above anaerobic threshold (AR AT), and d) active recovery (AR) above anaerobic threshold with oxygen (AR AT+O2). During the recovery, blood samples were taken at 5, 10, 15, and 20 minutes for the determination of lactate concentration. Weltman et al. (1979) concluded from their study that elevated blood lactate levels were not detrimental to maximal effort performance. There was no significant difference between the four modes of recovery on the

performance between Test 1 and Test 2. The passive recovery is of importance because this type of recovery is most commonly used in weightlifting. Weltman et al. (1979) showed lactate levels after the passive recovery technique were still up at around 12 mM after 20 minutes. These lactate levels were said to have not had an effect on the subsequent cycling performance, however it cannot be assumed that lactate levels above resting will not have an effect on an exercise of shorter duration and higher intensity such as weightlifting.

Wootton and Williams (1982) also looked at the effects of different rest intervals on exercise performance. In their study, the ability to perform repeated bouts of maximal dynamic exercise with different recovery durations was examined.The task consisted of five 6 second maximal sprints against heavy resistance on a bicycle ergometer with either a 30 second or a 60 second rest interval between each sprint. The results showed that with a 60 second rest interval the peak power output fell by only 3% from bouts 1 to 5 while the end power output decreased by 12.7% after the fifth bout. This is in contrast to the performance with a 30 second rest interval in which the peak power output fell by 17.9% through bouts 1 to 5 while the end power output fell by 29.1%. The blood lactate concentrations rose considerably in both protocols increasing approximately eleven fold with 30 second recovery periods and approximately ten fold with 60 second recovery periods. It was suggested that because recovery times were inadequate for

full PCr replenishment within the muscle then with each subsequent exercise bout there would be an increasing demand on glycolysis to maintain ATP levels. This may help explain why there were greater decrements in performance along with higher blood lactate levels during the exercise bouts with 30 second rest intervals compared to exercise bouts with 60 second rest intervals.

## THE EFFECT OF LACTATE ACCUMULATION AND CP DEPLETION ON MUSCLE FATIGUE

The following section will look at how an increase in lactic acid and/or a decrease in high energy phosphates in human skeletal muscle might cause fatigue as seen through a decrease in force output or a decrease in speed of movement.

Jacobs et al. (1983) wanted to evaluate the extent of anaerobic glycolysis in 10 and 30 seconds of supramaximal exercise by looking at intramuscular lactate concentration. The results showed that 10 seconds of supramaximal exercise caused lactate concentrations to increase approximately five times over resting levels. The lactate concentration for the male subjects after 10 seconds of exercise were 59% of the lactate concentration that was seen after 30 seconds of exercise. These percentages were based on a resting value of 6 mmol/kg dry weight.

These theories oppose an earlier study by Margaria et al. (1969) in which subjects ran on a treadmill for 10 seconds at a speed which would have them reach exhaustion after 30-40 seconds if continued. The subjects were allowed rest intervals in three different series: 10, 20, and 30 seconds. The results showed that as the rest interval was increased the total running time also increased. A 30 second rest interval between 10 second runs allowed the exercise to be carried out indefinitely. After looking at lactic acid formation, Margaria et al. (1969) stated that when the rest period was 25 seconds or longer, the phosphagen source was adequate and no call would be made on the lactate mechanism once a steady state was reached.

Harris et al. (1977) looked at the comparison of muscle phosphagen content of biopsies that were taken immediately after exercise to the corresponding lactate content. These biopsies were taken from the m. quadriceps femoris of males ranging in age from 18 to 33 years. It was seen that the CP decrease proceeded curvilinearly with respect to an increase in the muscle lactate content. It was also stated that this data was independent of exercise type, intensity, and whether the exercise had been maintained to exhaustion. Variations in both isometric and dynamic exercise protocols were used with none of the dynamic protocols lasting less than 6 minutes while the isometric exercise study did involve a load of 90-95% of the MVC which could be sustained for at least 2 seconds. Due to the protocols used in this study it is not

certain whether or not the curvilinear relationships between CP and muscle lactate would be the same using strenuous dynamic exercise that would cause fatigue after a much shorter duration.

One of the purposes of a study by Cheetham et al. (1986) was to examine the changes in muscle metabolites after a 30 second sprint on a non-motorized treadmill using eight female subjects. The results showed that muscle glycogen fell by 25% along with a 64% decrease in PCr and a 37% drop in ATP. The glycolytic intermediates before fructose 1,6 diphosphate, increased approximately 13 fold and pyruvate and lactate concentrations rose approximately 19 and 29 times respectively. Further calculations from the study attributed 64% of the ATP being used to sprint, coming from glycolysis with the rest being derived mainly from CP. Peak power was reached at an average of 1.63 +/- 0.74 seconds into the sprint followed by a gradual decline to 50 +/- 10% of the peak power at the end of the sprint. As the treadmill was non-motorized, this would help explain how the subjects could tap into both the anaerobic alactic and the anaerobic lactic energy systems within a 30 second time frame.

A similar study by Boobis et al. (1982) in which subjects attempted to pedal as fast as possible on a cycle ergometer against a pre-set load (75 g per kilogram body weight) was conducted to look at muscle metabolites during brief maximal exercise. It was observed that peak power output was achieved in the first 3-6

seconds after which the power output declined rapidly. Muscle samples showed that after 6 seconds of this type of work CP had dropped by approximately 35 percent, ATP by 10 percent and muscle lactate had increased approximately three fold over pre-exercise conditions. It was suggested from the results obtained that the glycogenolytic processes are initiated within 6 seconds and would contribute to the provision of energy during maximal dynamic exercise due to CP degradation.

A further look into the role of high energy phosphates in exercise was seen in a study by Rehunen et al. (1982) in which the high energy phosphates were investigated in ST and FT muscle fibres of resting sprinters and long distance runners, during light sprinting exercise, and during exhaustive running exercises. Their study suggested that during short-term exercise more CP stores are depleted in the FT fibres than in the ST fibres and that during strenuous activity, the sprinters showed a drop in CP stores in both FT and ST fibres suggesting that both muscle fiber types are recruited during sprinting. It was also suggested that in the sprinters the CP is resynthesized more quickly in FT than in the ST muscle fibres.

A more recent study by Tesch et al. (1989) seemed to agree with the suggestions of Rehunen et al. (1982). Tesch et al. (1989) looked at creatine phosphate in both fast and slow fibres of human skeletal muscle before and after exhaustive exercise. At rest the

CP content was approximately 13% higher in FT than in ST fibres. Tesch et al. (1989) stated that CP recovery may occur more readily in ST fibres because the resynthesis of CP is an oxygen dependant process and skeletal muscle blood flow is greater around ST fibres. This was also seen by Sahlin et al. (1979) who suggested that the initial fast phase of CP resynthesis was limited by availability of oxygen. Post exercise lactate values were also significantly higher compared to resting ($P<0.001$), this being after 15 seconds of actual concentric work (30 contractions each lasting 0.5 seconds).Tesch et al. (1989) also stated that it was not certain whether rate of force loss during contractile activity followed by the lower rate of force restitution shown in individuals rich in FT fibres could be correlated with CP metabolism.

Another investigation that involved sprinters was done in which Hirvonen et al. (1987) looked at the breakdown of high energy phosphate compounds and lactate accumulation during 40, 60, 80, and 100 meter sprinting at maximal speed on separate days. The purpose of their study was to try and find a metabolic explanation for muscular fatigue in suramaximal work. The subjects used in the study were Danish national level male sprinters. Blood samples were taken at rest (on the first day only), after 5 minutes of warming up, 30 seconds before each run, and then 0, 2, 4, 6, 8, and 10 minutes after each run. Hirvonen et al. (1987) found that about 88% of the creatine phosphate was depleted after 5.5 seconds in

work lasting 11 seconds and suggested that because of the low level of blood lactate (8.3 +/_0.6) seen in the subjects after having performed the 100 meter run, it was obviously not the primary reason for muscle fatigue and decreased running speed.

The present review has already noted hypotheses that lactic acid accumulation and a drop in pH brought about by an increase in hydrogen concentration are factors in the onset of muscle fatigue. During fatigue, another metabolite besides $H^+$ also increases in concentration and that is inorganic phosphate (Pi) which is a result of the breakdown of phosphocreatine (PCr) to creatine (Cr) and Pi. It has been observed by Wilkie (1986) in a re-analysis of his earlier P-NMR studies that a combination of an increase in $H^+$ and Pi leads to an increase in the monobasic phosphate concentrations ($Pi^-$) and suggests that $Pi^-$ might be a direct inhibitor of the actomyosin ATPase system.

A later study by Nosek et al. (1987) using chemically stained single fibres from rabbit psoas muscle have shown that a decline of pH normally seen with fatigue would not only inhibit force directly but indirectly as well by increasing the fraction of total Pi in the $H_2PO_4^{-1}$ form which is the diprotonated form of Pi. Thus it was concluded that a combined effect of an increase in intracellular Pi and a decreased pH, due to lactic acid accumulation, would result in a dramatic depression of maximal force production by the contractile apparatus. The results also supported the suggestion

that maximal force produced by the cross-bridge is dependent on $H_2PO_4^{-1}$ and not an $HPO_4^{-2}$ or total Pi.

A further P-NMR study on humans by Miller et al. (1988) also helped to confirm these earlier reports by including that a decline in MVC strongly suggested that both $H^+$ and $H_2PO_4^{-1}$ are important determinants of human muscle fatigue. However, observations by Wilson et al. (1988) in their P-NMR study using humans has implied that muscle fatigue during intense short-term exercise was primarily caused by an increase in intramuscular $H_2PO_4^{-1}$ rather than by a decrease in intramuscular pH.

## SUMMARY

After having reviewed the possible mechanisms of muscle fatigue, the above review of studies has indicated that an increase in lactic acid resulting in an increase in hydrogen ion concentration along with a drop in pH are important factors. Additionally, a drop in CP and a subsequent increase in the ionized forms of inorganic phosphate are also important factors in inhibiting the contractile processes thus producing a depressed force output.

In order to maintain a required high force output, the training stimulus to achieve such a result should ideally be free from any premature fatigue that would result in a lower volume of optimal performance. Thus it would seem important to know the necessary rest interval required between work bouts involving high speed and high resistance movements in order to maximize the quality of work being performed and minimize the premature onset of any muscle-fatiguing metabolites.

# CHAPTER THREE

# METHODOLOGY

## Introduction

This chapter will outline the experimental design and methods for this study, in which the rest interval between sets shall be manipulated in order to look at its effect upon blood lactate and speed of muscle contraction. The method of blood analysis to determine blood lactate levels shall also be described, along with the statistical design to determine significance among the variables chosen.

## Subjects

For this study, eight male volunteers ranging in age from 20 to 28 years were recruited who were all competitive athletes. All were considered experienced weight lifters who had a minimum of one year of weight training. Experienced subjects were used because they were all familiar with the movement pattern and this decreased the chance that learning effects would bias the study. They were also familiar with post-exercise responses to weightlifting and their competitiveness would insure that true maximums were being achieved throughout the study.

**Instrumentation**

The equipment used in this study involved a Scott Curl bench, installed at an angle of 45 degrees with the floor; a dumbbell in which weight could be varied; two Honeywell FE7C-RCGG retroreflective switches with reflectors; an IBM X/T personal computer and LABMASTER Board along with custom software programs for recording speed of movement between the two light gates.

The speed of limb movement was determined during elbow flexion-extension by the arm passing through two infrared retroreflective photoelectric cells which were positioned at selected angles relative to the face of the Scott Curl Bench. Analog to digital (A-D) conversion of the switch signals was accomplished by the LABMASTER installed in the IBM X/T microcomputer. Software was developed to retrieve the time values between switch signals and instantaneously calculate changes in the time values.

**Procedure**

The testing protocol extended over a period of eleven days (see table 2).

Table 2. Exercise Protocol

| DAY 1/3/5 | DAY 6/7 | DAY 8 | DAY 9/10 | DAY 11 |
|---|---|---|---|---|
| Determination of 1 RM | O<br>F<br>F | - Elbow flexion at 70% 1RM<br>- Rest between sets; half group 30 sec, half group 180 sec,<br>- Post lactates at 0, 1, 2 min | O<br>F<br>F | - Elbow flexion at 70% 1RM<br>- Rest between sets; half group 30 sec, half group 180 sec,<br>- Post lactates at 0, 1, 2 min |

On the first day of the testing protocol, each subject's one repetition maximum (1RM) in elbow flexion of the dominant arm was determined on the Scott Curl bench by progressively loading the dumbbell until a complete repetition could not be achieved. The 1RM recorded was the weight of the last fully completed repetition. This procedure was repeated on days three and five. The 1RM test was performed three times to ensure that true maximum was being achieved. Days two, four, six and seven were rest days in which the subjects were told to resume normal activity but abstain from any arm exercises. On day eight the subjects performed sets of elbow flexion and extension repetitions with 70% of their 1RM. This percentage was based on an average of the percentages discussed in the literature reviewed (Chapter 1 pp.1-2). They were instructed to execute the repetitions as fast as possible, while still maintaining control and full range of

motion. Each set lasted until fatigue occurred. Fatigue was determined by the computer software program, which calculated the speed of arm movement in the concentric phase, through the two photoelectric gates which were positioned at angles of 40 and 90 degrees relative to the face of the Scott Curl bench. The full range of motion was between 0 and 130 degrees with the midpoint being at 65 degrees. The positioning of the gates at 40 and 90 degrees were chosen because they represented an area around the midpoint where the arm would be considered to be travelling at its maximum velocity. When the speed of arm movement had slowed by 25% compared to the speed of the first repetition of that set, the computer signalled the end of the set by an auditory beep. Rest time between sets was predetermined at 30 seconds. The number of sets would continue until the first repetition of a set was 25% slower than the first repetition of the first set. At this time the exercise for a subject would be complete. The number of sets and repetitions were counted and recorded for the two conditions. Repetition data was taken for future reference as this is a traditional parameter in weight training. No analyses of the repetition data was intended or done as the thrust of the present study was to measure time not repetitions. Dominant hand fingertip blood samples were then taken from the subject at zero, one, and two minutes following the last attempted curl and analyzed for blood lactate concentration. These sample times were chosen based on pilot work that showed values had peaked by two minutes post exercise. On day nine and ten the subjects were told to resume

normal activity but refrain from any arm exercises. On day eleven the same protocol as day eight was used except the rest interval between sets was changed to 180 seconds. The subjects were randomly assigned into two groups so that the number of subjects having a 30 and 180 second rest intervals were equal on the two test days. The rest intervals of 30 and 180 seconds were based on physiological landmarks of half and full CP recovery respectively, in the anaerobic alactic energy system (Hultman et al., 1967).

**Method of blood sampling and analysis**

The blood samples were analyzed with a Kontron 640 Medical Lactate Analyzer to determine lactate concentration. The blood samples were obtained by puncturing the middle fingertip of the exercised hand with a Monojet Lancet device and transferring the blood into a capillary tube. 20 ul of whole blood was then pipetted from the capillary tube into a hemolyzing tube where the blood was immediately mixed with 180 ul of diluting solution. A sample of 100 ul of this solution was then injected into the analyzer to determine blood lactate concentration. The experimental error of the Lactate Analyzer was established at +/ - 0.05 mmol/L (Geyssant et al., 1985). This procedure was repeated for all samples on days eight and eleven. After the samples were taken, the subject's finger was cleaned with alcohol and covered with a band-aid to prevent infection. The Lactate Analyzer was calibrated to 0.00 and 5.00 mmol/L before any samples were

analyzed. Recalibration of the analyzer was done to 5.00 mmol/L after every three samples.

**Statistical design**

Initially, descriptive analyses were performed to provide means and standard deviations for total work time values obtained during the exercise protocol and lactate values obtained post exercise. In order to determine the relationship between total number of sets, blood lactate accumulation, and mean time per set a table of correlations was used. This was performed on each subject's data for the two conditions.

The statistical design used for this study were three one-way analyses of variance (ANOVA) with repeated measures. The independent variable of rest interval was fixed at two levels, 30 and 180 seconds. The dependant variables studied were blood lactate levels, total number of sets, and mean time per set.

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