1993

The effects of high and low repetition resistance training on the force profile of the rowing stroke

Benjamin Tarbox
Edith Cowan University

THE EFFECTS OF HIGH AND LOW REPETITION RESISTANCE TRAINING ON THE FORCE PROFILE OF THE ROWING STROKE

BY

Benjamin Tarbox

Bachelor of Applied Science (Sports Science)

A thesis submitted in partial fulfilment of the requirements for the award of

Bachelor of Applied Science (Sports Science) with Honours

Date of Submission : 22.12.1993

Acknowledgments

I would like to express my sincere gratitude to my supervisors, Andrea Schreiner who's practicality and realism complemented Dr. Colin James's theoretical knowledge and support amiably.

To Steven Lawrence who's patience was often tested and advice always meant more work.

To Nick Garratt and Pattie Pinkerton for their cooperation in letting me use their athletes as subjects for the study.

To the Western Australian Institute of Sports TIP rowing squad. Thankyou for all the blood, sweat and tears that went into training and testing.

To Peggy McBride for her invaluable assistance with the ergometer and advice on rowing.

To my parents who say they don't see me enough, and saw me even less during the course of my study, and to Andrea, who's support and patience with my absence was I know sometimes hard, but I hope worth it in the end.

Thankyou to you all.

DECLARATION

"I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any institution of higher education; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text."

Signature.

Date...22.12.1993...

Abstract

The effect of resistance training on the ability to generate force throughout the rowing stroke has to date been unreported. The purpose of this study therefore was to determine the changes that occur in the force profile of the rowing stroke, following low repetition strength (LRS) and high repetition endurance (HRE) resistance training. Eight female and 10 male sub elite heavy weight rowers matched according to gender, strength and anthropometric variables, completed 12 weeks of LRS or HRE resistance training. Pre and post testing was completed to determine changes in bench press and leg press repetition maximum (3RM) strength and strength endurance (repetitions to failure using 75% of 3RM). Changes in the force profile of the rowing stroke were determined by the changes in peak force, work per stroke and total work. All subjects completed a maximal and 3 minute effort biomechanical test on an instrumented Concept II rowing ergometer at 2 steps of increasing intensity. Significant difference ($p < .05$) was recorded in upper and lower body strength, lower body strength endurance and in all except one biomechanical variable in both biomechanical tests. Differences between the groups were only significant in endurance leg press repetitions and the 3 minute efforts work per stroke during the first step. Improvements made in endurance leg press repetitions were significantly greater (+33) for HRE, while changes in bench press strength where significant for LRS (+10.3kg) but not for HRE (+3.7kg). Post hoc and descriptive analyses showed HRE improved consistently more than LRS in all 3 minute biomechanical variables indicating that HRE may be of more benefit for increasing certain biomechanical variables of the simulated rowing stroke than LRS. These findings must however be viewed with caution, as more controlled research is required in the area.

TABLE OF CONTENTS

PAGE

APPENDICES

LIST OF TABLES

TABLE OF FIGURES

CHAPTER 1

Introduction

Rowing is an Olympic sport that requires a high percentage of an athletes maximal strength to be utilised for an extended period of time. Depending upon the amount of strength exerted during the rowing stroke, there is normally sufficient muscle tension in rowing to improve maximal strength and strength endurance (Herberger et al., 1990). However this effect is usually reduced as the novice becomes an elite rower. Therefore resistance training must be utilised to develop the strength characteristics required in rowing to a greater extent than what can be achieved in the boat alone. As a result, the resistance training regimes of rowers have traditionally focused on the development of maximal strength (low repetition) and/or strength endurance (high repetition). The adaptations to low repetition strength training have been investigated extensively, but little research has been completed on adaptations to high repetition training.

The human body responds to a training stimulus by physiologically adapting to the specific demands imposed upon it. During resistance training, both neural and peripheral mechanisms adapt to allow for a greater expression of force throughout a range of motion. Muscle and its ability to generate force varies throughout its range of movement and is referred to as the length-tension curve. With advances in biomechanical testing equipment, the muscles ability to generate force throughout a skilled movement (force curve) can be systematically recorded and analysed. This method of analysis can be used to monitor technical aspects of the skill and the changes that occur as a result of training. If adaptations to resistance training are

specific to the type of regime completed, then it seems plausible that different training regimes may cause different changes in the force profile of the skilled task.

If a particular training regime produces a more desirable change in the force curve of the rowing stroke, then that change may lead to an increase in rowing performance. Particularly in high performance sport were the difference between winning and losing is so small, any adaptation that improves performance will be of benefit to the athlete. The purpose of this study therefore, is to determine the changes in the force profile of the simulated rowing stroke that occur in moderately trained sub-elite rowers following low repetition strength and high repetition endurance resistance training.

It was hypothesised that high and low repetition resistance training will cause different changes in the force profile of the rowing stroke. In determining the nature of these changes, and how they affect performance, coaches and other specialists in the area will be better able to design more specific performance enhancing resistance training programs for rowers.

CHAPTER 2

Literature Review

Determinants of Strength

Strength is defined as the maximum force generated by a muscle or muscle group without relation to time (McArdle, Katch & Katch, 1986). The ability of a muscle to exert force is a function of intrinsic (muscle based) and extrinsic factors (DiNubile 1991). Muscle based determinants of strength include the cross sectional area (CSA) (MacDougall, 1986a; DiNubile, 1991) and fibre composition of a given muscle or muscle group. Extrinsic factors include neuromuscular activation and synchronisation, muscle length, angle of pull, body size and gender.

Ikai and Fukunaga (1968) in DiNubile (1991) found a strong correlation between the CSA of a muscle and its ability to develop force. Rutherford (1986) in Jones, Rutherford & Parker (1989) also found strong correlation ($r = 0.71$ & 0.76) between muscle CSA as measured by CT scanning and isometric quadricep strength of young male and female subjects, respectively. In general, the greater the CSA of a muscle, the greater its strength potential.

Muscle is composed of two different muscle fibre types, type I and II. Type II fibres can be further subdivided into type IIa and IIb. Each type has specific structural, metabolic and functional characteristics, and there is some evidence from both human and animal work that type II fibres are intrinsically stronger than type I (MacDougall, 1986; DiNubile, 1991; Jones & Rutherford, 1987; Jones et al., 1989). According to Tesch and Karlsson (1978), there is a strong correlation between isometric strength and power, and the percentage of type II fibres.

An athlete's fibre type profile is primarily controlled by genetics and programmed during foetal development. There is still however, wide variability in fibre type ratios between individuals and in a given individual from one muscle group to another (MacDougall, 1986; DiNubile, 1991). The vast majority of literature on human subjects has to date concluded that training is unable to convert or change one fibre type to another, but training can cause adaptations to fibres such that one fibre type can display similar characteristics to another type. Animal research however, has been able to show that under certain specific conditions, fibre type conversion is possible (Vrbova, 1979).

A maximal muscular contraction is the product of the number of motor units recruited and their state of activation (Schmidtbleicher, 1985; MacDougall, 1986). To generate maximal force, all motor units comprising a muscle or muscle group must be recruited at their optimal firing frequency. In general, an increase in firing frequency of up to 50 Hz will cause an increase in peak force, while frequencies above 50 Hz will increase the rate at which peak force is achieved (Sale, 1988).

Muscle has greater potential to develop maximal force when at a resting length or in a slightly lengthened position, as the available sites for actin and myosin interaction are maximal. In a shortened position however, the available sites for actomyosin formation are reduced because of the already existing cross-bridge interaction required in holding the shortened position (MacDougall, 1986).

Some individuals are genetically endowed with muscle tendon lever arrangements and muscle structures (shape and length) that strongly favour the development and expression of strength (DiNubile, 1991; Jones et al, 1989). Fibres in the quadricep muscle for example, do not lie parallel to the line of action of the muscle, rather they insert into the tendons at acute angles. A change in or different angles of insertion (penation) may alter the force measured between the ends of the muscle (Jones & Rutherford, 1987).

Berger (1982) found a positive correlation between body mass and absolute strength. There was however, a negative correlation when strength and mass were used to determine relative power to weight ratios. Absolute strength is of greater importance in activities where an external resistance is required to be displaced or where body weight is supported, such as in rowing.

In terms of absolute strength, men generally display at least 50% greater upper body strength and 30% greater lower body strength than women (Dinubile 1991). Wilmore (1974), in Wells (1991) speculated that upper body strength is relatively lower in women because they have not engaged in upper body strength activities as frequently as males due to previous social expectations and behaviours. Bishop, Cureton and Collins (1987) studied sex differences in strength among swimmers and untrained subjects. Differences in absolute strength were generally smaller for the swimmers than for the non athletes. When strength is expressed relative to lean body mass or to CSA of muscle, sex differences are often minimal or non existent (Bishop et al, 1987; Wells 1991, DiNubile, 1991). These findings

suggest that sex differences in muscular strength are almost entirely accounted for by the differences in muscle mass.

Force Characteristics of Muscular Contraction

The speed at which a muscle shortens is dependent upon the length of the muscle and its morphological characteristics. The greater the number of sarcomeres along a myofibril, the greater the number of cross bridges in series it will have to activate and the faster it will be able to contract. Characteristically, type II fibres have a greater cross bridge strength and higher activation thresholds than that of type I (MacDougall, 1986; DiNubile, 1991; Jones et al., 1987; Jones et al., 1989). The higher the ratio in favour of type II fibres, the greater potential that muscle will have to shorten at speed. The speed or velocity at which muscle can dynamically contract, is inversely related to the force developed. This relationship is known as the force-velocity relationship of muscular contraction (MacDougall, 1986).

The force of a muscle or muscle group varies throughout its range of movement (MacDougall, 1986; DiNubile, 1991). The curve representing the force produced at various angles of movement is referred to as the length tension curve. Length-tension curves vary from muscle to muscle and person to person, and are also influenced by minor changes in joint position and the types of resistance training chosen (DiNubile, 1991).

Adaptations to Resistance Training

Various studies (Moritani & DeVries, 1979; Young, Stokes, Round & Edwards, 1983; Jones et al., 1987) have demonstrated greater improvements in strength than can be accounted for by increases in muscle size. It has been claimed that, prior to training, untrained muscle cannot be maximally activated by voluntary contraction (Sale, 1988). This is hypothesised to be due to the neural systems inability to recruit high threshold motor units (Sale, 1988), the patterns of electrical stimulation of the motor units (Jones, et al., 1989) and neural inhibitions involving the golgi tendon and muscle spindle reflex arcs preventing the production of high forces which may cause damage to the untrained muscle and its tendinous attachment (Caiozzo, Perrine & Edgerton, 1981; Hakkinen & Komi, 1983).

Hakkinen et al. (1983) found that after 16 weeks of free weight isotonic training, improvements (21%) in isometric leg extension strength, were also accompanied by significant increases (14%) in recorded neural activation (IEMG) of the vastus medialis, lateralis and rectus femoris. Greater levels of neural activation may lead to the recruitment of additional high threshold motor units which contribute to the increase in strength.

Caiozzo et al. (1981) hypothesised that the forces produced by 5 untrained college students at 1.68 $rad{\cdot}s^{-1}$ were subject to a tension-limiting mechanism, which was of neural origin. The increases in strength seen in this area of the in vivo force-velocity curve after 4 weeks of isokinetic knee extension training at 1.68 $rad{\cdot}s^{-1}$ were strongly suggested to be attributed to adjustments in this neural tension limiting

mechanism. Resistance training may help improve strength expression by developing the neural systems ability to recruit the high threshold type II fibre motor units and/or by reducing the neural inhibitions associated with the reflex arcs (MacDougall, 1986). It is not known however, how much of an increase in strength is due to improved motor unit recruitment and activation or a decrease in neural inhibition.

Strength training using intensities that exceed 60-70 percent of an individual's maximum force generating capacities result in an increase in the total muscle tissue or CSA (MacDougall, 1992). This hypertrophy of muscle is directly related to an increase in both the size and number of myofibrils within each fibre (MacDougall, 1986b). Greater relative hypertrophy occurs in type II muscle fibres as a consequence of heavy resistance training, compared to type I fibres (MacDougall, Elder, Sale, Moroz & Sutton, 1980; MacDougall, 1986; Tesch, Hakkinen & Komi, 1985; Jones et al., 1989). Differences in motoneuron recruitment thresholds between fibre types have been postulated as the mechanism responsible for this selective hypertrophy of type II fibres (Edgerton, 1976; Edstrom & Ekblom, 1972) in MacDougall et al. (1980). High force contractions recruit the high threshold type II fibre motor units which then only provide them with the stimulus for growth.

Morphological characteristics of rowers show hypertrophy of type I fibres to be similar to that of type II (Hagerman & Staron, 1983). This may be attributed to the speed at which the rowing stroke is performed, allowing for the activation of the type I fibres (Warmolds & Engel, 1972; Secher et al., 1978, 1981) in Secher (1983),

which then respond to the hypertrophic stimulus in the same manner as that of type II fibres.

Relevant changes associated with muscular hypertrophy include a proportional increase in interstitial connective tissue (MacDougall, 1986) and a decrease in the capillary-to-fibre ratio and mitochondrial density (MacDougall, 1986; Sale, 1988; Tesch, Thorsson & Essen-Gustavsson, 1989; MacDougall, 1992). Short term low repetition resistance training has also been shown to decrease relative body fat, increase lean body mass and result in no or a slight increase in absolute body mass (DiNubile, 1991).

High resistance strength training does not cause significant changes in the muscles enzymes associated with aerobic-oxidative metabolism and is unlikely to provoke meaningful increases in enzymes favouring fast ATP replenishment or contractility (Tesch, 1992). Strength trained athletes do however, show slightly higher glycolytic activity of type II muscle fibres than that of sedentary people (Tesch et al., 1989). This may be attributed to the different fibre type recruitment patterns required by athletes in training compared to untrained individuals.

Women respond to resistance training with increases in strength but with comparatively less increases in muscle size than that experienced by males (MacDougall, 1986; DiNubile, 1991) This is speculated to be in part due to their lower absolute concentrations of blood androgen levels (Brown & Wilmore 1974; Mahew & Gross 1974) in Weiss, Cureton & Thompson (1982). After studying the

changes in serum testosterone concentrations in 40 males and females before and periodically after a bout of heavy resistance exercise, Weiss et al. (1983) found a significant sex by time interaction, indicating that there was a sex difference in the absolute testosterone response to training (12.7 times higher in males). It may cautiously be speculated that a sex difference in the androgen response to exercise could account for a sex difference in exercise induced hypertrophy. Further research in the area however is required as the role of testosterone and other androgens in muscular hypertrophy is still unclear.

Specificity of Resistance Training Adaptations

Strength and power improvements are not necessarily evident in other than the specific movement pattern performed during training (Jones et al., 1989). Rutherford, Greig, Sargeant & Jones (1986) found that after 12 weeks of lifting near maximal loads during leg extension, subjects improved training loads by 200% and isometric strength by 15%. Despite these increases, power output, assessed isokinetically on a modified cycle ergometer, showed no change. Indicating that large increases in training weight lifted was of little value in the different task of riding a cycle ergometer. Similarly, an increase in the strength of the quadricep muscles during leg extension, will not necessarily improve the power output of the legs during the drive phase of the rowing stroke. The reason being that the increase in strength achieved during training may not be transferable to the more complex and skilful movement pattern required in rowing (Bell, Petersen, Quinney & Wenger, 1989). Task specificity may be accounted for by an improvement in co-ordination of the different muscle groups that are involved in certain activities (Jones et al., 1989).

Research has demonstrated that the greatest increases in strength are achieved at or near training velocity (Caiozzo et al., 1981). Lesmes, Costill, Coyle and Fink (1978) however, found that significant increases in strength where only achieved at or below the training velocity. Muscular adaptations and the influences of neural activation are reported by Behm and Sale (1993) to be the underlying mechanisms behind velocity specificity.

Jones and Rutherford (1987) after 12 weeks of concentric and eccentric training found significant increases in training weights of 250 and 261% respectively. Despite this, isometric strength only increased by 15 and 11%. These increases in strength where found to be significantly less than those found as a result of isometric training (35% increase). Kanehisa and Miyashita (1983) found no improvement in isometric strength of the elbow flexors after both fast and slow isokinetic training. This research suggests that training is also specific to the type of contraction, with dynamic training not necessarily leading to improvements in isometric strength.

Increases in strength have been found to be greatest at the specific length adopted during training (Jones et al., 1989; Lindh, 1979; Thepaut-Mathien, Van Hoecke & Maton, 1988). Knapik, Mawdsley and Ramos (1983), found that isometric strength gains, were specific to the fixed angle plus or minus 10 degrees. Thepaut-Mathieu et al. (1988) concluded that the degree of specificity was dependent on the muscle length at which the training was carried out: the shorter the length, the greater the specificity. Variations in angle specificity during the first few weeks of

training may, according to Hakkinen et al. (1983), be partially explained by neural mechanisms. Most studies reporting muscle length specificity have been conducted using isometric training and testing protocols. Limited work has been done to show the adaptations to range specific dynamic training (Graves, Pollock, Jones, Colvin and Leggett, 1989) and testing. Technical limitations in training and testing equipment, and the problems associated with the interpretation of dynamic muscle movement data are potentially the reasons behind the lack of research in this area.

Gains in strength will improve skill performance to the greatest extent when the training program consists of exercises that include the muscle groups, movement type and range of motion that simulate the movement patterns used during the actual execution of the skill. Previous research looking at the specificity of training adaptations, are relatively short with varying subject types, populations and training regimes. Specific short term strength gains appear to be more attributable to neural factors (Hakkinen et al., 1983) and improved muscular co-ordination (Jones et al., 1989) than to structural changes within the muscle.

<u>Resistance Training</u>

Based on current literature and practices, different programs should be utilised for the development of muscular strength and muscular endurance. Strength is best achieved with high loads and low repetitions, where endurance is developed with the use of moderate loads and high repetitions (Fox, Bowers & Foss, 1988; DiNubile 1991).

Resistance training for rowers has traditionally attempted to develop both maximal strength and muscular endurance. Station training whereby the subject completes all sets of a given exercise before moving to another has primarily been used for the development of maximal strength, whilst circuit training has been shown to be particularly suited for developing strength endurance (Herberger et al., 1990; Bell, et al., 1989; Bell, Petersen, Wessel, Bagnall & Quinney, 1991). Strength training regimes have focused on subjects completing 3-5 sets of 2-12 repetitions with recovery periods of 3-5 minutes between sets. Strength endurance training regimes have used 2-4 circuits with repetitions ranging between 20 to 70 per exercise (Wright, Bompa & Shepard, 1976; Herberger et al., 1990), for each circuit.

The use of free weights and various isotonic machines, is the most commonly used means by which the general rowing fraternity trains. According to Herberger et al. (1990), the use of free weights allows for a maximum increase in strength with the least expenditure of time. For research purposes however, isokinetic training using variable resistance hydraulic machines (Bell, et al., 1989; 1991) and isokinetic dynamometers has been used extensively. The adaptations to dynamic isotonic resistance training are limited to date even though it is the most popular means of training. It is an area that requires further investigation.

Physiology of Rowing

Rowers in general display ecto/mesomorphic (linear and muscular) anthropometric characteristics (de Garay, 1974 in Hagerman, 1984). Muscle fibre composition of elite rowers closely follows that of other highly trained endurance

athletes except in fibre size where rowers tend to show greater CSA of both fibre types (Hagerman et al., 1983). Elite rowers display a ratio of 70:30 type I to type II fibres with very few of the type IIb fibres making up the fast twitch population (Hagerman et al., 1983; Larsson and Frosberg, 1980; Mickelson and Hagerman, 1982).

Mean maximal oxygen uptake (VO_{2max}) values of 5.95L·min^{-1} (67.6 ml·kg·min^{-1}) have been reported by Hagerman, Connors, Gault, Hagerman and Polinski (1978) when studying 310 highly competitive oarsmen during a 6 minute maximal rowing ergometer test. Hagerman et al. (1978) also reported that oarsmen worked consistently at 96-98% of their VO_{2max} for most of the test. Anaerobic thresholds of 83-95% of $VO_{2\ max}$ have been achieved by athletes in training and leading up to major competitions (Hagerman and Mickelson, 1981; Mickelson and Hagerman, 1982). Aerobic metabolism during competitive and simulated rowing is reported to provide over 70 percent of the required energy for oarsmen (Hagerman et al., 1978; Secher, 1983; Mickelson et al., 1982). Oarswomen according to Hagerman (1975) and Hagerman, Hagerman & Mickelson, (1979) show a slightly lower aerobic contribution (60-65%) but this, and all other research conducted before 1984, was completed at a time when women trained for and competed over a 1000 metre distance. Since 1985, women have competed over 2000 meters and it is expected that they now experience the same energy contribution from the different systems and display similar morphological characteristics as that of their male counterparts.

Lactate values of 126-240 $mg \cdot 100ml^{-1}$ have been reported (Hagerman et al., 1978; Secher, Vaage, Jensen & Jackson, 1983), 90% of which had formed during in the first of a 6 minute maximal rowing ergometer test and peaked during the second minute (Hagerman et al., 1978). These values are indicative of the involvement of anaerobic metabolism (approximately 30%) during simulated and competitive performance.

Biomechanics of Rowing

Due to the dynamic nature of the rowing movement, most major muscle groups are involved at some stage (Secher, 1993). The rowing stroke consists of a cyclic sequence of events that include the catch, drive, release and recovery (Lamb, 1989; McBride 1993), and the effectiveness of the force applied to the oar changes as it passes through these different phases. The catch occurs as the oar is placed quickly in the water and force is rapidly applied to the handle. Most of this force serves to push the water in a direction away from the boat with only a small portion contributing to propulsion. The drive phase is associated with the movement of the oar through the water. As it moves to a position perpendicular to the boat, close to 100% of the force contributes to propelling the boat (McBride, 1993). The release occurs as the oar is withdrawn from the water and is followed by the recovery where the oar is moved through the air and is prepared to re-enter the water to initiate the next catch. Only a small portion of force is effective during the release where the oar serves to push water in a direction towards the boat.

If stroke distance (cm) and pulling force (N) are measured and graphically represented on X and Y axis respectively, resultant biomechanical force profiles of the rowing stroke are attained. Mason, Shakespear and Doherty, (1988) have used this technique on a Gjessing rowing ergometer to monitor the changes in effective work rate, effective work output per stroke and stroke rate after 1 month of intensive rowing training. The peak force (N) is a measure of the maximum amount of force that can be applied to the handle, work per stroke (j) (work/stroke) is the area under the curve for an average stroke and total work is the total area under all curves during a specified time and is strongly correlated to ergometer performance (McBride, 1993). The ideal force profile is one in which a large amount of force is applied over a long stroke length.

Ergometer v On-Water Rowing

The similarity of mechanical efficiencies for actual rowing and ergometer rowing reported by Hagerman et al. (1978) support the utilisation of a rowing ergometer to adequately represent the task of racing. Lamb (1989) found through vector loop analysis of 30 experienced rowers that similar kinematics were displayed between on-water and ergometer rowing for both the leg and trunk components, although he did show different kinematics of the upper arm and forearm segments. Ergometer rowing does not model the finish of the stoke accurately as there is no required oar lift and a self returning handle decreases the necessary muscle activity of the upper extremity required during the recovery phase (Rodriguez, Rogriguez, Cook & Sanborn, 1990).

Summary

Strength, defined as the maximum force generated by a muscle or muscle group, is determined by a number of structural and neural mechanisms. Muscle morphology, recruitment and activation thresholds, muscle length, anthropometry and gender all play important roles in its expression.

Neural factors have a very real and significant impact on strength gains but due to the extremely complex nature of neural activation and data acquisition techniques, research in this area is limited and equivocal (Kraemer, 1988). Short term training studies attribute early increases in strength more to neural adaptation than to muscle based mechanisms. Muscle hypertrophy however, is considered to be the limiting factor to strength gain in the long term. Associated changes with hypertrophy include a decrease in the capillary to fibre ratio, mitochondrial volume and little if any significant increases in the enzymes associated with the energy yielding processes.

Gains in strength will improve skill performance to the greatest extent when the training program consists of progressive resistance exercises that include the muscle groups, movement velocity and range of motion that simulate the movement patterns most often used during the actual execution of the skill. Specificity in short term training studies is hypothesised to be in part due to neural factors (Hakkinen et al., 1983) and improved muscular co-ordination (Jones et al., 1989).

Traditionally high and low repetition resistance training has been utilised in an attempt to develop the specific physical and physiological characteristics required in rowing. The effect of training on the ability to generate force throughout the rowing stroke has not been extensively studied, with no research available on the changes in the force profile of the rowing stroke that occur as a result of resistance training. Further research in this area would enable coaches and other specialists in the area to make more informed decisions as to the type of training regimes that are most effective in improving rowing performance.

CHAPTER 3

Methods and Procedures

Design

The present study used a 15 week resistance training design with pre, mid and post-testing. All subjects were tested after a three week preparatory phase and assigned to one of two resistance training regimes, high repetition endurance (HRE) or low repetition strength (LRS). Mid and post testing was completed during weeks 11 and 18 of the training program (Appendix A).

Sample and Setting

Eighteen sub elite heavy weight rowers involved in the Talent Identification Program (TIP) at the Western Australian Institute of Sport (WAIS), were used in the study. The group consisted of 8 female and 10 male athletes who where matched according to gender, anthropometric and strength similarities. The matched pairs where then randomly assigned to one of the two training regimes. All testing and training was completed at the WAIS physiology laboratory and strength training facility.

Instrumentation

Anthropometric.

Height as measured by a Holtain Ltd. stadiometer to the nearest 1.0 mm.

Mass as measured by SECA balance scales to the nearest 0.1 kg.

Body fat as measured by Harpenden skinfold calipers, calibrated to $10g/mm^{-2}$ and measuring to the nearest 0.5 mm.

Anatomical circumferences as measured by a Rabone Chesterman retractable diameter tape (3150) measuring to the nearest 1.0 mm.

Breadths as measured by the adapted Mitutoyo bone calipers and measuring to 1.0 mm.

Strength.

Upper and lower body strength and strength/endurance was measured using a free weight bench press and 45 degree isotonic leg press slide. Strength was measured in kg and strength endurance by the total successful repetitions that could be completed at a predetermined sub-maximal load.

Biomechanics of the Rowing Stroke.

Force profiles of the rowing stroke were measured using an instrumented air braked Concept II rowing ergometer (large cog, vent closed). The ergometer was instrumented by the connection of a "208A03 Series ICP Force Transducer" (Appendix B) in the chain between the oar handle and fly wheel, and placement of a "Green Plot CPP-3555" displacement transducer along the undercarriage of the ergometers mono rail. Both transducers were electrically connected to a "PCB Amplifier, MODEL No. 484B" (Appendix C) and an Australian Institute of Sport designed interface box. Data was displayed and recorded using a "DT/Gallery" application program (SP0390 VERSION V01.01). The instrumentation enabled handle displacement and pulling force to be graphically represented on X and Y axes respectively, enabling the force-displacement (force profiles) of each stroke to be simultaneously displayed and recorded (Appendix D).

Procedures

Anthropometry.

Anthropometric data was collected using the methods according to Ross and Marfell-Jones (1991).

Strength.

Strength and strength/endurance measures were determined according to the guidelines as outlines by the Western Australian Institute of Sports upper and lower body strength test protocol (Appendix E).

Biomechanics of the Rowing Stroke.

Biomechanical testing was performed at 6 steps of increasing intensity, as monitored by stroke rate (SR) (Appendix F). Two biomechanical tests were completed, the first involved the subjects attempting 4-8 of the most powerful strokes they could perform at each of the specified stroke rates (maximal effort), and the second required a 3 minute effort at an intensity controlled by SR and time per 500m split (3 minute effort) (Appendix F).

On arrival, all subjects completed a 5-10 minute warm up using both a cycle and Concept II rowing ergometer. They were then verbally instructed as to the nature of the first biomechanical test and given a practice trial at the lowest SR. Subjects where given the first two strokes at each rate to build momentum and by the third to fifth stroke it was expected that they were performing each stroke at a maximal intensity and holding the rating consistently. Upon satisfaction that this was

being achieved, biomechanical recording started as the handle passed over the knees during the recovery phase of the last completed stroke, ensuring that recording did not start through the drive phase, and only whole strokes were recorded. Recording was set for 17 seconds which enabled 4-5 strokes to be recorded at the lower steps and up to 12 at the maximum intensity. Approximately 3 minutes recovery separated each maximal effort step.

The 3 minute effort required the subjects to row at intensities controlled by SR and time per 500m split. The test commenced on a verbal command from the tester with force profiles being recorded continuously throughout each step. Each workload was followed by 4-5 minutes recovery and the subjects where expected to complete all six steps or continue until volitional exhaustion.

Resistance Training Program

Training commenced with a 3 week general preparatory phase where all subjects completed the same general circuit program using a variety of free weights and isotonic machines. Following pre-testing the athletes where matched and assigned to one of the two training groups. The exercises for both groups where the same (Appendix G) with the subjects alternating between session A and B during weeks 5-10 and 12-17. Each group trained three times per week using the required sets and repetitions specific to their group and week of training (Appendix A).

Testing Schedule

Testing was completed over four days. Biomechanical and anthropometric testing was completed on days 1 and 2, and strength days 3 and 4 for females and males respectively (Appendix H). All subjects where asked to follow the WAIS pre-testing guidelines (Appendix I) and to have one complete day of rest between the biomechanical and strength testing. During the testing week, only on water and supplementary aerobic work was scheduled, no strength training sessions where completed.

The proposed hypotheses was investigated by monitoring the changes in:

1. Upper and lower body strength and strength endurance;
2. Average peak force;
3. Average work per stroke;
4. Total work;
5. The percentage of the maximum peak force and work/stroke that rowers work at during simulated rowing;
6. Rowing performance tests.

Instrument and Interrater Reliability

Calibration of the force transducer and distance transducer where completed as outlined by the AIS Biomechanical department guidelines (Appendix J). Force was calibrated before each biomechanical recording at every step for both the maximal and 3 minute effort tests, and distance once before the first step of the maximal effort and again before the 3 minute effort. Interrater reliability was maintained from

pre, mid and post testing, by ensuring that each component of the testing protocol was performed by the same tester.

Assumptions and Limitations

Assumptions.

1. Subjects followed the pre-testing guidelines of no food drink 3 hours prior to testing and no training the day of biomechanical and strength testing.

2. Subjects followed testing week guidelines of no resistance training during the testing week, with one complete days rest between the scheduled biomechanical and strength testing session.

3. Subjects followed and responded to the training and testing to the best of their ability and with consistent motivation.

Limitations.

1. The study is limited to a small and selective group of athletes.

2. Matching the subjects prior to their random assignment reduces the validity of the study.

3. Complete control of supplementary aerobic and on water training is unrealistic with these subjects. Therefore any changes in the force profile of the rowing stroke that occur may not be conclusively attributed to the resistance training alone.

4. Although the repetitions completed by the LRS group during training are strength orientated, they are not true maximal strength training ranges (1-6 reps).

5. The 3RM upper and lower body strength tests is more a measure of sub-maximal strength, as maximal strength would be tested using a 1RM.

CHAPTER 4

Results

All data was analysed using SPSS/PC for Windows statistical software (Release 6.0). Descriptive characteristics of the subjects are presented in Table 1. Comparison between pre-test means of matched groups was completed using an Independent T-test (Appendix K). Due to the small sample size and large standard deviation in scores, males and females within each group were pooled, and showed no significant differences in any of the matching variables (Appendix L).

Analyses of strength, biomechanical, performance and anthropometric data were completed using a repeated measures two by two ANOVA with significance accepted at $p < .05$. A Tukey Post Hoc comparison of the means was completed on all significant results found within the groups (Appendix M-P). Means for male and female LRS and HRE groups were used in substitute for missing data in all but the 2500 meter performance test, where only complete cases were used ($n = 11$) due to large amounts of missing data.

Although force profiles were recorded at all 6 steps during the biomechanical testing, only steps 1 and 6 were statistically analysed. The rationale being that step 1 closely represents the intensity at which the majority of aerobic conditioning and technical acquisition occurs at in the boat, whilst step 6 is a maximal effort and simulates competitive racing. These two steps are the most applicable to rowing and are of the greatest interest to coaches and other professionals in the sport.

Weight and bicep girth where the only two anthropometric variables to show significant change over the training period (Table 2). Weight also showed a significant interaction between groups with the LRS and HRE groups increasing by 0.9 and 2.4kg, respectively. Interaction is a measure of when the two types of resistance training cause changes in the dependent variable that are not the same between groups over time. Interaction does not imply a significant difference between groups, it is only indicative that changes over time are not the same in size and/or direction. That is, changes within the groups are not parallel to one another (Hinkle, Wiersma & Jurs, 1979).

Significant difference was recorded pre to post testing for bench press (+7) and leg press (+ 74.1) 3RM strength (kg), and endurance leg press repetitions (+16.8), but not in bench press repetitions (Table 3). Improvement between the groups was significantly different in endurance leg press repetitions where HRE improved by 33 repetitions more than LRS. A significant interaction effect was shown in all strength testing measures (Table 3, Figures 1-4). The LRS group showed greater improvement in all 3RM strength measures, whilst the HRE group displayed greater gains in bench and leg press endurance repetitions.

Training induced significant improvement in all biomechanical variables except maximal and 3 minute efforts work/stroke during the 6th step (Table 4, Figures 5-16). Differences between the two groups was significant in the 3 minute effort work/stroke at the first step, where a change of 35.8 and 61.7N in the LRS and HRE groups occurred, respectively. Although no interactions between groups

was found, post hoc analysis showed that the HRE group improved significantly in the 3 minute efforts peak force, work per stroke and total work in step 1, while the LRS groups did not. SR showed no significant difference over time or between groups.

By using the maximal effort results as an indication as the highest achievable biomechanical values that could be attained, the percentage of maximum that rowers work at during simulated rowing was calculated. No statistical change was seen in the percentage of maximum peak force and work/stroke from pre to post testing (Table 5).

Significant improvement was shown in both the total metres (+15.4) rowed during the last step of the 3 minute effort, and the time (-9 sec) taken to row a 2500m distance on a concept II rowing ergometer (Table 6). Although overall the subjects significantly increased the total metres in the last 3 minute effort, post hoc analyses showed only the HRE groups change to be significant (+19.1).

Table 1

Mean (± S.D.) Descriptive Characteristics of Subjects

Sex	n	Age (yr)	Height (cm)	Weight (kg)	Sum of Skinfolds (mm)
Male	10	17.5 (0.7)	189.7 (4.3)	87.9 (4.7)	88.8 (22.6)
Female	8	16.5 (0.9)	177.5 (4.8)	81.6 (6.1)	146.0 (41.4)

Table 2

Mean (± S.D) Changes in Anthropometric Characteristics

Variable	Pre-Test	Post-Test
Weight (kg)	85.1 (6.2)	86.6 (6.2)** ***
Skinfold Total (mm)	114.2 (42.8)	110.3 (39.1)
Calf Girth (cm)	40.6 (1.8)	40.2 (2.2)
Bicep Girth (cm)	33.6 (2.1)	34.6 (2.4)**

Note. $p < .05$ * Between Groups, ** Pre to Post, *** Interaction.

Table 3

Mean (± S.D.) Changes in Strength

Variable	Pre-Test	Post-Test
Bench Press		
Strength (kg)	53.6 (14.2)	60.6 (16.1)** ***
Endurance (Reps)	17.5 (4.6)	19.2 (5.8)***
Leg Press		
Strength (kg)	266.7 (53.8)	340.8 (46.6)** ***
Repetitions (Reps)	26.9 (12.2)	43.7 (19.9)* ** ***

Note. $p < .05$ * Between Groups, ** Pre to Post, *** Interaction.

Table 4

Mean (± S.D.) Changes in Biomechanical Data

Variable	Pre-Test	Post-Test
Maximal Effort		
Peak Force Step 1	1066.4 (155.9)	1149.8 (125.6)**
Peak Force Step 6	1001.4 (130.6)	1117.7 (135.0)**
Work P/Stroke Step 1	984.2 (179.8)	1099.9 (186.2)**
Work P/Stroke Step 6	855.3 (130.4)	946.7 (155.3)
3 Minute Effort		
Peak Force Step 1	568.4 (79.9)	617.2 (67.9)**
Peak Force Step 6	870.0 (128.1)	927.0 (122.0)**
Work P/Stroke Step 1	501.7 (37.6)	548.4 (44.2)* **
Work P/Stroke Step 6	694.8 (137.2)	773.9 (158.7)
Total Work Step 1	25758.4 (1475.5)	28051.6 (2489.3)**
Total Work Step 6	57931.3 (14637.6)	67409.8 (15953.0)**

Note. Peak force (Newtons), Work per stroke (joules).
$p < .05$ * Between Groups, ** Pre to Post, *** Interaction.

Table 5

Mean (± S.D.) Changes in the Percentage of Maximum Peak Force & Work/Stroke that Rowers Work at During Simulated Rowing.

Variable	Pre	Post
Peak Force Step 1	54.8 (13.1)	54.6 (10.2)
Peak Force Step 6	87.2 (8.5)	83.0 (5.5)
Work P/Stroke Step 1	52.7 (10.8)	51.2 (8.7)
Work P/stroke Step 6	81.0 (9.8)	80.9 (6.2)

Table 6

Mean ($\pm$ S.D) Changes in Performance

Test	Pre-Test	Post-Test
2500m Time (sec)	531.6 (43.4)	522.6 (38.9)**
3min Meters (total)	896.2 (82.0)	911.6 (76.0)**

Note. $p < .05$ * Between Groups, ** Pre to Post, *** Interaction.

Figure 1. Mean Changes in Endurance Leg Press Repetitions

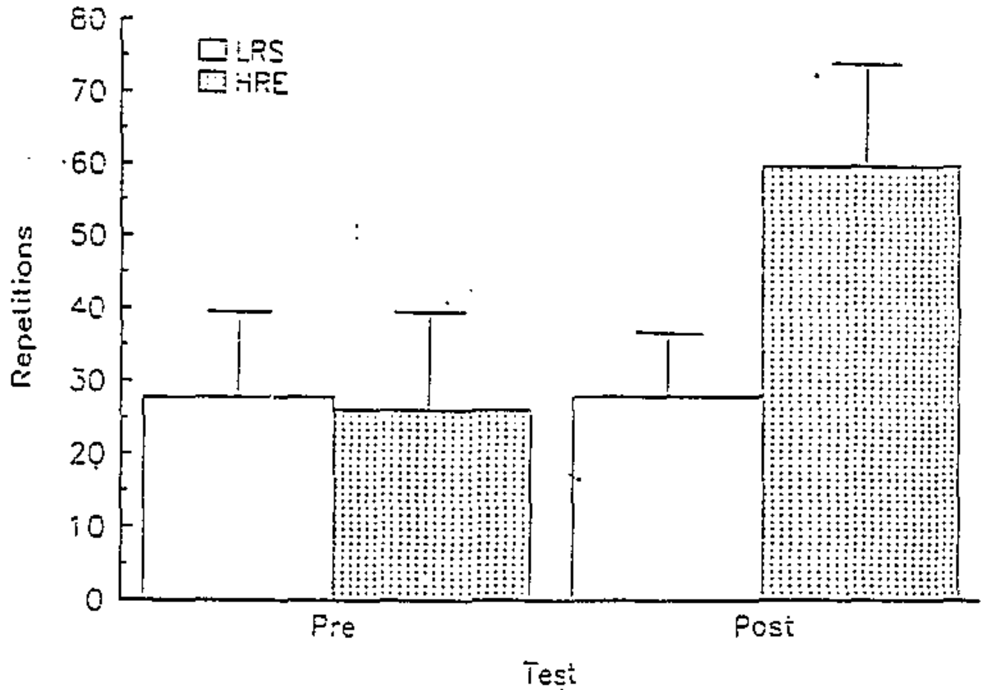


Figure 2. Mean Changes in 3RM Leg Press Strength

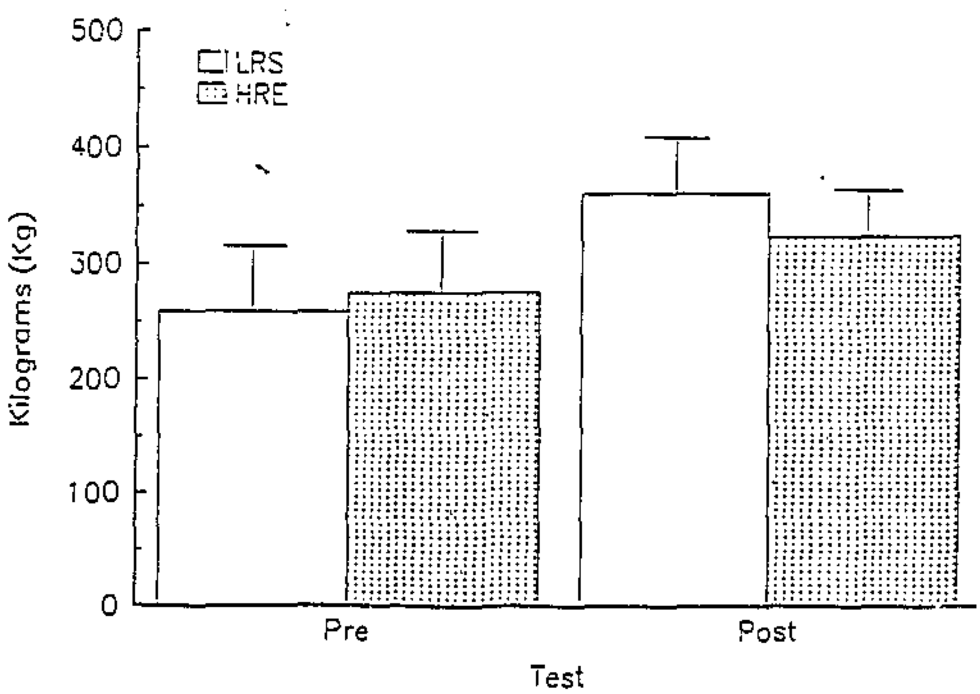


Figure 3. Mean Changes in Endurance Bench Press Repetitions

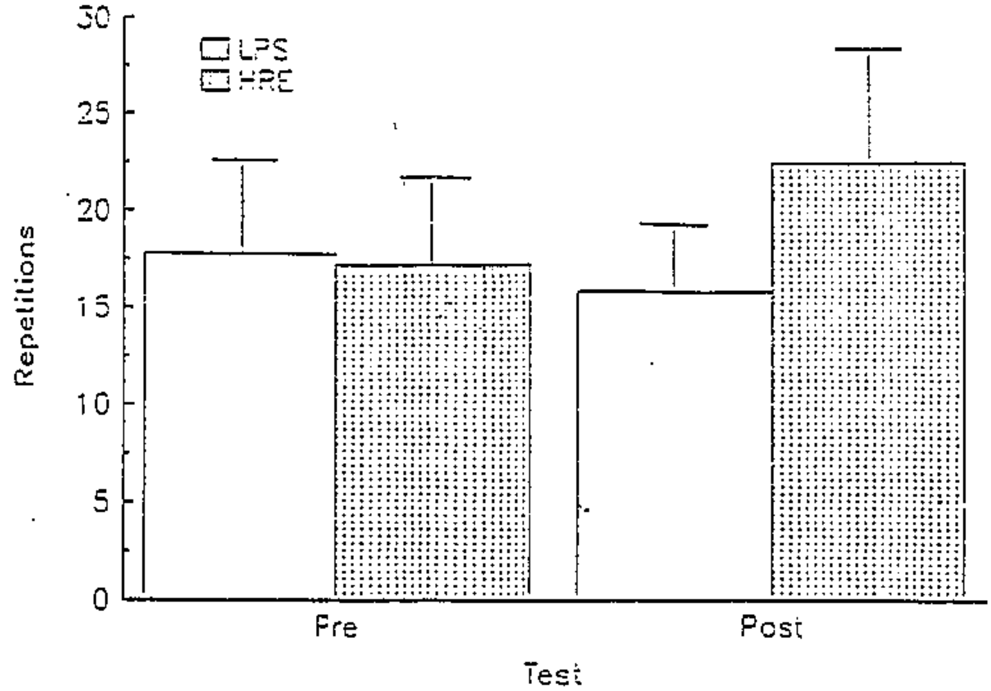


Figure 4. Mean Changes in 3RM Bench Press Strength

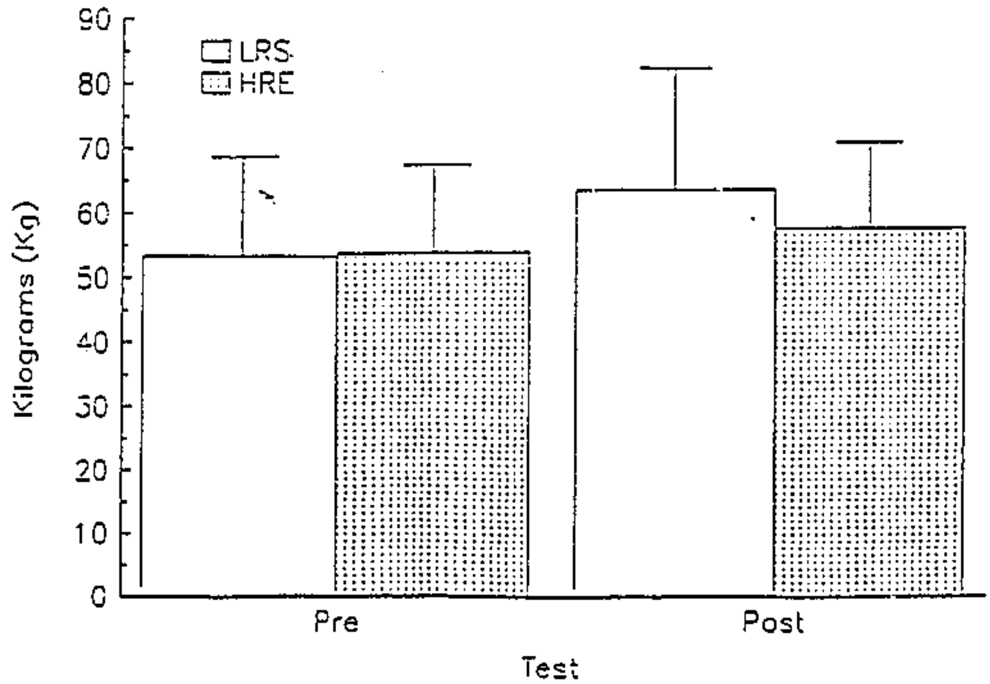


Figure 5. Mean Changes in Maximal Effort Peak Force Step 1

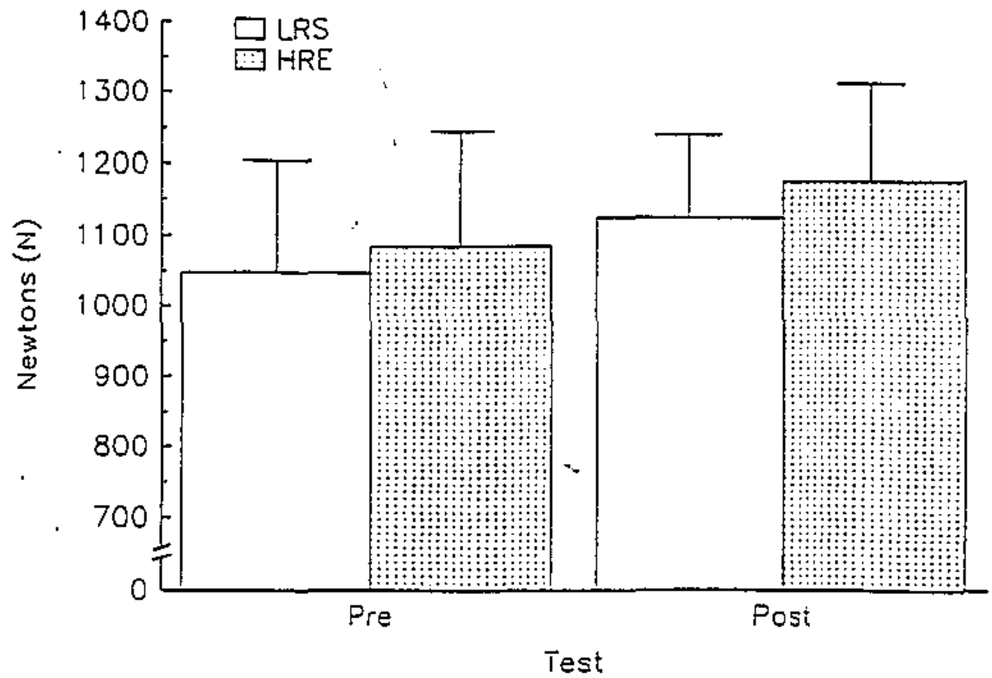


Figure 6. Mean Changes in Maximal Effort Peak Force Step 6

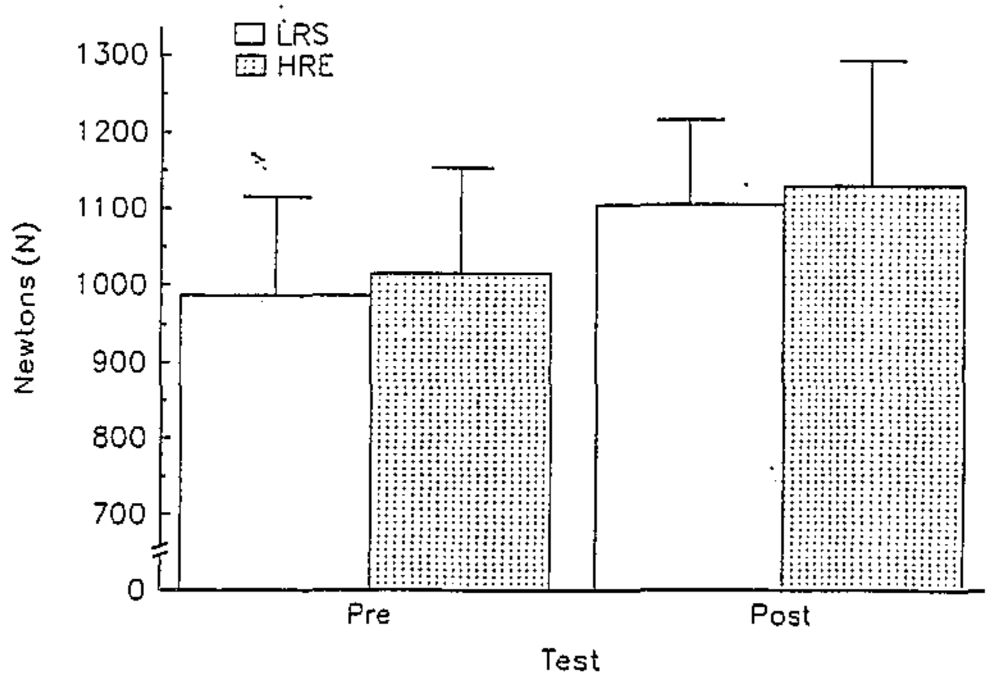


Figure 7. Mean Changes in Maximal Effort Work/Stroke Step 1

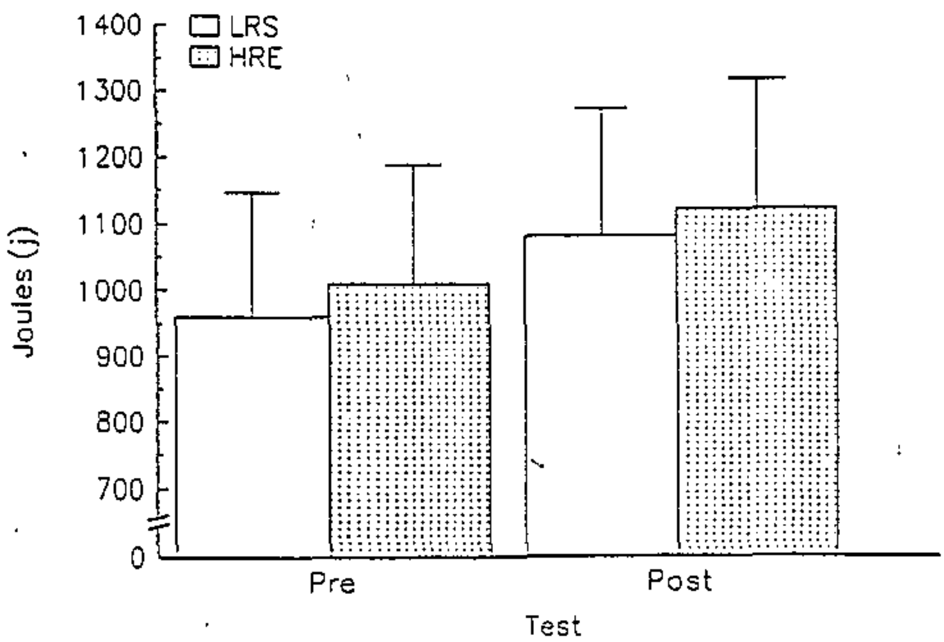


Figure 8. Mean Changes in Maximal Effort Work/Stroke Step 6

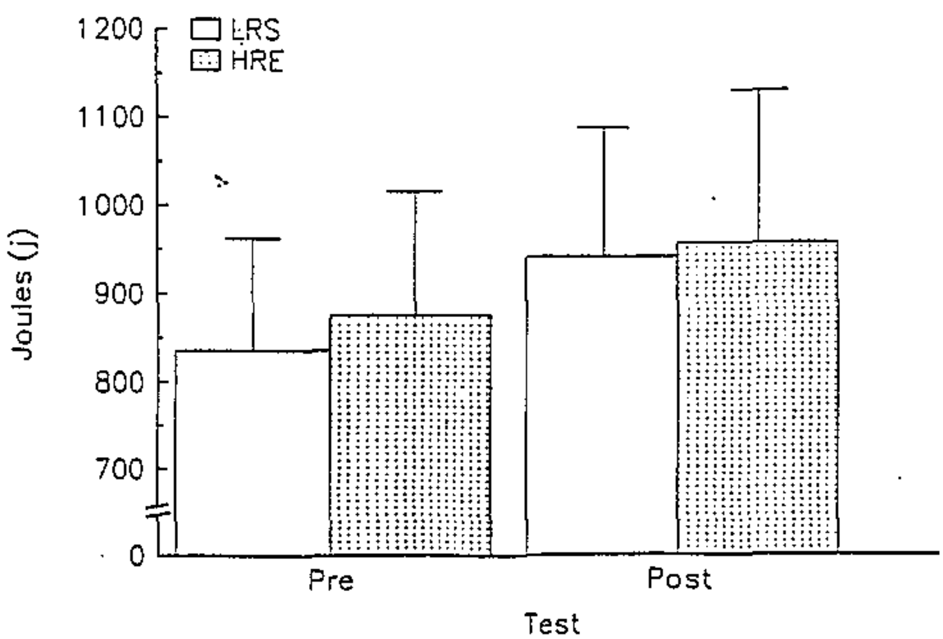


Figure 9. Mean Changes in 3 Minute Effort Peak Force Step 1

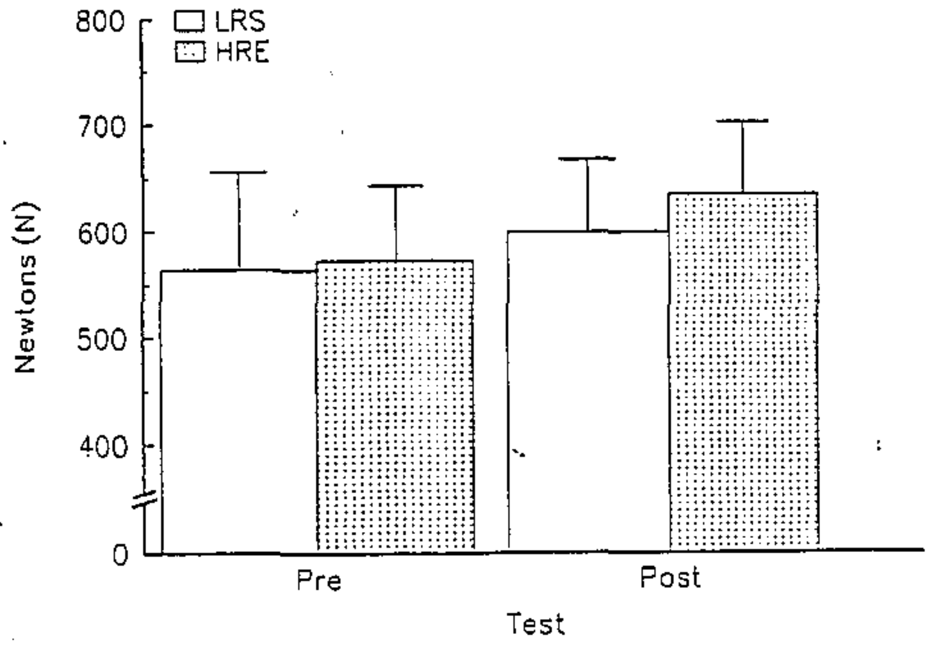


Figure 10. Mean Changes in 3 Minute Effort Peak Force Step 6

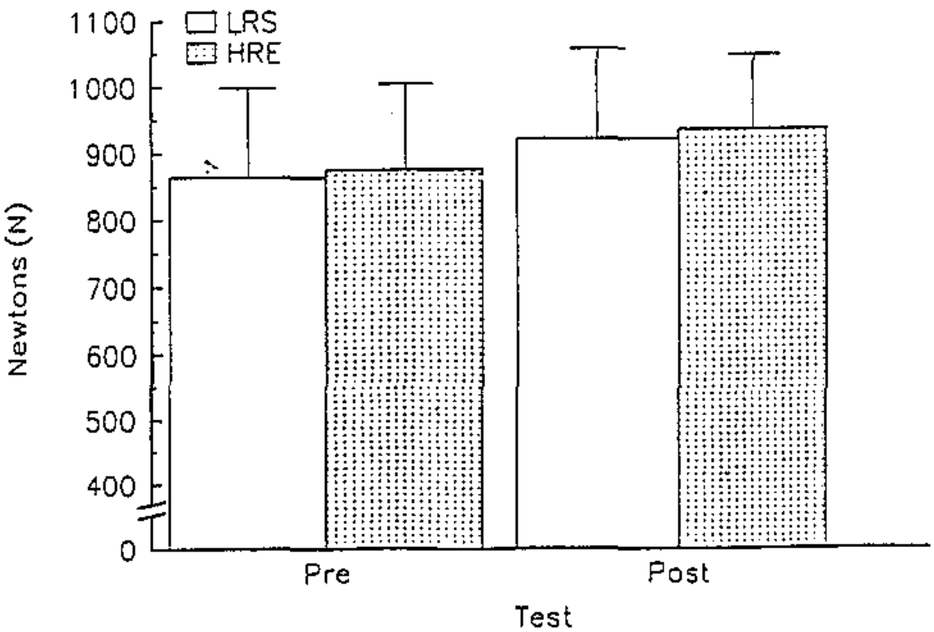


Figure 1 1. Mean Changes in 3 Minute Effort Work/Stroke Step 1

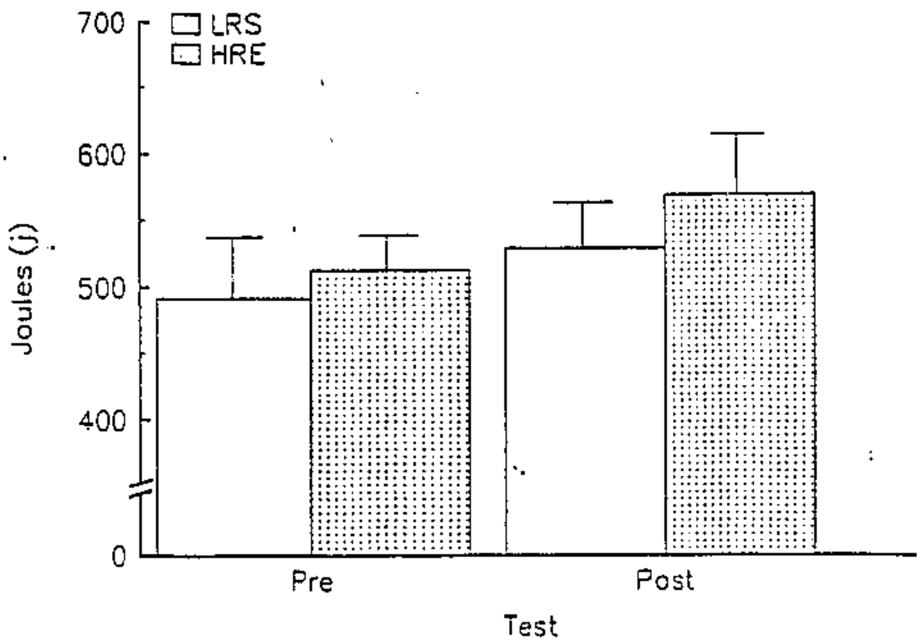


Figure 1 2. Mean Changes in 3 Minute Effort Work/Stroke Step 6

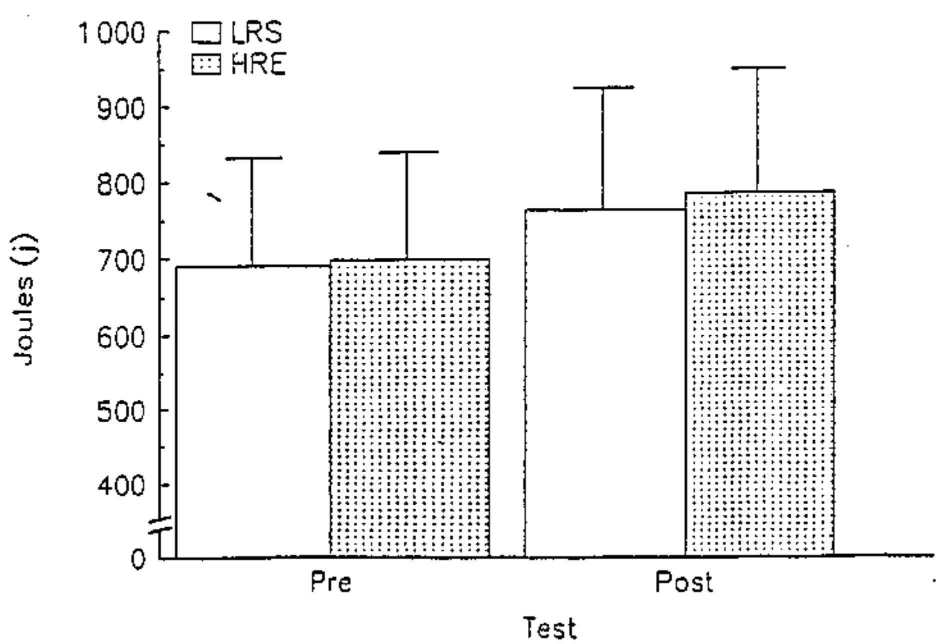


Figure 1 3. Mean Changes in 3 Minute Effort Total Work Step 1

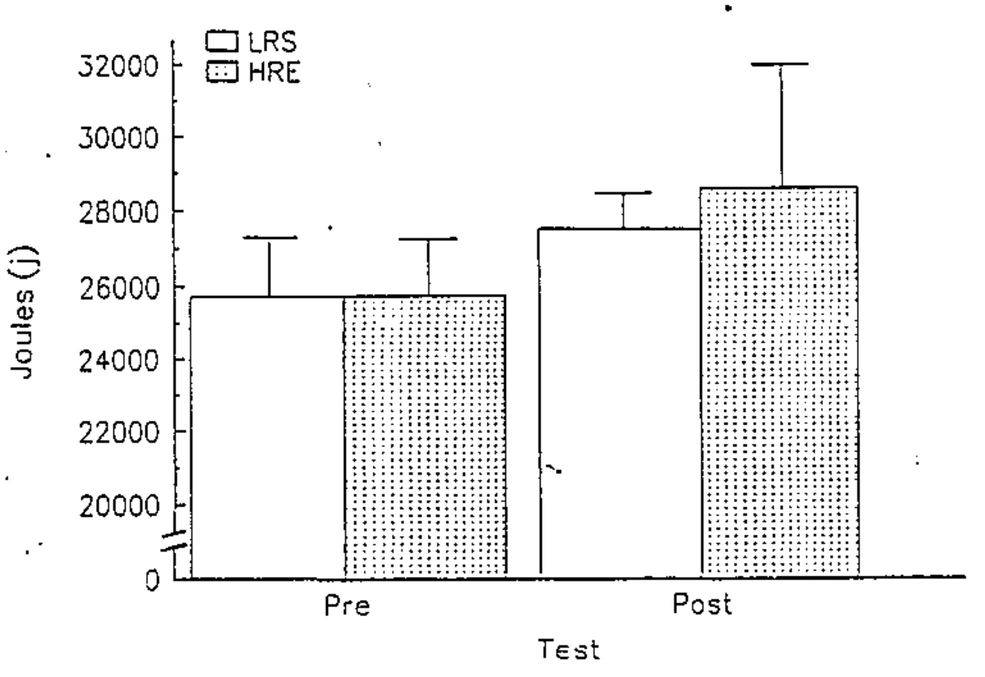


Figure 1 4. Mean Changes in 3 Minute Effort Total Work Step 6

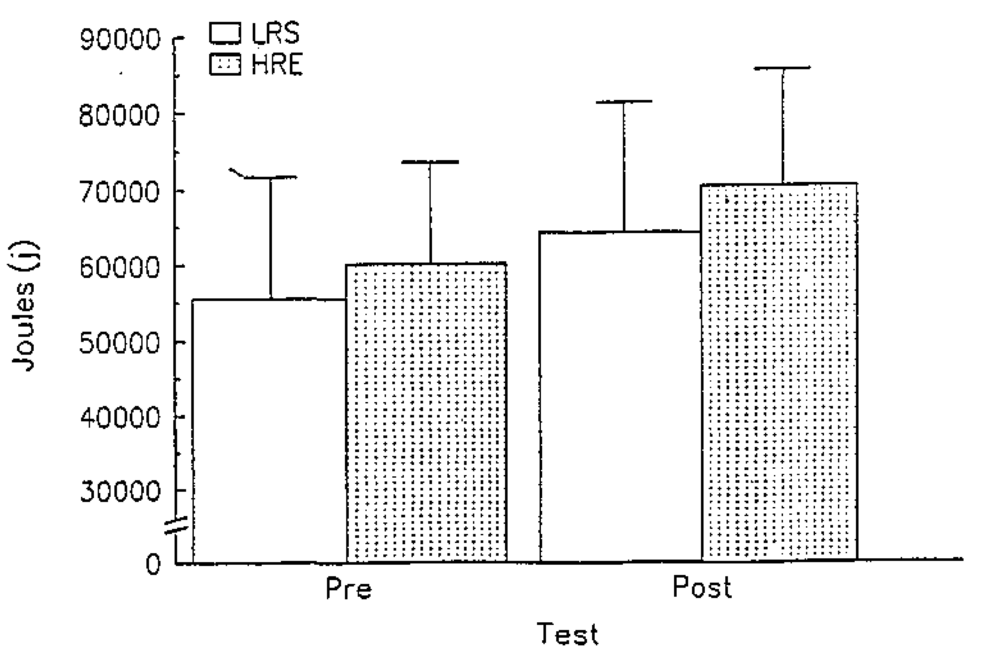


Figure 15. Mean Changes in 2500m Time

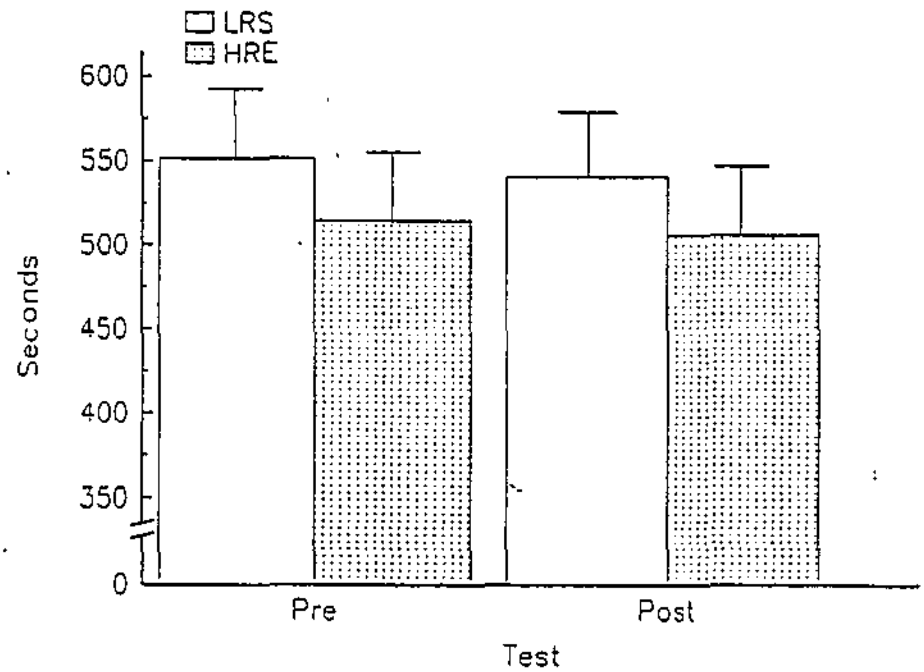
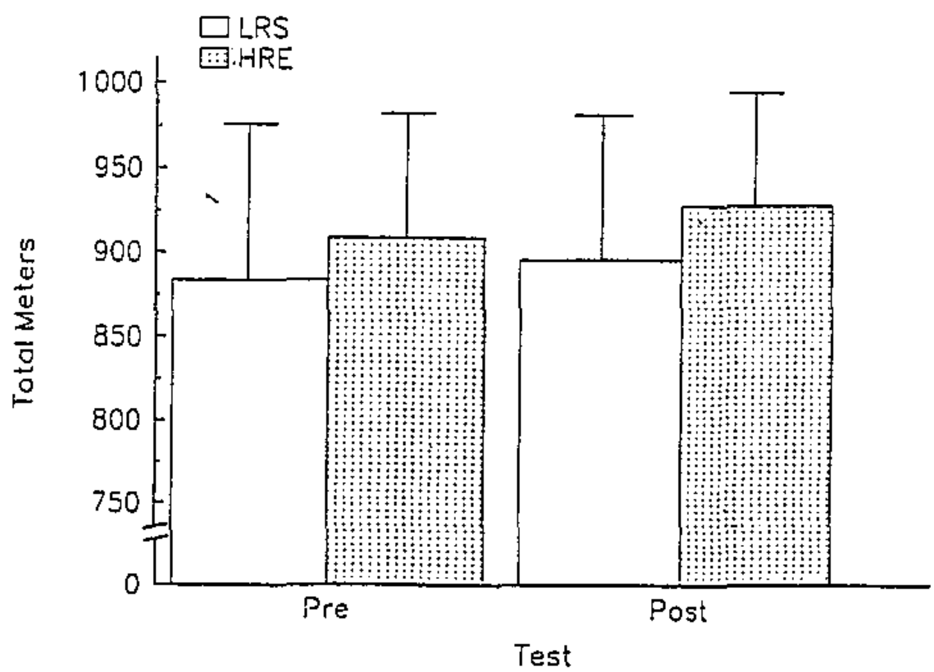


Figure 16. Mean Changes in 3 Minute Meters



CHAPTER 5

Discussion

Strength

The subjects used within the study were a very specific group considered to have the potential to be high performance heavy weight rowers in Western Australia. With their commitment to the Talent Identification Program conducted by the Western Australian Institute of Sport, all athletes where required to complete their resistance training as part of their overall training program, which also included on water and supplementary aerobic work. Extraneous variables such as the aerobic conditioning and skill acquisition both in the boat and on the rowing ergometer may therefore have contributed to the changes in the dependent variables. These limitations to the study make the research a practical based design applicable to rowers in a high performance training and testing program.

Most research looking at changes in strength after resistance training, have used isometric and isokinetic testing and training protocols. Limited work (Sale, Jacobs, MacDougall & Garner, 1990; Bell, Syrotuik, Attwood & Quinney, 1993) has been done using isotonic training and testing. Sale et al. (1990) used a similar leg press test to the current study but a 1RM test was used to measure strength and 80% of the 1RM to measure strength endurance, as opposed to 3RM and 75% of 3RM. Changes in the force curve of the rowing stroke as a result of training are

equally scarce with the only published research coming from Mason et al. (1988) who looked at the changes in effective work rate, effective work output per stroke and stroke rate after 1 month of intensive rowing training. No work has been reported on the changes in the force profile as a result of resistance training.

Significant increases in strength where shown in all but the endurance bench press repetitions. Post hoc analyses of changes within the groups and the significant interaction found between all strength measures indicate that the changes found were different depending upon the type of resistance training completed. Interaction was expected between the groups as the different training regimes where not expected to develop strength and endurance equally. LRS was designed to increase the ability to generate maximal force, whereby HRE tried to increase the ability to work repeatedly at a given percentage of maximum.

LRS improved by 6.6 kg (12.4%) and 52.7 kg (21.4%) more than HRE in upper and lower body strength, respectively, and HRE showed 7.3 (42%) and 33.2 (128.5%) greater improvements in endurance repetitions for bench and leg press. The lower levels of improvement made by the LRS group in endurance repetitions can partially be accounted for by the greater sub-maximal loads they were required to lift as a result of their higher 3RM values. These results would indicate that the adaptations to training were specific to the type of training regime used.

Absolute strength gain has been shown to be impaired in subjects who train for strength and aerobic endurance on alternative days as compared to strength alone (Dudley & Djamil, 1985) or when training for strength and aerobic endurance on the same day as opposed to alternative ones (Sale et al., 1990). Bell et al. (1991) found however, that there was no significant difference in right knee isokinetic peak torque or total work after 12 weeks of concurrent strength and rowing ergometer endurance training compared to a strength only training group of a non-rowing population. The time course of adaptation between the two groups was however, descriptively different and in discussion the authors proposed that if training had continued for a longer period, reduced strength adaptation with concurrent endurance training may have been more apparent.

This study indicates the possibility that increases in strength seen within the LRS and HRE groups over the training period may have been limited by the subjects concurrent on-water and supplementary aerobic training. If strength is impaired by simultaneous aerobic training, any endurance sport that has a correlation between strength and performance would be required to take greater care in periodising training so that the development of strength does not impede the development of the aerobic energy system.

Biomechanical

Step 6 during the 3 minute effort test was designed to assess changes in biomechanical variables at simulated race intensities. Although the time duration is somewhat shorter (approximately half) than that required to complete a 2000m distance, the test duration and intensity are still representative of competitive rowing.

Training caused significant improvement during the 3 minute effort in all biomechanical variables except work/stroke during the sixth step. Although descriptively there was a 79.1 joule improvement, the change was not recorded as being significant. Significance may not have been recorded within this variable and between group changes in other dependent variables due to the large standard deviations in data from the small sample group. Although changes were not significant statistically, a physiological adaptation may still have occurred. In elite sport where the difference between winning and losing is small, any training adaptation that helps improve performance may be of benefit to the athlete.

Although differences in changes between the groups was only significant in the 3 minute efforts work/stroke during step 1, post hoc and descriptive analysis showed that HRE training improved all biomechanical variables and 3 minute total metres during the last step consistently more than LRS training. Based on this trend, it may be that HRE training is of more benefit to increasing certain biomechanical

aspects of the simulated rowing stroke than LRS. To conclusively state that HRE training is a more superior regime of training without taking into account the uncontrolled extraneous training variables and the mechanics of the rowing stroke, would be an erroneous assumption. Therefore these findings, although important for furthering the knowledge on the adaptations to resistance training as they relate to rowing stroke biomechanics, must be viewed with caution and require further investigation.

Herberger et al. (1990) have suggested that during competition the average strength used per stroke during a race can only achieve a fraction of the maximum strength. The size of this fraction depends on the individual's relative strength endurance and although the difference between the maximum and average strength cannot be eliminated entirely, it can be reduced. The strength used per stroke can be increased in one of two ways. The first is to try and decrease the fraction between average and maximal strength through HRE and the second is to try and increase the maximal strength by LRS training, so that although the fraction between the two remains the same the average absolute value increases.

A maximal and 3 minute effort test was conducted so that both maximal and sub-maximal changes in stroke biomechanics could be monitored. Use of the maximal test enabled calculations to be made as to the fraction or percentage of the

maximal that rowers work at during simulated training (51-55%) and racing (81-87%) intensity. This data has to date not been researched and has important implications for program design. With a greater understanding regarding this percentage of maximal effort, coaches would be able to prescribe more specific intensities to resistance training programs. These percentages are representative of the biomechanical aspects of the stroke, and their relationship to strength may not be linear and must therefore be considered in the context of the discussion. If the percentage of maximal strength that rowers work at can be determined through the biomechanical data, then biomechanical testing may in addition to providing valuable information on technique and performance, help in the design of resistance training intensities.

In summary, LRS and HRE resistance training caused, although not always statistically, specific changes in all strength and biomechanical variables tested. LRS showed greater improvements in maximal strength, while HRE showed greater gains in strength endurance. HRE compared to LRS showed consistently greater increases in all 3 minute biomechanical variables indicating that it may be of more benefit to increasing certain biomechanical variables of the simulated rowing stroke than LRS training. These conclusions must be viewed with caution however as there are numerous extraneous variables which may have contributed to the reported changes.

Suggestions for Future Research

If strength is impaired by simultaneously training for strength and aerobic endurance, then a more controlled design whereby subjects only complete resistance training may provide a better understanding as to changes in the force profile of the rowing stroke due to different types of resistance training. Further research might also look at the sequencing of strength and aerobic training within the overall training year and how that effects the force curve.

As the current research was primarily a weight training study, matched pairs where selected on strength characteristics. If research was to look primarily at the changes in biomechanical data as a result of training , then matching the subjects on biomechanical performances would be more appropriate.

Limited research (Bompa, 1980; Secher, 1975) has been done to correlate strength measures to rowing performance. Research is needed to determine what changes in strength are correlated to changes in performance so that most effective resistance training programs can be designed in order to bring about optimal physiological adaptations.

REFERENCES

Behm, D. G. & Sale, D. G. (1993). Velocity Specificity of Resistance Training. *Sports Medicine, 15*(6), 374-388.

Bell, G. J., Petersen, S. R., Quinney, H. A. & Wenger, H. A. (1989). The Effects of Velocity-Specific Strength Training on Peak Torque and Anaerobic Rowing Power. *Journal of Sport Sciences, 7*, 205-214.

Bell, G. J., Petersen, S. R., Wessel, J., Bagnall, K. & Quinney, H. A. (1991). Physiological Adaptations to Concurrent Endurance Training and Low Velocity Resistance Training. *International Journal of Sports Medicine, 12*, 384-390.

Bell, G. J., Syrotuik, D. G., Attwood, K. & Quinney, H. A. (1993). Maintenance of Strength Gains While Performing Endurance Training in Oarswomen. *Journal of Applied Physiology, 18*(1), 104-115.

Berger, R. A. (1982). *Applied Exercise Physiology*. Philadelphia: Lea & Febiger.

Bishop, P., Cureton, K., & Collins, M. (1987). Sex Differences in Muscular Strength in Equally Trained Men and Women. *Ergonomics, 30*, 675-687.

Bompa, T. O. (1980). Technique and Muscle Force. *Canadian Journal of Applied Sports Sciences, 5*(4), 245-249.

Caiozzo, V. J., Perrine, R. J. & Edgerton, V. J. (1981). Training Induced Alterations in the In Vivo Force-Velocity Relationship of Human Muscle. *Journal of Applied Physiology, 51*(3), 750-754.

DiNubile, N. A. (1991). Strength Training. *Clinics in Sports Medicine, 10*(1), 33-62.

Dudley, G. A. & Djamil, R. (1985). Incompatibility of Endurance and Strength Training Modes of Exercise. *Journal of Applied Physiology, 59*(5), 1446-1451.

Fox, E. L., Bowers, R. W. & Foss, M. L. (1988). The Physiological Basis of Physical Education and Athletics. *New York:* Saunders College Publishing.

Graves, J. E., Pollock, M. L., Jones, A. E., Colvin, A. B. & Leggett, S. H. (1989). Specificity of Limited Range of Motion of Variable Resistance Training. *Medicine and Science in Sports and Exercise, 21*, 84-89.

Hagerman, F. C. (1975). Teamwork in the Hardest Pull in Sports. *Physician and Sports Medicine, 3*, 39-44.

Hagerman, F. C. (1984). Applied Physiology of Rowing. *Sports Medicine, 1*(4), 303-326.

Hagerman, F, C., Connors, M. C., Gault, J. A., Hagerman, G. R. & Polinski, W. J. (1978). Energy Expenditure During Simulated Rowing. *Journal of Applied Physiology, 45*, 87-93.

Hagerman, F. C., Hagerman, G. R. & Mickelson, T. C. (1979). Physiological Profiles of Elite Rowers. *Physician and Sports Medicine, 7*(7), 74-81.

Hagerman, F. C. & Mickelson, T. C. (1981). A Task Specificity Comparison of Anaerobic Thresholds among Competitive Oarsmen. (Abstract). *Medicine and Science in Sports and Exercise, 13*, 17-20.

Hagerman, F. C., & Staron, R. S. (1983). Seasonal Variations Among Physiological Variables in Elite Oarsmen. *Canadian Journal of Applied Sport Sciences, 8*, 143-148.

Hakkinen, K & Komi, P. V. (1983). Electromyographic Changes During Strength Training and Detraining. *Medicine and Science in Sports and Exercise, 15*(6), 455-460.

Herberger, E., Beyer, G., Harre, D., Kruger, H. O., Querg, H. & Sieler, G. (1990). Rowing. *Toronto:* Sports Books Publisher.

Hinkle, D. E., Wiersma, W. & Jurs, S. G. (1979). Applied Statistics for the Behavioural Sciences. *Boston:* Houghton Mifflin Company.

Jones, D. A. & Rutherford, O. M. (1987). Human Muscle Strength Training: The Effects of Three Different Training Regimes and the Nature of the Resultant Changes. *Journal of Physiology, 391*, 1-11.

Jones, D. A., Rutherford, O. M., & Parker, D. F. (1989). Physiological Changes in Skeletal Muscle as a Result of Strength Training. *Quarterly Journal of Experimental Physiology, 74*(3), 233-256.

Kanehisa, H. & Miyashita, M. (1983). Effect of Isometric and Isokinetic Muscle Training on Static Strength and Dynamic Power. *European Journal of Applied Physiology, 50*, 365-371.

Knapik, J. J., Mawdsley, R. H. & Ramos, N. U. (1983). Angular Specificity and Test Mode Specificity of Isometric and Isokinetic Strength Training. *Journal of Orthopaedic Physical Therapy, 5*, 58-65.

Kraemer, W. J., Deschenes, M. R. & Fleck, S. J. (1988). Physiological Adaptations to Resistance Exercise: Implications for Athletic Conditioning. *Sports Medicine, 6*, 246-256.

Lamb, D. H. (1989). A Kinematic Comparison of Ergometer and On-Water Rowing. *The American Journal of Sports Medicine, 17*(3), 367-373.

Larsson, L. & Frosberg, A. (1980). Morphological Muscle Characteristics in Rowers. *Canadian Journal of Applied Sports Sciences, 5*, 239-244.

Lesmes, G. R., Costill, D. L., Coyle, E. F. & Fink, W. J. (1978). Muscle Strength and Power Changes During Maximal Isokinetic Training. *Medicine and Science in Sports and Exercise, 10*(4), 266-269.

Lindh, M. (1979). Increase of Muscle Strength from Isometric Quadriceps Exercise at Different Knee Angles. *Scandinavian Journal of Rehabilitation Medicine, 11*, 33-36.

MacDougall, D. J. (1986). *Module V: Principles of Strength and Power Training.* Unpublished Manuscript, McMaster University, Ontario.

MacDougall, D. J. (1986b). Morphological changes in human skeletal muscle following strength training and immobilisation. In N. L. Jones, N. McCartney & A. J. McComas (Ed.), *Human Muscle Power* (pp. 269-288). Illinois: Human Kinetics.

MacDougall, D. J. (1992). Hypertrophy or Hyperplasia. In P. V. Komi (Ed.), *Strength and Power in Sport* (pp. 230-238). Oxford: Blackwell Scientific Publications.

MacDougall, D. J., Elder, G. C. B., Sale, D. G., Moroz, J. R. & Sutton, R. J. (1980). Effects of Strength Training and Immobilisation on Human Muscle Fibres. *European Journal of Applied Physiology, 43*, 25-34.

Mason, B. R., Shakespear, P. & Doherty, P. (1988). The Use of Biomechanical Analysis in Rowing to Monitor the Effect of Training. *EXCELL, 4*(4), 7-11.

McArdle, W., Katch, F. & Katch v. (1986). Exercise Physiology: energy, Nutrition and Human Performance (2nd.ed.). *Philadelphia:* Lea & Febiger.

McBride, P. (1993). *Rowing Biomechanics.* Unpublished Notes, Australian Institute of Sport, Canberra.

Mickelson, T. C. & Hagerman, F. C. (1982). Anaerobic threshold Measurements of Elite Oarsmen. *Medicine and Science in Sports and Exercise, 14*, 440-444.

Moritani, T. & DeVries, H. A. (1979). Neural Factors Versus Hypertrophy in the Time Course of Muscle Strength Gain. *American Journal of Physical Medicine, 58*, 115-130.

Rodriguez, R. J., Rogriguez, R. P., Cook, S. D. & Sanborn, P. S. (1990). Electromyographic Analysis of Rowing Stroke Biomechanics. *The Journal of Sports Medicine and Physical Fitness, 30*(1), 103-108.

Ross, W.D. & Marfell-Jones, M. J. (1992). Kinanthropometry. In J. D. MacDougall, H. A. Wenger & H. J. Green (Ed.), *Physiological Testing of the High-Performance Athlete* (2nd.ed.) (pp. 223-308). Illinois: Human Kinetics Books.

Rutherford, O. M., Greig, C. A., Sargeant, A. J. & Jones, D. A. (1986). Strength Training and Power Output: Transference Effects in the Human Quadriceps Muscle. *Journal of Sports Science, 4*, 101-107.

Sale, D. G. (1988). Neural Adaptation to Resistance Training. *Medicine and Science in Sports and Exercise, 20*(5), S135-145.

Sale, D. G., Jacobs, I. MacDougall, J. D. & Garner, S. (1990). Comparison of Two Regimes of Concurrent Strength and Endurance Training. *Medicine and Science in Sport and Exercise, 22*(3), 348-356.

Schmidtbleicher, D. (1985). Strength Training: Part II. *Science Periodical On Research and Technology in Sport, September*.

Secher, N. H. (1975). Isometric Rowing Strength of Experienced and Inexperienced Oarsmen. *Medicine and Science in Sports, 7*(4), 280-283.

Secher, N. H. (1983). The Physiology of Rowing. *Journal of Sport Sciences, 1*(1), 23-53.

Secher, N. H. (1993). Physiological and Biomechanical Aspects of Rowing: Implication for Training. *Sports Medicine, 15*(1), 24-42.

Secher, N. H., Vaage, O. Jensen, K. & Jackson, R. C. (1983). *European Journal of Applied Physiology, 51*, 155-162.

Tesch, P. A. (1992). Short and Long Term Histochemical and Biochemical Adaptations in Muscle. In P. V. Komi (Ed.), *Strength and Power in Sport* (pp. 239-248). Oxford: Blackwell Scientific Publications.

Tesch, P. A., Hakkinen, K. & Komi, P. V. (1985). The Effect of Strength Training and Detraining on Various Enzyme Activities. *Medicine and Science in Sports and Exercise, 17*, 245.

Tesch, P. A., & Karlsson, J. (1978). Isometric Strength Performance and Muscle Fibre Type Distribution in Man. *Acta Physiologica Scandinavica, 103*, 47-51.

Tesch, P. A., Thorsson, A. & Essen-Gustavsson, B. (1989). Enzyme Activities of FT and ST muscle fibres in heavy resistance trained athletes. *Journal of Applied Physiology, 67*, 83-87.

Thepaut-Mathieu, C. Van Hoecke, J. & Maton B. (1988). Myoelectrical and Mechanical Changes Linked to Length Specificity During Isometric Training. *Journal of Applied Physiology, 64*(4), 1500-1505.

Vrbova, G. (1979). Influence of activity on some characteristic properties of slow and fast mammalian muscles. *Exercise and Sports Science Review, 7*, 181-213.

Weiss, L. W., Cureton, K. J. & Thompson, F. N. (1983). Comparison of Serum Testosterone and Androstenedione Responses to Weight Lifting in Men and Women. *European Journal of Applied Physiology, 50*, 413-419.

Wells, C. L. (1991). Women, Sport, and Performance: A Physiological Perspective. *Illinois:* Human Kinetics Books.

Wright, G. R., Bompa, T. & Shephard, R. J. (1976). Physiological Evaluation of Winter Training Program for Oarsmen. *Journal of Sports Medicine, 16*, 22-37.

Young, A., Stokes, M., Round. J.M. & Edwards, R. H. T. (1983). The Effect of High Resistance Training on the Strength and Cross-sectional Area of the Human Quadriceps. *European Journal of Clinical Investigation, 13*, 411-417.

Appendix A

Testing and Training Plan

WEEK	LRS (Sets x Reps)	HRE (Sets x Reps)
1	3 X 15	3 X 15
2	"	"
3	"	"
4 PRE-TESTING		
5	3 X 12	3 X 50
6	"	"
7	"	"
8	3 X 10	3 X 60
9	"	"
10	"	"
11 MID-TESTING		
12	3 X 8	3 X 70
13	"	"
14	"	"
15	3 X 6	3 X 80
16	"	"
17	"	"
18 POST-TESTING		

Appendix B

PCB 208A03 Force Transducer Specifications

PCB PIEZOTRONICS

SPECIFICATIONS
VOLTAGE OUTPUT
FORCE TRANSDUCER

REVISIONS
-C-REV#2164 DAM 4/3/81

SHEET 1 OF 2

MODEL NO		208B	208A02	208A03
COMPRESSION RANGE	lb	10	100	500
MAX COMPRESSION	lb	1000	1000	5000
TENSION RANGE	lb	10	100	500
MAX TENSION	lb	500	500	750
RESOLUTION	lb	.0002	.002	.01
F.S. OUTPUT VOLTAGE	+volt	5	5	5
SENSITIVITY (NOMINAL)	mV/lb	500	50	10
RESONANT FREQUENCY	kHz	70	70	70
RISE TIME	μSec	10	10	10
DISCHARGE TIME CONST ⚠2	Sec	≥50	≥500	≥2000
LOW FREQ RESPONSE -5%	Hz	.01	.001	.0003
LINEARITY ⚠1	% FS	1	1	1
POLARITY COMPRESSION		POSITIVE	POSITIVE	POSITIVE
POLARITY TENSION		NEGATIVE	NEGATIVE	NEGATIVE
OUTPUT IMPEDANCE	ohm	<100	<100	<100
OUTPUT BIAS	+volt	8 to 14	8 to 14	8 to 14
OVERLOAD RECOVERY	μSec	10	10	10
TEMP COEFFICIENT	%/°F	≤.03	≤.03	≤.03
TEMPERATURE RANGE	°F	-100 to +250	-100 to +250	-100 to +250
VIBRATION (W/O MASS LOAD)	G's peak	2000	2000	2000
SHOCK (W/O MASS LOAD)	G's peak	10000	10000	10000
STIFFNESS	lb/μin	10	10	10
SEALING		EPOXY	EPOXY	EPOXY
CASE MATERIAL		ST STL	ST STL	ST STL
WEIGHT	gm (oz)	25 (.9)	25 (.9)	25 (.9)
CONNECTOR (micro)	coaxial	10-32	10-32	10-32
EXCITATION	+Vdc/mA	24-27/2-20	24-27/2-20	24-27/2-20

⚠2 AT ROOM TEMPERATURE
⚠1 ZERO BASED BEST STRAIGHT LINE.

SUPPLIED ACCESSORIES:
MOD 081B05 (2) MOUNTING STUD
MOD 084A03 (1) IMPACT CAP
MOD 080A81 THREADLOCKER

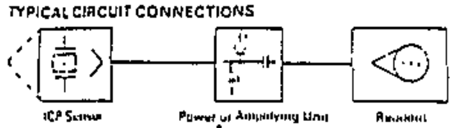
APP'D / ENGR / SALES

SPEC No. 208-2010-80

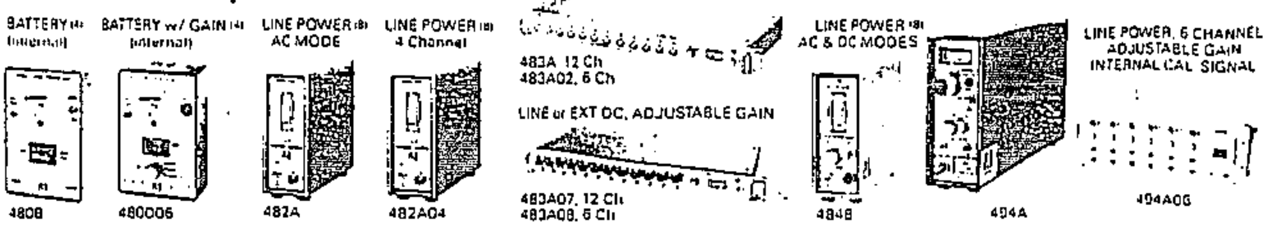
Appendix C

ICP 484B Amplifier Specifications

TYPICAL CIRCUIT CONNECTIONS



For powering transducers with built-in, attached or in-line amplifiers and coupling them to readout instruments. Models with battery or line power, with or without gain, in single and multichannel configurations are available. For telemetry applications see separate data sheet on Model 495B

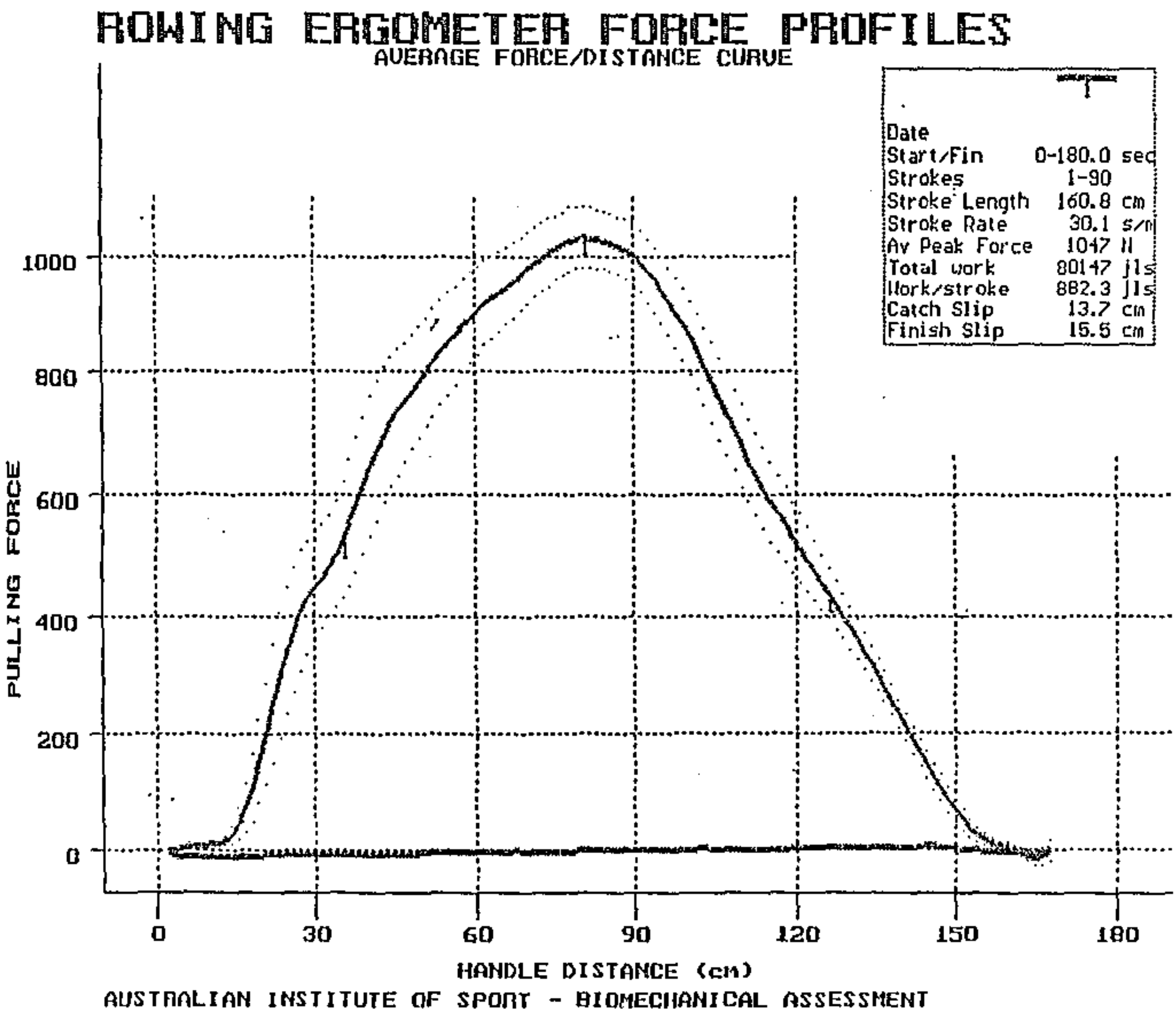


Model Numbers / See optional models below specifications	480B	480D06	482A	482A04	483A	483A07	484B	494A	494A06
A Fixed Constant-Current Supply B Adjustable CC Supply C AC Mode D DC Mode E Self-Test Meter Monitor F Buffer Amplifier G Adjustable Gain									
FUNCTIONS	A, C, E	A, C, E, G	B, C, E	B, C, E	B, C, E	B, C, E, F, G	B, C, D, E, F	B, C, E, F, G	B, C, E, F, G
Transducer Excitation +VDC	27	27	24	24	24	24	24	24	24
Excitation Current[6] mA	2	2	2 to 20[5]	2 to 20[5]	2 to 20[5]	2 to 20[5]	2 to 20[5]	2 to 20[5]	2 to 20[5]
Voltage Gain	unity	1, 10, 100	unity	unity	unity	0 to 100	unity	0.1 to 100	0.1 to 100
Coupling Capacitor[3] µF	10	22	10	10	10	buffered output	10 (AC Mode)[1]	buffered output	buffered output
Frequency Response[2] ± 5% Hz	.05 to 500 000	.15 to 100 000	.05 to 500 000	.05 to 500 000	.05 to 500 000	.25 to 100 000	DC to 200 000	.25 to 100 000	.25 to 100 000
Output Signal FS ±V	10	+10, −8	10	10	10	10	10	10	10
Output Current mA	1	1	3	3	3	5	10	50	50
Output Impedance ohm	<100	<100	<100	<100	<100	<50	<50	2 max	2 max
Noise (pk to pk) mV	0.20	0.2, 2.0, 20.0	0.30	0.30	0.35	0.60	0.60	0.60	0.60
Power Required V/Hz/A	three (160 hr)[4] 9V batteries	three (40 hr)[4] 9V batteries	115/60/.125[7]	115/60/.125[7]	115/60/.25[7] (or 24-28V DC)	115/60/.25[7] (or +24 −15V DC)	115/60/.25[7]	115/60/.25[7]	115/60/.50[7]
Power Connector	ext DC jack	ext DC jack	3 wire, 6' cord	3 wire, 6' cord	3 wire, 8' cord	3 wire, 8' cord	3 wire, 5' cord	3 wire, 8' cord	3 wire, 8' cord
Transducer Connector coax	10-32 thd	10-32 thd	10-32 thd	10-32 thd	iso BNC	iso BNC	10-32 thd	BNC	BNC
Output Connector coax	10-32 thd	10-32 thd	BNC	BNC	iso BNC	iso BNC	BNC	BNC	BNC
Size (w x h x d) in	2.9 x 4 x 1.5	2.9 x 4 x 1.5	1.75 x 4 x 5.5	1.75 x 4 x 5.5	19 x 1.7 x 7	19 x 1.7 x 7	1.75 x 4 x 5.5	2 x 5 x 10.5	19 x 5.2 x 12
Weight lb	1	1	2	2	4.5	6	2	4	14
Optional Models: With BNC Conn	480B02[4]	480D09[4]	482A06	482A05	483A02 (6 Ch)	483A08 (6 Ch)	484B06		
Optional Models: With Gain	480D06[4]		482A10				484B10	494A21	
Other Features[8,9] (see specific data sheet)	480A08[4] integrating				483B03, 483B05 Filtered	483A17, 483A18 Longer TC	484B02 zero clamp		

Notes: (1) DC coupling accommodates 0 to 12V and 4.5 to 6V transducer bias levels
(2) With one megohm load impedance
(3) Coupling time constant is 10.0 seconds with one megohm load
(4) Model 488B Charger with NiCd battery option is available
(5) Adjustable, factory set to 4mA
(6) Use higher excitation current to drive long input cables at high frequencies
(7) 105 to 125V, 50 to 400 Hz. For 220V option, add prefix "F" to model number
(8) Rack mounting adaptors, which hold up to 10 units, are also available
(9) Options include gain, standardization, attenuation, filtering, housing, test signal insertion and special coupling capacitors

Appendix D

Rowing Ergometer Force Profiles



APPENDIX E

WESTERN AUSTRALIAN INSTITUTE OF SPORT UPPER AND LOWER BODY STRENGTH TEST PROTOCOL

GENERAL CONSIDERATIONS PRIOR TO TESTING

Ensure that all athletes undertake an extensive warm-up and stretching routine prior to any strength testing. A progressive increase from light to maximal weights over 6-8 sets of 3 repetitions on each of the exercises is an effective way of building the athlete into the test.

A 3 repetition maximum (3RM) test at 100% is the maximum or heaviest weight an athlete can lift 3 times with good technique and without any external assistance.

75% of 3RM is calculated by multiplying the weight recorded for 3RM by 0.75 and rounding the weight off to the nearest load achievable that can be placed on the bar/machine. If the 75% weight is the midpoint of two achievable loads, then the athlete is required to lift the lighter of the two.

All testing should be supervised by the team/individual's coach or certified strength and conditioning specialist. Spotting of the athlete is required for all attempts at all weights.

BENCH PRESS

Bench press is required to be completed using free weights as opposed to the use of a machine.

Individual athletes may choose the width of grip that they prefer initially but this must remain consistent over consecutive attempts and tests.

The bar is required to touch the chest between repetitions but is not allowed to bounce. To prevent this a slight pause at the end of the eccentric or lowering phase is required before the lift (concentric phase) is completed.

The athlete is to be in control of the bar at all times if the repetition is to be valid. An uneven bar during the concentric phase, arching of the lower back, raising of feet off the ground or bouncing the bar off the chest all result in making the repetition invalid.

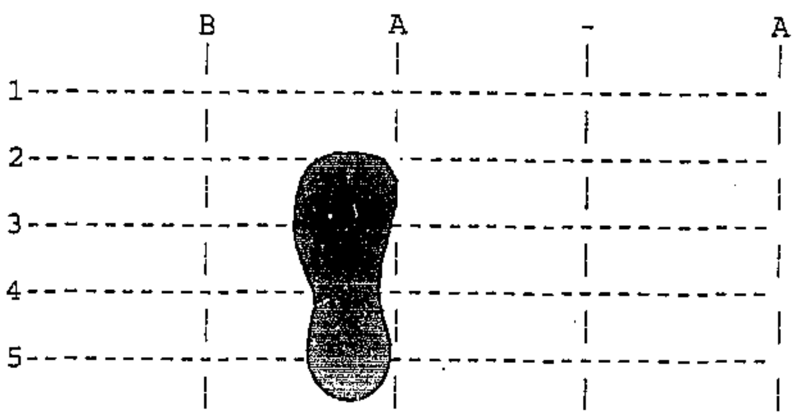
The 75% 3RM strength endurance bench press requires the athlete to lift the specified weight as many times as possible until failure or until any of the above

technical errors are performed. The total repetitions recorded should be those that the athlete completed successfully pre failure or technical error.

LEG PRESS

Leg press is required to be completed using a 45 degree leg press slide with the seat at a right angle (90 degrees) to the slide.

Feet can be placed on any point of the platform approximately shoulder width apart but they must remain consistent over consecutive attempts and tests. Feet positioning can be monitored by using a grid reference whereby the position of the medial border of the foot can be donated by a letter and the distal most portion of the toes by numbers.



eg. A:2
Left Foot

The leg press requires the athlete to bring the sled down to such a depth that the knee joint forms a 90 degree angle. The use of a goniometer should be used to measure 90 degrees knee flexion and a scale (measuring tape) on the side of the leg press used to reference the position. Each repetition must be to the required 90 degree knee flexion or reference point if it is to be valid. Any repetition that does not go to the specified depth is not valid and should not be included in the total repetitions successfully completed.

The 75% 3RM strength endurance leg press requires the athlete to lift the specified weight as many times as possible until failure. An important safety factor associated with this test is the use of spotters either side of the leg press, as the weights being lifted are sometimes in excess of the capacities of one spotter.

Appendix F

Maximal and 3 Minute Effort Step Intensities

Females			Males	
Step	Stroke Rate	500m Split (min)	Stroke Rate	500m Split (min)
1	18	2:14	20	2:14
2	20	2:07	22	2:00
3	22	2:00	24	1:50
4	24	1:55	26	1:44
5	26	1:50	28	1:38
6	Maximal	Maximai	Maximal	Maximal

Appendix G

Resistance Training Program Exercises

Weeks 1-3
Bench Press Leg Press Seated Row Leg Curl Back Extension Upright Row Latpulldown Biceps Curl Sit-Ups Hanging Knee Raise

Weeks 5-10 & 12-17				
Session A	Weeks 5-7	Weeks 8-10	Weeks 12-14	Weeks 15-17
Squats				
Leg Press				
Leg Curl				
Bench Pull				
Bench Press	wide grip	wide grip	medium grip	medium grip
Seated Row	medium grip	medium grip	narrow grip	narrow grip
Back Ext.	3 x 15	3 x 15	3 x 12	3 x 12
Abdominals	incline sit-ups 3 x 20	crunches 3 x 25	twist.sit-ups 3 x 30	twist.incline sit-ups 3 x 30
Session B				
Squats				
Leg Press				
Leg Curl				
Bench Pull				
Latpulldown	wide behind	wide forward	medium forward	narrow forward
Biceps Curl	bar	bar	dumbell	dumbell
Back Ext	3 x 15	3 x 15	3 x 12	3 x 12
Abdominals	hanging knee raise 3 x15	sit-ups 3 x 20	elbow to knees 3 x 25	hanging knee raise 3 x 15

Appendix H

Testing Schedule

Day	Testing Day	Test Description
Monday		
Tuesday	1	Biomechanical & Anthropometric ♀
Wednesday	2	Biomechanical & Anthropometric ♂
Thursday	3	Strength ♀
Friday	4	Strength ♂
Saturday		
Sunday		

Note. ♀ Females, ♂ Males.

Appendix I

PHYSIOLOGICAL TESTING

To :

Test Date :

Test Time :

Venue : WAIS Sport Science Laboratory - Superdrome
Stephenson Avenue Mount Claremont

To ensure controlled pre-test preparation and to minimise those factors which can affect your performance during physiological testing, please follow the guidelines set out below:

1. No training inducing severe fatigue in the 24 hours prior to testing.
2. .o physical activity on the day of the test prior to appointment.
3. No food, cigarettes or caffeine intake 2 hours prior to testing.
4. No alcohol on the day of the test.
5. Restrict fluid intake to water for 2 hours prior to testing.
6. Empty your bowel and bladder immediately prior to testing.
7. Wear light, comfortable clothing and your normal jogging shoes.
8. Do not take any dietary supplements (eg iron tablets) on the day of the test.

Please inform the person in charge of testing if you are currently taking any form of medication or have any injury or illness which may affect test performance.

Any queries you have regarding testing should be directed to the Sport Science Department.

Appendix J

Force and Distance Calibration Procedure

- Place handle at the cage and stop the flywheel if it is spinning.
- Type "F" for Force Calibration.
- The force calibration menu should appear.
- The Amp. setting should be -215.6 mechanical units/volt. Press <return> to advance to the next entry.
- At the 'zero offset' line, press the space bar to clear any existing entry.
- Press <return> to display real time readings of the force output.
- To obtain a zero offset reading, turn the adjustment knob on the amplifier so that the value on the computer screen is close to zero.
- When you are satisfied with the zero reading, press <return> to obtain a sample.
- When the force calibration is complete. press <return> to get back to the main menu.

- Type "D" for Distance Calibration.
- The distance calibration menu should appear and it should be obvious that output from the stroke length device will be sampled at four positions (0, 50, 100, 150 cm).
- Place the handle against the flywheel cage. This is the "zero handle position".
- Press <return> to obtain the current output value form the stroke length device. The chain should be lifted and the gear rotated until a value between 1 and 10 is obtained when the handle is at the cage.
- Once the reading for the zero position (handle at the cage) is within the acceptable range, calibrate the distance at 0 cm, 50 cm, 100 cm, and 150 cm (press <return> to initiate and complete sampling). The resulting calibration factor (cm/unit) should be fairly consistent for each interval.
- The easiest way to ensure that the distances from the cage are accurate is to use a measured marker marked at 50 cm intervals.
- When the distance calibration is complete, press <return> to get back to the main menu.
- If the value does not change as you move through the stroke, ensure that all the wires are properly connected and all the switches are on.
- As the handle is moved through the stroke, the value should increase linearly to the end of the stroke (and decrease in the opposite direction). It should not return to zero during the stroke.

Appendix K

Mean (± S.D.) Strength and Anthropometric Characteristics of Matched Groups

Variable	Females	Males
Bench Press (3RM)		
LRS	50.7 (7.5)	74.3 (12.1)
HRE	48.4 (6.0)	71.7 (4.5)
Leg Press (3RM)		
LRS	306.1 (59.1)	316.3 (66.2)
HRE	274.3 (21.6)	344.5 (43.7)
Arm Span (cm)		
LRS	182.0 (4.1)	196.3 (7.5)
HRE	181.6 (6.6)	195.5 (3.6)
Leg Length (cm)		
LRS	83.3 (4.2)	92.8 (3.7)
HRE	85.0 (5.5)	94.0 (2.6)

Note. Strength expressed as a percentage of body weight.

Appendix L

Mean (± S.D.) Strength and Anthropometric Characteristics of Pooled Groups

Variable	LRS	HRE
Bench Press (3RM)	63.8 (15.8)	61.4 (13.2)
Leg Press (3RM)	311.8 (59.4)	313.3 (50.0)
Arm Span (cm)	189.9 (9.6)	189.3 (8.7)
Leg Length (cm)	88.6 (6.2)	90.0 (6.1)

Note. Strength expressed as a percentage of body weight.

Appendix M

Mean (± S.D.) Group Changes in Anthropometric Characteristics

Variable	Pre-Test	Post-Test
Weight (kg)		
LRS	82.5 (5.53)	83.4 (5.6)
HRE	87.3 (6.2)	89.7 (5.4)**
Bicep Girth (cm)		
LRS	33.6 (2.1)	34.2 (2.0)
HRE	33.5 (2.2)	35.0 (2.8)**

Note. Tukey post hoc.
$p < .05$ *, $p < .01$ **.

Appendix N

Mean (± S.D.) Group Changes in Strength

Variable	Pre-Test	Post-Test
Bench Press		
Strength (3RM)		
LRS	53.3 (15.5)	63.6 (18.8)**
HRE	53.9 (13.6)	57.6 (13.4)
Endurance (Reps)		
LRS	17.8 (4.9)	15.8 (3.5)
HRE	17.2 (4.6)	22.5 (6.0)
Leg Press		
Strength (3RM)		
LRS	258.9 (56.4)	359.4 (47.6)**
HRE	274.4 (53.2)	322.2 (39.7)**
Endurance (Reps)		
LRS	27.7 (11.7)	27.9 (8.6)
HRE	26.0 (13.4)	59.4 (14.2)**

Note. Tukey post hoc.
$p < .05$ *, $p < .01$ **.

Appendix O

Mean (± S.D.) Group Changes in Biomechanical Data

Variable	Pre-Test	Post-Test
Maximal Effort		
Peak Force Step 1		
LRS	1047.9 (157.8)	1124.5 (115.3)**
HRE	1085.0 (161.2)	1175.1 (137.0)**
Peak Force Step 6		
LRS	987.6 (128.3)	1105.7 (109.7)**
HRE	1015.2 (139.0)	1129.7 (162.4)**
Work P/Stroke Step 1		
LRS	959.6 (187.4)	1080.0 (145.8)**
HRE	1008.9 (179.4)	1119.7 (192.0)**
Work P/Stroke Step 6		
LRS	835.4 (126.2)	939.3 (145.8)
HRE	875.3 (139.0)	954.2 (172.9)
3 Minute Effort		
Peak Force Step 1		
LRS	563.8 (92.3)	599.6 (68.2)
HRE	573.1 (70.6)	634.8 (66.8)**
Peak Force Step 6		
LRS	864.1 (134.4)	920.2 (136.5)**
HRE	875.8 (129.3)	933.9 (113.5)**
Work P/Stroke Step 1		
LRS	491.2 (45.5)	528.5 (34.2)
HRE	512.3 (26.1)	568.3 (45.6)**
Work P/Stroke Step 6		
LRS	690.7 (141.9)	762.9 (161.6)
HRE	698.8 (140.9)	784.9 (164.6)
Total Work Step 1		
LRS	25765.3 (1527.0)	27508.5 (965.1)
HRE	25751.5 (1514.7)	28594.6 (3401.9)**
Total Work Step 6		
LRS	55561.7 (16162.1)	64330.7 (17073.6)**
HRE	60300.9 (13470.5)	70488.9 (15098.6)**

Note. Peak force (Newtons), Work per stroke (joules).
Tukey post hoc.
$p < .05$ *, $p < .01$ **.

Appendix P

Mean (± S.D.) Group Changes in Performance

Variable	Pre-Test	Post-Test
2500m (sec)		
LRS	551.6 (41.2)	541.6 (37.9)*
HRE	514.8 (40.8)	506.8 (40.9)*
3 Minute Meters		
LRS	883.6 (92.3)	895.3 (85.8)
HRE	908.8 (73.5)	927.9 (65.8)**

Note. Tukey post hoc.
$p < .05$ *, $p < .01$ **.