Strength testing and training of elite rowers

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Attestation of authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

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TRENT LAWTON

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Co-authored Works

The contribution of co-authors for publications arising from these studies and from whom approval has been granted for inclusion in this doctoral thesis, is as follows:

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Under review

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Conferences and presentations

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Ethical Approval

The ethical approval for this thesis was granted by the AUT University Ethics Committee (AUTEC). Chapters 3 and 4 were covered by Ethics Application Number 09/215 "The reliability and validity of a continuum strength assessment to rowing performance" (see Appendix 1). On revision of the post-graduate study proposal, AUTEC approved the second stage of research and further studies contained in this thesis (Chapters 5 up to 7), allowing the upgrading of the qualification from a Masters of Philosophy to fulfil the requirements for the degree of Doctor of Philosophy (see Appendix 2).

Abstract

In the quest to optimise 2000-m rowing performance, various weight-training protocols have been incorporated into preparation plans for rowers, despite beneficial evidence for such practice remaining unclear. Subsequently, the purpose of this thesis was to establish the benefits of strength testing and (weight) training over various phases of preparation for international regattas for elite rowers.

Initially a series of three descriptive investigations were undertaken to establish reliable and valid strength tests. The major findings of these studies were: 1) low-repetition testing (e.g. 5RM leg pressing) is recommended, as the measurement error associated with high-repetition tests (e.g. 30RM, 60RM or 120RM) involving upper-body exercise was considered problematic when testing elite rowers (i.e. percent typical error > 5.0% or intra-class correlations < 0.90); 2) after adjustments were made for strength covariates (effect sizes (ES) = 0.9 to 1.4), greater 2000-m performance differences were attributed to the greater upper–body strength (males) and muscular–endurance (females) of seniors in comparison to junior rowers; and, 3) the best two strength determinants of 2000-m ergometer time (R^2 = 59%; SEE = 6.3 sec) recommended as assessments for senior rowers, were a 5RM leg press (r = –0.69; 90% confidence interval (CI) = –0.88 to –0.30) and 6RM prone bench pull (r = –0.68; 90%CI = –0.88 to –0.28).

As descriptive relationships do not imply cause and effect, the second phase of this thesis consisted of three case-control research designs, to establish benefits associated with strength testing and training within the context of training time (weeks) available to prepare elite rowers for competition. After 8–weeks training, differences in aerobic condition (Watts.kg^{-1} @ blood lactate 4 mmol/L, ES = 0.15; ± [90% confidence limit]

0.28, P = 0.37) and upper-body strength (6RM prone bench pull (kg), ES = 0.27; ±0.33, P = 0.18) between weight–training and rowing–only controls were trivial. However, only weight–trained rowers increased lower–body strength (isometric pull: 12.4 ± 8.9%, P<0.01, and 5RM leg press: 4.0 ± 5.7%, P<0.01) and muscular–endurance (30RM leg press: 2.4 ± 5.4%, P<0.01). Similarly, after 14–weeks of intensive training involving resisted rowing (e.g. towing ropes), leg strength was only increased when weight–training was integrated with rowing (5RM leg press, ES = 0.72; ±0.62, P = 0.03). As the link between greater lower–body strength and on–water rowing performance was unclear, the final study investigated factors influencing selection of national crews. Selected crews who won by an average margin of 13.0 ± 0.7 seconds over 1500 meters had no better 2000-m ergometer times (ES = 0.2, 90%CL = -0.6 to 1.1, P = 0.63) nor any anthropometrical advantage, but had moderately greater leg strength (5RM leg press: ES = 1.1; 90%CL = 0.3 to 0.9, P = 0.03).

In conclusion, strength testing provides valid data on which to benchmark development and to select rowers. Furthermore, where the volume of training to prepare for international regatta is less than 14 weeks, greater leg strength to improve boat speed can be gained from weight-training.

Chapter 1: Introduction

Rationale

In the quest to maximize average propulsive stroke impulses over 2000-m racing, testing and training of various strength parameters has been incorporated into the physical conditioning plans of rowers. While strength explains much of the variances in 2000-m ergometer performance, the clinical and practical benefits associated with strength training of novice and sub-elite rowers is unclear, primarily due to an absence of quality long-term controlled experimental research designs (Lawton, Cronin, & McGuigan, 2011). Furthermore, the use of valid and reliable assessments of strength and the utility of various strength training protocols as part of preparation plans of elite rowers is relatively unexplored.

International travel associated with competition and increases in endurance training volumes by more than 20% over the past three decades (Fiskerstrand & Seiler, 2004) can make weight training problematic for elite rowers. Furthermore, if any doubt exists with respect to the specific benefits gained from the integration of strength training into the preparation plans of rowers, then elite coaches and rowers are hesitant to use such training methods. Unsurprisingly therefore, testimonies by successful professionals can polarize views about strength or more succinctly the utilisation of weight training in the preparation of rowers. For example, from July 2004 and in contrast to other international rowing associations, Rowing New Zealand (RNZ) discontinued weight training as part of non-competition preparations (i.e. October to May) for some senior crews. This can be partly attributed to RNZ lacking access to expertise to design, implement or to critically evaluate any benefits associated with weight training for these rowers. However, New Zealand crews can also continue with training and competitive rowing over the off-season' because domestic competitions are conducted in the southern-hemisphere over summer (i.e. northern-hemisphere winter). Although some crews did not perform weight-training and strength testing was not used to monitor rowers, New Zealand was successful at international regattas (e.g. four gold medals at 2005 World Championships, Gifu, Japan).

Nonetheless, younger rowers aspiring to senior national representation continue to perform weight training as part of preparations. However, it remains unclear whether any advantage can be gained from using qualifying benchmarks for specific strength testing as an aid in the selection of junior and senior rowers (Hay, 1968). Therefore, in support of the national high performance centre for rowing excellence, High Performance Sport New Zealand (HPSNZ) has invested in the provision of strength and conditioning expertise and the commissioning of this research in order to establish any possible benefits associated with strength testing and weight training that may 'positively impact on performance (as perceived by rowers and coaches alike)' so that 'more New Zealand rowers are winning on the world-stage' (Collins & Birnie, 2010).

Originality and research aims

The purpose of this doctorate study is to establish the benefits associated with integrating strength testing and training over various phases of preparation for international regattas for elite rowers. With context to the rationale and on critical review of the literature (Chapter 2), five key areas of investigation account for the originality in design of this study:

- the reliability of low and higher repetition measures used to monitor strength or to evaluate differences in strength training efficacy with respect to champion elite rowers is unknown;
- the extent of differences in 2000-m performance attributable to strength parameters and the rate of development required for juniors to attain the strength and muscular endurance attributes of senior elite rowers is unclear;
- the relevance of specific strength, power and muscular endurance assessments with respect to various rowing performance measures of interest to champion elite rowers is unknown;
- there exists an absence of research to clarify the benefits associated with incorporating weight training into rowing preparation plans (in contrast to endurance rowing only), thus few definitive recommendations can be made with respect to essential strength program design over various phases of preparation (i.e. non-competition and competition). For example, it remains unclear whether performance changes are attributable to lower– or upper–body strength, or in emphasizing one over the other; or, whether any particular exercises (such as the leg press or power cleans) are potentially more beneficial than specific rowing practices (such as 'towing ropes' on–water), and finally;
- it was unclear whether greater levels of strength are associated with the performance differences between successful and unsuccessful selection of crew-rowers.

Significance of study

Research that recruits internationally successful rowers and involves short-term training interventions is rare. In contrast, this study was intimately tied to the selection, training and assessment of elite rowers who over a period of two years represented New Zealand at various international regattas. Of note, this research was conducted at a time when New Zealand achieved its best–ever performances at international regattas (i.e. World Cup and Rowing Championships, 2009 and 2010).

This thesis also provides information for target groups of elite rowers less commonly examined in the literature (i.e. junior elite and senior elite women), for whom the appropriate applications of weight training, testing and benchmarks for strength, are lacking. We were cognizant therefore in our analysis that we had to consider the benefits of strength testing and training with context to the longitudinal development plans for these rowers. Subsequently, each study in this thesis was implemented sequentially as preparations for competitions intensified each training phase. By encompassing a longer–term evolution framework for this investigation, the researchers were able to clarify the performance benefits attributable to weight training, as the training experience preceding each intervention were more uniformly controlled.

Finally, while the integration of strength testing and training may appear conceptually simple on review of this thesis, there were many logistical challenges associated with international travel, medical support and professional commitments of elite rowers in the execution of this research. Subsequently, the various testing and training strategies used in this thesis are of greater relevance to the year-round preparations of 'semiprofessional' elite rowers from the southern-hemisphere than previous research recruiting northern-hemisphere club or varsity rowers.

Thesis organisation

The design of this thesis consists of a literature review (Chapter 2) and six original experimental investigations (Chapters 3–8), all of which have been submitted for publication. Subsequently, each chapter is presented in the format of the journals for which they were written; with the exception that each study is preceded by a brief explanatory prelude rather than summary abstract. For consistency, all referencing is in APA format, and for ease of reference, a single citation summary is contained at the end of the thesis.

Initially (Chapter 3–5), a series of three descriptive studies were performed to establish reliable and valid measures of strength to discriminate between the performance abilities of rowers and include:

- (Chapter 3) – a repeated measures study to quantify the reliability of low– and high– repetition strength testing involving upper– and lower–body exercises;
- (Chapter 4) – a cross-sectional descriptive cohort study to compare the 2000-m performance abilities of junior and senior elite rowers, with effects adjusted for any substantial differences in anthropometry and low– or high–repetition strength evident between groups; and,
- (Chapter 5) – a cross-sectional (structured equation modelling) descriptive cohort study to establish strength, power and muscular-endurance determinants of champion elite rowing performance.

As differences exist between squads/rowers preparation philosophies with regard to the utility of weight training in build up to competition, controlled-contrast designs in training for research purposes were possible on integration of strength testing, with negligible disruption to existing regimes. For ease of implementation, investigations were integrated into national training plans using pre-existing performance measures (e.g. 2000-m time trials). The second phase of this study consists of three case–control research designs to establish the benefits associated with weight training and the possible use of strength testing as part of rowing selection, and includes:

- (Chapter 6) – a case-control study (pre- and post-intervention) to quantify differences in anthropometry, aerobic condition, upper– and lower–body strength, power and muscular–endurance over a non–competition ‘extensive endurance’ preparation phase between strength and non-strength trained rowers;
- (Chapter 7) – a case–control study (crossover intervention) to quantify differences in anthropometry, upper– and lower–body strength after repeating a pre-competition ‘intensive-endurance’ preparation phase with and without strength training; and;
- (Chapter 8) – a cross-sectional descriptive cohort study to compare lower–body strength and 2000-m ergometer performance abilities between groups of successful (selected) and unsuccessful (non-selected) crew-scullers, adjusted for any significant differences in anthropometry. Measures of on-water rowing ability are constrained by large standard errors, thus this concluding investigation is one of the first studies to determine on-water performance

outcomes attributable to strength, in the comparison of rowers vying for national selections.

The final chapter of this thesis (Chapter 9) consists of a general summary of findings with limitations and future research recommendations as well as conclusions and practical recommendations for practitioners providing strength testing and training support to elite rowers. Finally, an overall thesis reference list and appendices that present relevant peripheral material including informed consent forms, ethics approval, subject information sheets and abstracts (as submitted for publication), has been collated to assist with review or future recreation of research arising from this study.

Chapter 2: Literature review

Prelude

International competition in rowing is based in the northern-hemisphere and consists of a series of three world cup regattas held over late spring and summer (i.e. May to July), culminating with the world rowing championships in August of each year. Over the winter, weather can be inclement, in-land waterways may freeze and daylight hour’s too brief for rowing year-round on-water. Alternative (aerobic) cross-training activities such as cross-country skiing or indoor exercise such as rowing on an ergometer, running on a treadmill or cycling on wind-trainers may be performed. It is also common practice for rowers, particularly for those clubs who have access to resources, to perform weight training. Heavyweight rowers can use weight training to increase their muscle mass and strength, whereas lightweight rowers might perform circuit weight-training to develop (local) muscle-endurance. It is not uncommon for benchmarks to be set for weight training because unlike on-water crew rowing, individual training loads (intensity and volume) can be prescribed and progress readily assessed. Often coaches and sports physiologists use such benchmarks and data to compare the performance of rowers of varying competitive ability. However, as summer conditions prevail in the southern-hemisphere over the ‘off-season’ from international competition, rowing can be continued on-water. There may be no need or benefit gained from cross-training or weight-training. Subsequently, the purpose of this literature review was to evaluate the current strength testing and training evidence and practices in rowing, to guide the formation of studies for investigation in this thesis.

Introduction

Depending on crew size, boat type and weather conditions, an Olympic 2000-m rowing event lasts somewhere between 5:19.85 and 7:28.15 minutes, based on 2009 world best times. A relatively high energy cost with sculling (two oars) or rowing (single oars), was attributed to drag created by wind and water resistance (Shephard, 1998). Subsequently, elite rowers have developed better technique, demonstrating a more efficient recovery phase (particularly in the timing of forces at the catch), a faster stroke rate and a stronger, more consistent and effective propulsive stroke (Baudouin & Hawkins, 2004; Hagerman, 1984; Hofmijster, Landman, Smith, & Van Soest, 2007; Hofmijster, Van Soest, & De Koning, 2008; Kleshnev & Kleshnev, 1998; Millward, 1987; Shephard, 1998; Smith & Spinks, 1995). All other factors remaining equal, rowers who sustain greater net propulsive forces (or strength) achieve faster boat speeds (Hofmijster, et al., 2007; Smith & Spinks, 1995).

From this relatively simplistic description, and with consideration of the impulses required to change boat inertia on starting or over the finishing burst of 2000-m racing, it would appear that rowing requires muscle strength, endurance and power. For the purposes of this review, strength was broadly defined as the amount of force produced in a specific task or activity. Irrespective of the mode of assessment or the duration required, the peak or greatest force achieved in any task has commonly been defined as the 'maximum strength' (Kraemer, et al., 2002). 'Strength endurance' (or muscle endurance) on the other hand, was defined as the total concentric work produced over a number of repetitions, often within a designated time interval (Kramer, Leger, Paterson, & Morrow, 1994). A rower who performed an equal quantity of work more quickly was more powerful; therefore, a third and equally important measure of strength was muscle 'power' (Lund, Dolny, & Browder, 2006). Given these demands and that on-water performance could not be predicted precisely from any single test, including ergometer time trials (Hahn, 1990; Hay, 1968; Kramer, et al., 1994; Mikulic, Smoljanovic, Bojanic, Hannafin, & Matkovic, 2009; Nevill, Beech, Holder, & Wyon, 2010; Russell, Le Rossignol, & Sparrow, 1998; Smith & Spinks, 1995), testing and training of various strength parameters have been incorporated into the physical preparation of rowers. The reliability and relevance of such practice in the context of the physical preparation of the rower provided the focus for this review.

Therefore, the purpose of this review was two-fold: to identify strength tests that were reliable and valid correlates (predictors) of rowing performance; and, to establish the benefits gained when strength training was integrated into the physical preparation plans of rowers.

Search strategy

This review evaluated and interpreted the current evidence base to provide coaches, sport scientists and rowers alike, with an understanding of the rationale and application of strength testing and training principles to rowing. The conclusions of this article were drawn from either peer-reviewed journal publications or conference proceedings. Books or association journals were excluded in the analysis, but cited where of value for understanding the concepts of rowing or the training of rowers.

Google Scholar and the EBSCO Host search engines with varying combinations of the keywords 'strength', 'power' and/or 'endurance' with the term 'rowing' or ‘oarsmen/women’ (in any field) were used to filter relevant research from electronic databases such as MEDLINE, CINAHL, Biomedical Reference Collection: Basic, PubMed, and SPORTDiscus®. Bibliographic referral was an equally important search strategy.

Studies were included in the analysis if the investigation utilized dynamometry to assess muscle strength (including tests using Electromyography (EMG), rowing ergometers or on-water analysis which were considered measures of rowing force) or strength training interventions (excluding resisted inspiration studies). For inclusion, a project must have recruited rowers with at least one year of experience.

For the purposes of this review, the level of rower was defined by the level of competition experience (where identified). An ‘elite’ subject sample utilized rowers who participated in open-age international competition (Class A), such as the World Cup regattas or World Championships. A ‘sub-elite’ sample recruited junior or under-23 age competitors with international experience, or open-age rowers of national ranking or competition experience. Finally, ‘non-elite’ rowers participated in club or university rowing events.

Evaluation of quality of current evidence base

In total, the search process recovered 53 papers. Around half (n = 27) used rowers classified as sub-elite or elite. The authors were unable to find any scientific paper that incorporated a measure of strength into a model of on-water rowing performance (i.e. race ranking or 2000-m times) because models utilizing on-water results have limitations primarily due to large standard error of the estimates of data (Mikulic, et al., 2009). Therefore, discussion was limited to the relevance of strength testing and training as part of the physiological preparation and reduction of injury risk associated with competitive rowing. The majority of studies (n=35) were descriptive investigations that used strength testing to characterize differences between rowers (e.g. non-elite and elite) with non-rower populations.

Less than one-third (n = 17) of the recovered research was intervention based, of which ten papers involved strength training along with a pre- and post-measure of rowing performance (i.e. ergometer time trial) and strength (e.g. one-repetition maximum [1RM] leg press). The methodological quality of this experimental research was assessed using the qualitative evaluation criteria proposed by Brughelli and colleagues (Brughelli, Cronin, Levin, & Chaouachi, 2008). Their method used a 10-item scale to rate the quality of the research design overcoming the harsh Delphi, PEDro and Cochrane scales ratings of most strength and conditioning research due to the lack of blinding and randomization of intervention treatments. However, most of the 'quasi-experimental' interventions reviewed lacked use of either a crossover research design, control group and/or randomization allocation of rowers to treatment interventions. Subsequently, many papers rated poorly when the Brughelli et al. evaluation criteria were used (see Table 2.1). Nonetheless, these descriptive research interventions reported positive performance outcomes of clinical (Koutedakis, Frischknecht, & Murthy, 1997; Tse, McManus, & Masters, 2005) and practical significance (Ebben, et al., 2004; Gallagher, DiPietro, Viser, Bancheri, & Miller, 2010) from the short-term inclusion of strength training that warranted discussion within the relevant sections of this review.

Table 2.1 Methodological rating of the quality of intervention studies incorporating strength testing, training and rowing performance

Item[a]	**Bell et al. (1993)**	**duManoir et al. (2007)**	**Ebben et al. (2004)**	**Gallagher et al. (2010)**	**Haykowsky et al. (1998)**	**Kennedy and Bell (2003)**	**Kramer et al. (1983)**	**Syrotuik et al. (2001)**	**Tse et al. (2005)**	**Webster et al. (2006)**
Inclusion criteria were clearly stated	1	2	1	2	2	1	1	1	2	1
Rowers were randomly allocated to groups	2	0	2	2	0	0	0	1	1	0
Intervention was clearly defined	1	1[b]	2	1	1[b]	1[b]	2	2[b]	1	1
Groups were tested for similarity at baseline	1	1	2	0	1	1	2	1	2	1
Use of a control group	0	0	0	2	0	0	1	1	1	0
Outcome variables were clearly defined	2	2	2	1	2	2	2	2	2	2
Assessments were practically useful	2	2	1	1	2	2	2	2	2	2
Duration of intervention was practically useful	1	1	1	1	1	1	1	1	1	1
Between-group statistical analysis was appropriate	2	2	2	2	2	2	2	2	2	2
Point measures of variability	1	1	1	1	1	1	1	1	2	1
Rating (out of 20)	13	12	14	13	12	11	14	13	16	11

[a] The score for each criterion was as follows: 0 = clearly no; 1 = maybe; and 2 = clearly yes.

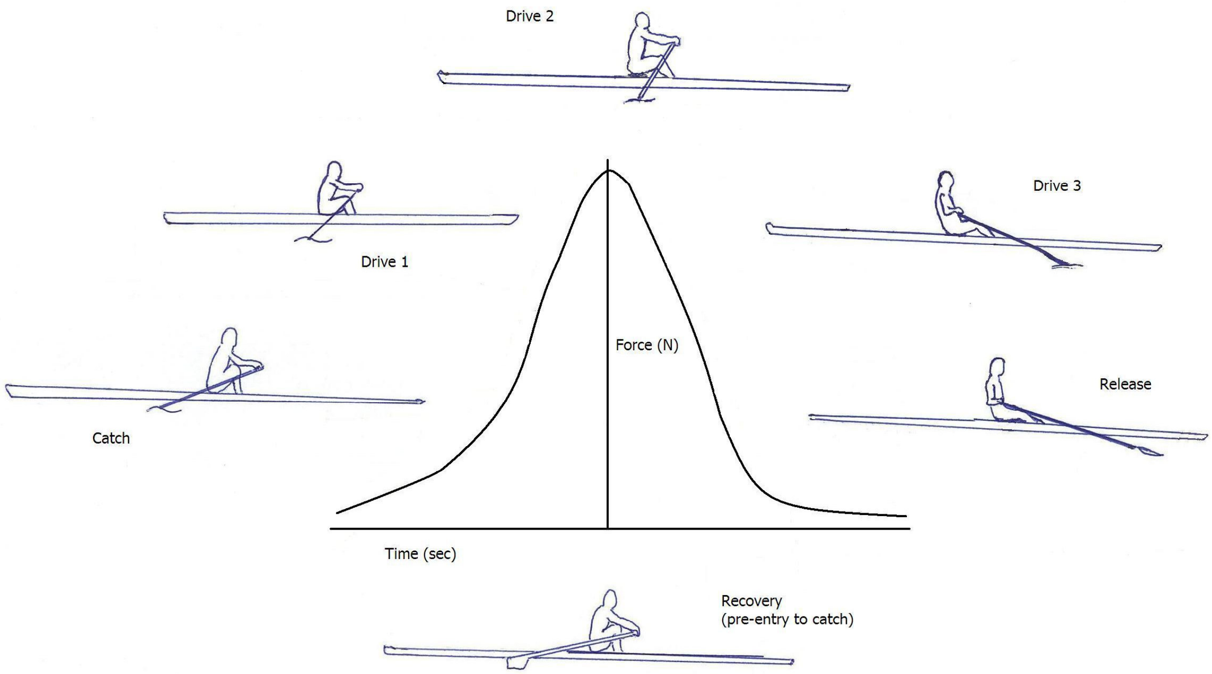
[b] Strength training intervention was not the primary independent variable of interest.

There were also constraints to the relevance and applicability of some data when reviewed in the context of contemporary rowing practices. For example, over the past 30 years, training volumes have increased by >20% in many countries, with medal winners now training between 1100 and 1200 hours a year (Fiskerstrand & Seiler, 2004). Such volumes of endurance training are far greater than the 4 days (or around 6 hours) a week deployed in the referenced research. Additionally, this review synthesized data from research spanning over 40 years (1968 to 2010). After allowing for a population trend of increasing height of 0.03 m, the 21st century elite rower is some 0.06 m taller at 1.94 ±0.05 m and 1.81 ±0.05 m (male and females, respectively), and about 6.4 kg and 12.1 kg heavier at 94.3 ±5.9 kg and 76.6 ±5.2 kg than Olympic rowers of just over two decades earlier (Kerr, et al., 2007). Given the significant influence of height and lean body mass on 2000-m performance (Bourgois, et al., 2001; Bourgois, et al., 2000; Kerr, et al., 2007; Mikulic, 2008, 2009; Yoshiga & Higuchi, 2003b), the divergent characteristics of rowing populations must not be overlooked in review of the data. Finally, 2000-m ergometer times of < 328 seconds and 374 seconds respectively, for heavy and light weight males (379 seconds and 407 seconds respectively, for females) were recently proposed as benchmarks for a medal placing in the A-Finals for small boat categories (e.g. single or double sculls) at the 2007 World Championships (Mikulic, et al., 2009). While not the definitive measure of an elite rower, such benchmarks were considerably faster than average ergometer times of rowers reviewed in this article. Thus, it would appear warranted to revisit many of the past experimental themes in future research. In particular, with consideration of the increased professionalism, endurance training volumes and general changes in anthropometrical build, the testing and training of strength parameters within the distinct phases of physical preparation of the champion elite warrant investigation. Stronger experimental research designs (e.g. use of control groups or crossover designs) over periods of longer intervention (e.g. more than 12 weeks) were also required (regardless of the experience of the population examined). Finally, where standard errors with modelling data permit, the common variances shared between changes in strength and on-water performance data should be explored.

Measuring rowing strength

Without doubt, the most valid and specific measure of rowing strength is to assess the force vectors produced during 2000-m racing. Hartmann et al. (1993) reported that peak force significantly decreased during maximal free rating 6-minute rowing ergometry. From the first stroke to the last stroke, peak forces after the initial and most forceful ten strokes (around 1350 N for men and 1020 N for women) did not exceed more than 65 to 70% of maximum force thereafter. As the level of force declined, rowers substituted both an increase in stroke speed and rate in order to sustain mechanical power assessed at the flywheel. Similar results have been reported during on-water racing, the level of force up to 1000 N and 1500 N for the start; thereafter, speed was maintained with peak rowing forces between 500 and 700 N for the 210 to 230 strokes performed over 6 minutes (Steinacker, 1993).

Figure 1 Schema of the main phases and force-time characteristics of the propulsive rowing stroke



Relatively modest forces produced at fast movement speeds accentuate the importance of stroke-to-stroke consistency, stroke smoothness and a high mean propulsive stroke power in order to achieve fast boat speeds (Hofmijster, et al., 2007; Millward, 1987; Smith & Spinks, 1995). Forces measured at the oar-pin during the drive phase (Millward, 1987; Smith & Spinks, 1995) from catch (i.e. oar-blade entry into the water) to finish (i.e. oar-blade exit from the water) rise then fall producing a bell-shaped propulsive impulse (see Figure 1). When disaggregated to examine the timing and relative contribution of the main body segments involved in the propulsive stroke, analysis showed that the leg drive (i.e. knee extension) produced just under half, the trunk swing (i.e. hip and trunk extension) almost one-third and the arms (i.e. elbow flexion and shoulder adduction) less than one-fifth of total stroke power (Kleshnev & Kleshnev, 1998; Tachibana, Yashiro, Miyazaki, Ikegami, & Higuchi, 2007). Subsequently, strength tests of these main body segments have been used to compare the differences between elite and non-elite rowers, irrespective of rowing experience or skill. For example, stronger non-elite oarswomen produced greater leg extension power across a spectrum of loads (e.g. 17.5% greater power at 50% 1RM) compared with weaker controls (Lund, et al., 2006) and stronger sub-elite oarsmen sustained greater power (849.4 W) in 30 seconds of arm cranking than club level (610.2 W) rowers (Koutedakis & Sharp, 1986). Similarly, isokinetic leg flexion strength tests proved useful for the early identification of individuals with the physiological potential to excel at rowing (Hahn, 1990), while also having been used to identify possible training interventions to bridge the gap between slower and faster rowers of equivalent skill (Pyke, Minikin, Woodman, Roberts, & Wright, 1979).

How strong are elite rowers?

Internationally successful rowers are taller, heavier, of greater sitting height and lower fat-mass than their less successful peers (Bourgois, et al., 2001; Bourgois, et al., 2000; Drarnitsyn, Ivanova, & Sazonov, 2009; Kerr, et al., 2007; Mikulic, 2008, 2009). They have some of the highest absolute aerobic power (e.g. maximum oxygen uptake values over 6.0 l/min and 4.0 l/min for males and females, respectively) reported of any competitive sport (Hagerman, 1984; Secher, 1993; Steinacker, 1993). Rowers are also relatively strong when comparisons of strength are made with other endurance athletes (Grant, et al., 2003; Hagerman, 1984; Jurimae, Abernethy, Quigley, Blake, & McEniery, 1997; Koutedakis, Agrawal, & Sharp, 1999). The comparison of greatest interest to rowers and coaches alike is 'how strong are the fastest rowers?'.

Elite male rowers generated a force of more than 2000 N in an isometric simulated-row position (Secher, 1975) and forces over 4000 N at 120^{o} knee extension (Peltonen & Rusko, 1993). They can produce forces of around 300 N at 1.05 radians per second during isokinetic leg extension (Hagerman & Staron, 1983; Hahn, 1990; Larsson & Forsberg, 1980), and cable or bench row 1RM loads of around 90 kg (Cronin, Jones, & Hagstrom, 2007; Liu, Lormes, Beissnecker, & Steinacker, 2003). Based on the strength training data of elite male rowers, strength targets (expressed as a factor relative to body mass) for 1RM dead lift (1.9), back squat (1.9) and bench row (1.3) have been suggested (McNeely, Sandler, & Bamel, 2005). Elite female rowers produce a force of around 200 N at 1.05 radians per second during leg extension (Clarkson, Graves, Melchionda, & Johnson, 1984; Hahn, 1990). Strength targets expressed as a factor relative to body mass for 1RM dead lift (1.6), back squat (1.6) and bench row (1.2) have also been reported based on the strength data of elite female rowers (McNeely, et al., 2005).

Other useful data can be interpreted from the substantial literature that has investigated novice and sub-elite rowers. In summary, male non-elite rowers leg press around 290 kg for a 1RM (Chun-Jung, Nesser, & Edwards, 2007; duManoir, et al., 2007; Jürimäe, et al., 2010; Kennedy & Bell, 2003; Webster, et al., 2006) (168 kg for women) (Kennedy & Bell, 2003; Kramer, et al., 1994; Kramer, et al., 1983; Webster, et al., 2006) and bench row around 80 kg for a 1RM (Jürimäe, et al., 2010). Sub-elite rowers might perform over 100 repetitions with a load of approximately 50 kg (or about 50% of a

1RM) for a bench pull task over 6 minutes (Jensen, Freedson, & Hamill, 1996; Jürimäe, et al., 2010).

Reliability of strength, power and endurance tests

Comparisons between the strength of novices and elite rowers are interesting but potentially meaningless if the reliability and validity of such tests to rowing performance is questionable. Hopkins (2000) argued, when selecting tests to monitor the progression of an athlete, that it is important to take into account the uncertainty or noise in the test result, ideally, for the specific population of interest. The precision of testing is important particularly if an attempt is made to replicate the data of previous research, or when the tests are used to assess different sample populations.

The reliability for a range of strength and power measures commonly used with rowers appears quite robust. Intra-class correlations (ICC) for isokinetic leg extension peak torque range from 0.82 to 0.94 (Bell, et al., 1993; Kramer, 1990; Kramer, Leger, & Morrow, 1991). The coefficient of variations (CV) for concentric power using a linear encoder on a seated cable row ranged from 3% to 5% (Cronin, et al., 2007). Also, the reliability of tests using the leg press or prone bench pull exercise trialled with rowers appear as robust as reliability trials using the same exercises but with inexperienced middle aged men (reported ICCs of 0.99, or typical [standard] error of the mean expressed as a CV [log transformed] of 3.3%) (Bell, et al., 1993; Levinger, et al., 2009).

The authors were unable to ascertain the reliability for typical upper and lower body (e.g. leg pressing or arm rowing) repetition endurance tests typically used by rowers from previous literature. It is likely that they are less robust compared with maximal strength assessments, given the need to standardize lifting tempos, test durations and qualitative technical criteria to assess in the determination of test data (i.e. completed repetitions).

Isometric measures of strength endurance of the abdominal core of the body appear reasonably stable, but again, like repetition tests, the duration of the test and qualitative assessment to determine test completion reduce the precision and reliability of the measures with reported ICCs ranged from 0.76 to 0.89 for right and left side static holds over 90 seconds, 0.88 for a spine extension test lasting 2 minutes on average and 0.93 for a spine flexor test lasting almost 3 minutes (Chan, 2005). However, ICCs ranging between 0.97 and 0.99 for the same tests with rowers of similar age, experience and build (height and lean body mass) have also been reported (Tse, et al., 2005).

Validity of strength, power and endurance tests

Strength data, while offering satisfactory precision, needs to be a relevant and valid measure of rowing ability. One form of validity can be inferred when strength significantly differentiates rowers of varying ability (e.g. novice and elite). Alternatively, the validity of strength data can be evaluated using correlation and regression analysis in an attempt to explain variances in rowing performance (e.g. 2000-m ergometer time trial).

The estimation of correlation coefficients is dependent on a number of statistical criteria, namely the assumption of normality, linearity, and homoscedasticity of data and a sample size adequate for the number of variables included in the analysis. Many of the studies reviewed do not report or violate one or all of these assumptions.

This may be of little concern given that the strength of the relationship is often of interest within the unique population selected. However, the risk here is that often these predictor data are used to model performance outcomes and the relationships between data are ignored. At this point, it should be noted that a curvilinear regression between leg extension power (W) and ergometer time (seconds) provided a better fit ($r2 = 41\%$) to the explained variance in rowing performance than linear regression ($r2 = 38\%$) (Yoshiga & Higuchi, 2003a). In practical terms, this may mean relatively small increases in strength are associated with relatively large improvements in rowing performance changes for weaker rowers, whereas, relatively large increases in strength may be associated with comparatively small, although significant, improvements in rowing performance for stronger rowers.

Peak forces (maximal strength)

The earliest tests of strength in rowers used strain gauges to assess isometric muscle forces of body segments at specific joint angles (Hay, 1968; Koutedakis & Sharp, 1986; Secher, 1975). However, these isometric strength tests did not appear in any precise way to discriminate between levels of rowing performance. For example, a simulated rowing position differentiated the strength between world class rowers and national champions and between national champion and senior rowers (Secher, 1975); however, multiple regression analysis found that the rank of a rower for crew selection was weakly explained ($R = 0.577$; $p<0.05$) by isometric strength and experience compared with rowing ergometer trials ($R = 0.895$; $p<0.05$) (Hay, 1968). Furthermore, maximal isometric force did not correlate with power or force production during modified ergometer rowing (albeit small sample sizes) (Peltonen & Rusko, 1993).

Table 2.2 Leg strength assessment and ergometer performance

Study	Strength test	Rowers (n)	Phase, mean strength and ergometer results (± SD)	Main findings
Isoinertial				
Chun-Jung et al. (2007)	45° incline leg press (knee flexion ~90°), Cybex (USA). 1RM (kg)	Non-elite (17)	Non-competitive: *Males (n = 10)* 1RM: 154.6 ± 26.9 kg, 2000 m (C2): 452.2 ± 25.3 sec *Females (n = 7)* 1RM: 130.5 ± 15.3 kg,2000 m (C2): 521.4 ± 19.2 sec	Pooled 1RM (144.7 ± 25.4 kg) correlated with ($r = -0.536$; $p < 0.05$) 2000-m time (481 ± 41.4 sec)
Jürimäe et al. (2010)	45° incline leg press (knee flexion ~90°), unstated manufacturer. 1RM and continuous max. reps with 50% 1RM in 7 min (reps)	Non-elite males (12)	Competitive: 1RM: 252.3 ± 44.3 kg, max. reps: 173.5 ± 11.8 2000 m (C2): 417.2 ± 14.3 sec	Max. reps correlated with 2000-m time ($r = -0.677$; $p < 0.05$), but not 1RM
Kramer et al. (1994)	45° incline leg press (knee flexion ~100°), Champion Barbell Company (USA). 1RM and max. reps at 28 reps/min with 70% 1RM in 7 min (J)	Non-elite females (16), sub-elite females (4)	Non-competitive: 1RM: 172.6 ± 33.0 kg max. reps: 13 932 ± 5335 J 2500 m (C2): 591 ± 41 sec	1RM and max. reps correlated with 2500-m time ($r = -0.57$ and -0.51, respectively; $p < 0.05$)
Isokinetic				
Kramer et al. (1991)	Unilateral leg extension, Kin-Com (USA). Peak and average torque (Nm) of 3 reps at 160 °/sec	Non-elite lightweight males (15)	Competitive: PT: 202 ± 24 Nm AT: 171 ± 19 Nm 2000 m (C2): 412.5 ± 11.5 sec	Oarside significantly stronger than non-oarside (~6%; $p < 0.01$). Poor correlations between oarside and non-oarside strength measures and 2000-m times (ranged from 0.32 to -0.42; $p > 0.05$)

Table continued next page

Table 2.2 continued

Study	Strength test	Rowers (n)	Phase, mean strength and ergometer results (± SD)	Main findings
Kramer et al. (1994)	Unilateral leg extension, Kin-Com (USA) Peak torque at 180°/sec from sum of highest 5 concentric reps for each leg	Non-elite females (16), sub-elite females (4)	Non-competitive : PT: 279 ± 44 Nm 2500 m (C2): 591 ± 41 sec	No significant correlation between isokinetic leg extension with ergometer time (range, $r = -0.27$ to -0.37; $p > 0.05$) Isokinetic strength high correlation with 1RM 45° leg press ($r = 0.75$)
Russell et al. (1998)	Bilateral leg extension, Cybex (USA) Peak torque at 1.05 rad/sec of 3 reps	Sub-elite males (19)	Non-competitive: PT: 268 Nm (SD not stated) 2000 m (C2): 403 ± 16.2 sec	VO_{2max} ($r = -0.43$), body mass ($r = -0.41$) and leg extensor strength ($r = -0.40$) were the major significant ($p < 0.05$) predictors of rowing ergometer performance
Accommodating resistance				
Shimoda et al. (2009)	Horizontal bilateral leg press, Anaeropress (Japan) Peak power (W) from average of best two efforts of 5 trials	Non-elite males (16)	NS PP: 2241 ± 286 W 2000 m (C2): 409.3 ± 12.2 sec	Ergometer time correlated with VO_{2max} ($r = -0.61$; $p = 0.012$), leg press power ($r = -0.68$; $p = 0.004$) and stroke power consistency ($r = 0.69$; $p = 0.003$)
Yoshiga and Higuchi (2003a)	Horizontal bilateral leg press, Anaeropress (Japan) Peak power (W) from average of best two efforts of 5 trials	Non-elite males (332)	NS PP: 2260 ± 367 W 2000 m (C2): 425 ± 20 sec	Ergometer time related to height ($r = -0.48$; $p < 0.001$), body mass ($r = -0.73$; $p < 0.001$), fat-free mass ($r = -0.76$; $p < 0.001$) and leg press power ($r = -0.62$; $p < 0.001$)
Yoshiga and Higuchi (2003b)	Horizontal bilateral leg press, Anaeropress (Japan) Peak power (W) from average of best two efforts of 5 trials	Non-elite males (78)	NS PP: 2300 ± 379 W 2000 m (C2): 426 ± 14.9 sec	Absolute leg press power correlated with ergometer time ($r = -0.52$; $p < 0.001$), but not when expressed relative to bodyweight ($r = -0.21$; $p > 0.05$)

1RM = one-repetition maximum; **AT** = average torque; **C2** = Concept2 rowing ergometer; **max.** = maximum; **NS** = not specified**; PP** = peak power; **PT** = peak torque; **reps** = repetitions.

Dynamic muscle strength and power tests more effectively discriminate between performance abilities (Murphy & Wilson, 1996; Wilson & Murphy, 1996). Highly ranked elite rowers perform better in isokinetic leg strength (Hahn, 1990; Larsson & Forsberg, 1980; Pyke, et al., 1979) and arm cranking power tests (Koutedakis & Sharp, 1986). Those strength tests with superior discriminative ability involve bi-lateral recruitment of large muscle mass, such as the leg press exercise (see Table 2.2). However, maximal dynamic tests involving smaller muscle mass, such as the upper body, provide ambiguous insight into ergometer performance (see Table 2.3).

In reviewing the literature, it was not obvious whether advances in strength testing technology provided any superior precision, reliability or validity of data to rowing performance. In terms of the interrelationships amongst these tests, some researchers found that isokinetic leg strength data were strongly correlated with isoinertial leg strength data ($r = 0.75$; $p<0.05$) (Kramer, et al., 1994). Therefore, either maximal isoinertial leg strength (kg) (Chun-Jung, et al., 2007; Kramer, et al., 1994) or power (W) (Shimoda, et al., 2009; Yoshiga & Higuchi, 2003a, 2003b) or peak isokinetic quadriceps strength data (N) (Kramer, et al., 1994; Russell, et al., 1998) can be used to provide valid physiological measures and predictors of non-elite and sub-elite rowers' ergometer performance. It should be noted that this relationship has not been tested with elite-level rowers.

Table 2.3 Arm strength and ergometer performance

Study	**Strength test (isoinertial)**	**Rowers (n)**	**Phase, mean strength and ergometer results (± SD)**	**Main findings**
Chun-Jung et al. (2007)	Inverted rows performed in a squat rack, MF Athletic Corp. (USA) Max. reps with bodyweight	Non-elite (17)	Non-competitive: *Males (n = 10)* max. reps: 13.9 ± 4.0 2000 m (C2): 452.2 ± 25.3 sec *Females (n = 7)* max. reps: 3.9 ± 3.4 2000 m (C2): 521.4 ± 19.2 sec	Pooled max. reps data (9.8 ± 6.3) correlated with ergometer time ($r = -0.624$; $p < 0.05$)
Jürimäe et al. (2010)	Prone bench pull, unstated manufacturer 1RM and continuous max. reps with 50% 1RM in 7 min	Non-elite males(12)	Competitive: 1RM: 82.0 ± 12.6 kg max. reps: 122.6 ± 17.7 2000 m (C2): 417 ± 14.3 sec	1RM and max. reps not significantly correlated with ergometer time (correlation not reported)
Kramer et al. (1994)	Prone bench pull, Universal Inc. (USA) 1RM and max. reps at 28 reps/min with 70% 1RM in 7 min (J)	Non-elite females (16), sub-elite females (4)	Non-competitive: 1RM: ~48.7 ± 7.1 kg max. reps : 5528 ± 2511 J 2500 m (C2): 591 ± 41 sec	1RM, but not max. reps, significant relationship with ergometer time ($r = -0.52$; $p < 0.05$; and $r -0.25$; $p > 0.05$, respectively)

1RM = one-repetition maximum; **C2** = Concept2 rowing ergometer; **max.** = maximum; **NS** = not specified; **reps** = repetitions.

Acknowledging limitations with single factor performance models (Russell, et al., 1998), the greater strength of elite rowers can in part be attributable to a larger muscle mass (Bourgois, et al., 2001; Bourgois, et al., 2000; Kerr, et al., 2007; Mikulic, 2008, 2009). Along with maximal oxygen uptake, greater lean body mass was a significant attribute of champion elite rowers (Bourgois, et al., 2001; Bourgois, et al., 2000; Kerr, et al., 2007) and strongly correlated with ergometer performance (r = –0.77 to –0.91) (Mikulic, 2009; Yoshiga & Higuchi, 2003b). Maximal strength was also strongly associated with muscle mass and cross-sectional area (r = 0.57 to 0.63) (Clarkson, et al., 1984; Gerdle, Karlsson, Crenshaw, Friden, & Nilsson, 1998; Hagerman & Staron, 1983; Larsson & Forsberg, 1980). It appears likely that a more valid strength test to rowing, targets those body segments more critical to the development of rowing power (i.e. anterior thigh, posterior chain complex and erector spinae muscle groups of the legs and trunk) (Tachibana, et al., 2007).

Sustained forces (strength endurance)

Given a large aerobic energy contribution (approximately 70–85%) in racing 2000-m (Hagerman, 1984; Maestu, Jurimae, & Jurimae, 2005; Shephard, 1998; Steinacker, 1993), it was not surprising that tests of local muscle strength endurance (i.e. repetition endurance tests) have been investigated. Strength endurance has been assessed as the maximum repetitions achieved with a load of approximately 50% of 1RM (Liu, et al., 2000; Liu, et al., 2003; Liu, Lormes, Wang, Reissnecker, & Steinacker, 2004; Simsch, et al., 2002), or calculated from the quantity of work achieved based on distance and repetitions executed using a load of 70% of 1RM (Kramer, et al., 1994; Kramer, et al., 1983). A lifting tempo and time constraint for the test is typical for this type of assessment. However, the number of repetitions completed in these tests remains much less than the number of strokes completed during 2000-m of rowing. These tests also overlook important kinematic data that may prove useful in the analysis of performance differences (e.g. time and velocity of concentric muscle actions). Nonetheless, strength endurance tests using a leg press, report strong to modest correlations with ergometer time ($r = -0.68$ and -0.51 respectively; $p<0.05$) (Jürimäe, et al., 2010; Kramer, et al., 1994).

In contrast, non-significant correlations are associated with upper body repetition tests (e.g. bench pull) and ergometer times (see Table 2.3). Furthermore, a 6-minute bench pull repetition endurance test using a 41 kg load correlated poorly with on-water power during a simulated race (104.8 ±26.75 repetitions; $r = 0.21$, $p>0.05$) (Jensen, et al., 1996). Unlike maximal strength assessments, the validity to rowing performance of upper body repetition endurance test appears questionable. This is somewhat surprising given the logical validity of muscle endurance testing to endurance performance and warrants discussion.

The number of repetitions completed using a set percentage of 1RM varies according to the quantity of muscle groups utilized as well as the training history and sex of the rower (Douris, et al., 2006; Hoeger, Barette, Hale, & Hopkins, 1987; Hoeger, Hopkins, Barette, & Hale, 1990). At an equal percentage of maximal ability, the number of repetitions attained with an upper body activity will be lower than that of a lower body activity. Jurimae et al. (2010) found that the number of repetitions performed in leg pressing at 50% 1RM was closer (repetitions = 173.5 ±11.8) to the number of average strokes taken to complete a 2000-m time trial ($n = 194.2 \pm 19.5$) than bench pulling (repetitions = 122.6 ±17.7) at 50% 1RM, thus explaining the significant and strong correlations found for leg pressing. Arguably, a lower percentage of 1RM was required for bench pulling; however, such a contention remains untested. It may be that repetition endurance tests, whether isokinetic or isoinertial, provide data better used to differentiate training experience and muscle morphology. That is, at a fixed percentage of 1RM, individuals with greater endurance training experience, proportions and hypertrophy of slow-twitch fibres perform a greater number of repetitions at sub-maximal loads (Desgorces, Berthelot, Dietrich, & Testa, 2010; Douris, et al., 2006; Gerdle, et al., 1998; Lindstrom, Lexell, Gerdle, & Downham, 1997). Internationally, successful rowers have significantly greater proportions (e.g. 70% to 85%) and hypertrophy of slow-twitch fibres of the quadriceps muscle than lesser ranked national rowers (e.g. 66.1%) (Clarkson, et al., 1984; Hagerman, 1984; Larsson & Forsberg, 1980; Steinacker, 1993) and, subsequently, perform better in repetition endurance tests of the legs (Clarkson, et al., 1984; Hagerman, 1984). Whereas relatively similar variances in rowing performance may be shared with repetition endurance tests involving the legs, given a relatively smaller muscle mass and limited contribution to rowing power (Kleshnev & Kleshnev, 1998; Tachibana, et al., 2007), it would appear repetition endurance tests of the arms have little common variance with rowing performance.

Scaling of strength and endurance data

To account for differences in body size (height and weight), it is common practice to normalize data by dividing the result by body mass (also known as ratio scaling) or by first raising body mass using a power exponent based on the theory of geometric symmetry (known as allometric scaling) (Crewther, Gill, Weatherby, & Lowe, 2009;

Jaric, Mirkov, & Markovic, 2005; Nevill & Holder, 1995). Ratio and allometric scaling of strength data reduces observed differences between males and females or between elite athletes in participating in endurance sports. When allometric scaling was used to normalize ergometer 2000-m times, the resultant data provided a stronger model to predict on-water performance (Nevill, et al., 2010). To our knowledge, neither ratio nor allometric scaling of strength data have been used to examine relationships with on-water performance. Given somatotype differences (Bourgois, et al., 2001; Bourgois, et al., 2000; Kerr, et al., 2007) and body mass constraints, allometric or ratio scaling of strength data might prospectively explain variances in on-water performances between heavyweight and lightweight, male and female, or novice and elite rowers.

Alternative applications of strength testing

Apart from quantifying the physiological capacity of a rower, strength testing has also proved useful for the refinement of an optimal rowing technique. For example, past isometric strength testing established that the strongest rowing action was one where the elbows were kept at 180 degrees during the leg driving phase, and where the arms were adducted and hands held at umbilicus height during the arm pulling phase of the rowing stroke (Bompa, 1980). Such strength tests may also prove useful as feedback to assist a rower to establish and refine their rowing technique.

Strength tests may also provide data that is equally useful for evaluating musculo-skeletal conditions associated with pain or injury when rowing. For example, non-elite rowers with poor hamstring strength relative to the extensor muscles of the knee (e.g. ratio less than 45%) reported more frequent occurrences of low back pain affecting their participation in rowing (Koutedakis, et al., 1997). Sub-elite rowers with a past rib-stress fracture occurrence were found to have lower knee extensor to elbow flexor strength ratios (i.e. 4.2 ±0.22 to 1) when matched to non-injured controls (i.e. 4.8 ±0.16 to 1; $p<0.05$) (Vinther, et al., 2006). In addition, elite rowers were reported to have greater strength and better symmetry (i.e. 1 : 1 ratios) between trunk flexor and extensors than weaker control non-rowers, more akin to the imbalances observed in low back pain populations (McGregor, Anderton, & Gedroyc, 2002). The asymmetry of muscle development and strength associated with pain pathology, particularly of the legs and back observed in novice rowers, may be attributable to the asymmetrical rotation of trunk during the sweep-oar rowing technique (Parkin, Nowicky, Rutherford, & McGregor, 2001). For example, unilateral strength tests show that the oarside leg of non-elite lightweight oarsmen was significantly stronger (around 6%; $p<0.05$) than the non-oarside leg (Kramer, et al., 1991); however, such differences were not observed amongst more experienced sub-elite oarsmen (Parkin, et al., 2001). It may therefore be that the interpretation of strength test data and the utilization of subsequent musculo-skeletal interventions differ between novice and elite rowers.

The effects of strength training on rowing performance

This review thus far has highlighted that muscle strength data significantly explains much of the variance in ergometer performance. Therefore, the efficacy of various strength training interventions on rowing performance warranted investigation. The purpose of this section is to examine whether strength training offers any benefits or performance edge over and above that attainable by rowing itself.

Strength training improves muscle function by inducing neuromuscular adaptations (e.g. improved muscle recruitment, rate and synchronicity of fibre contractions) with long-term benefits ultimately attributable to (selective) hypertrophy of muscle fibres, vascular proliferation and expansion of energy substrates within the muscle (Campos, et al., 2002). In terms of increasing maximal strength, RM loading ranging from 1–12RM for up to three to four sessions a week, are thought optimal loading parameters for intermediate training (individuals with 6 months of consistent exercise history) (Kraemer, et al., 2002). More frequent strength training may be required for experienced athletes (up to 6 days each week) where muscle-group training is divided over two sessions in order to limit the total duration of exercise as training volumes approach up to eight sets for each muscle group (Peterson, Rhea, & Alvar, 2004). The acute training objective is to progressively increase the intensity of the exercise (determined as a proportion of maximum ability), rather than increase the volume of repetitions to increase muscle fatigue (Drinkwater, et al., 2007). Indeed, strategies to reduce fatigue significantly increase the rate of muscle work (i.e. power), thus, improve the quality of training and rate of muscular adaptation (Izquierdo-Gabarren, Expasito, deVillarreal, & Izquierdo, 2010; Lawton, Cronin, Drinkwater, Lindsell, & Pyne, 2004).

There is some contention about the efficacy and utility of various strength training modalities, particularly for advanced endurance athletes. Concurrent maximal strength and aerobic endurance training appears counterproductive to strength development (Bell, Syrotuik, Martin, & Burnham, 2000). It has been proposed that the acute fatigue of muscle fibres from endurance training compromises the intensity of the training required for strength development. It was also proposed that adaptations induced at the muscle level from endurance exercise are antagonistic to the hypertrophy response required to optimize strength [for reviews see Docherty and Sporer (2000) and Leveritt et al. (1999)]. From this literature, it seems that the successful integration of strength training may be difficult for endurance athletes. However, short-term resistance strength training interventions (e.g. 5–10 weeks) with highly trained endurance cyclists and distance runners provided evidence that a performance edge was gained when units of strength training were scheduled in place of, and not in addition to, endurance exercise (Yamamoto, et al., 2010; Yamamoto, et al., 2008).

If it is decided that strength training is to be utilized in an athlete's preparation, a rower's first challenge is to decide how to successfully integrate and sequence endurance and strength training units. Irrespective of whether the objective is to build or maintain maximal strength, strength training should be scheduled after a rower has had opportunity to recover. Any preceding endurance exercise should consist of low-intensity continuous exercise, avoiding the use of the glycolytic energy system (De Souza, et al., 2007). However, often time constraints mean this may not be practicable. Therefore, an alternative integration strategy is to sequence phases of physiological preparation (known as periodization) and to prioritize strength training during the non-competition phase (Bell, Petersen, Quinney, & Wenger, 1988; Bell, Petersen, Wessel, Bagnall, & Quinney, 1991). A typical prioritized strength phase ranged between 9 and 10 weeks (refer Table 2.4). On average, a little less than 5 hours of endurance exercise was scheduled, distributed over three to four sessions each week. Strength training was normally performed on alternate days to the endurance exercise, with between two and four sessions scheduled each week. Such periodised training sequences allowed non-elite and sub-elite rowers to achieve significant average weekly strength gains of around 2.5% a week (duManoir, et al., 2007; Haykowsky, et al., 1998; Kennedy & Bell, 2003;

Kramer, et al., 1983; Syrotuik, et al., 2001; Webster, et al., 2006). At the end of the training phase, significant improvements in 2000-m ergometer performance times were also reported (Table 2.4). However, as noted in the 'evaluation of the quality of the current evidence base' (section 3), the reader needs to be aware of the limitations of research in this area. That is, it is inconclusive whether any performance edge was attributable to strength gains in examination of the standardized effect sizes due to the absence of any control groups or crossover research designs. Nonetheless, emphasizing strength training over an off–season would appear to be an effective strategy to promote strength development without loss of endurance or performance gains.

After a period of prioritization over the off–season, a rower may have little time or sufficient energy to commit to further strength gains. General strength training might be ceased and replaced with specific on-water practices such as towing ropes to increases boat drag, thus providing resistance to promote muscle strength. To our knowledge, there is no evidence regarding the efficacy of such strategies.

Table 2.4 Intervention studies involving strength testing, training and rowing performance

Study	Rowers level; sex (n); age; height; weight [a,b]	Phase and strength training intervention	Strength tests and rowing performance assessment[c]	Main findings
Bell et al. (1993)	Non-elite; F (20); 20.4 ± 1.5 y; 170.7 ± 9 cm; 64.9 ± 8.8 kg	Non-competitive: 10 wk concurrent strength (~4–5 sets × ~6 reps at 64–81% 1RM, 3 d) and ergometer endurance training (<2 h/wk). Then, for 6 wk, group 1 performed one strength session each wk (~3–4 × ~6 reps at 73–79% 1RM) while group 2 performed two strength sessions each wk as endurance training steadily increased (<4 h/wk, 4 d). Descriptive study, no control group for strength intervention	Pre- and post-tests used to calculate total load (i.e. weight × reps) based on 6–11RM for all strength exercises prescribed (e.g. inclined leg press, data not stated Change in 7-min row power (Gjessing Ergorow, Oslo Norway) Average power:176.7 ± 26.6 W	After 10 wk, strength increased for all exercises ($p < 0.05$, ES not calculated) as did average power for 7-min rowing ergometer test (ES = 0.51, $p < 0.05$) Inclined leg press strength results were maintained for a further 6-wk phase whether one or two sessions a week at sufficient intensity (e.g. 73–79% 1RM) were performed (ES not calculated)
duManoir et al. (2007)	Non-elite; M (10); 31.2 ± 12.1 y; 184.4 ± 4 cm; 79.2 ± 9.0 kg	Non-competitive: 10 wk concurrent strength (2–6 sets × 4–10 reps, 3 d) and endurance training (<4 h/wk, 3 d). Descriptive study, no control group for strength intervention	Pre- and post-strength tests: 1RM 45° leg press (90° knee flexion): 339.2 ± 44.4 kg Change 2000 m (C2) time: 436.1 ± 18.2 sec	Significant improvements ($p < 0.05$) in 1RM leg press (2.83% per wk, ES = 1.14) and 2000 m time (20.7 sec faster, ES = 0.67).
Ebben et al. (2004)	Non-elite and sub-elite; F (26); 20.0 ± 1.0 y; 170.0 ± 6 cm; 71.0 ± 7.0 kg	Non-competitive: 8 wk concurrent high load (3 × 12–5RM) or high rep (2 × 15–32RM) strength (3 d) and endurance training.[d] Descriptive study, no control group for strength intervention	No strength tests: average total volume (i.e. kg × reps) calculated for all strength exercises prescribed Change 2000 m (C2) time: non-elite: 509 ± 26 sec; sub-elite: 476 ± 19 sec[e]	Average total volume for strength cycle was 105 003 kg for high rep and 84 744 kg for high load. Both high load and high-rep groups improved 2000 m time regardless of strength protocol ($p < 0.001$; ES = 0.36–0.35 and 0.60–0.20, respectively) Greater positive effects noted for

Study	Rowers level; sex (n); age; height; weight [a,b]	Phase and strength training intervention	Strength tests and rowing performance assessment[c]	Main findings
				high-rep training for non-elite and high load for sub-elite (ES not stated).
Gallagher et al. (2010)	Non-elite; M (18); 20.2 ± 0.87 y; 188.0 ± 8 cm; 82.4 ± 33.3 kg	Non-competitive: 8 wk concurrent strength (2 d) and endurance training (<2 h, 2 d), as well as regular on-water training.[d] Intervention design for high rep (2–3 sets × 15–30RM) or high load (3–5 sets × 1–5RM) strength training with control group (no strength training, but 2 h less training each week)	No strength tests: Change in total volume (i.e. kg × reps) calculated for all strength exercises prescribed Change 2000 m (C2) time: control 418.3 ± 5.4 high rep 386.2 ± 4.4 high load 403.3 ± 4.7	High rep increased total volume by 9.44% and high load by 2.02% All 2000 m times improved, however, no differences between control, high rep and high load ($p < 0.96$, ES = 3.28, 2.48 and 2.22 respectively). However, practical significance of improvements between high load (3.5% or 15 sec), high rep (3.1% or 12 sec) and control (2.8% or 11 sec) argued to equal one boat-length over 2000 m
Haykowsky et al. (1998)	Non-elite rowers (n = 25) M (8); 23.0 ± 6.1 y; 1.83 ± 8 cm; 78.1 ± 12.5 kg F (17); 22.7 ± 5.0 y;170.6 ± 8 cm; 65.8 ± 9.8 kg	Non-competitive: 10 wk concurrent strength (3–6 sets × 2–6 reps, 2 d) and endurance (<5 h/wk, 4 d) training. Descriptive study, no control group for strength intervention	Pre- and post-strength tests: average group 1RM 45° leg press (90° knee flexion): 306.0 ± 58.0 kg Average group change 2500 m (C2) time: 577.0 ± 34.7 sec	Significant ($p < 0.05$) improvement in 1RM leg press (2.76% per wk, ES = 1.50) and 2500 m time (20.3 sec faster, ES = 0.50)
Kennedy et al. (2003)	Non-elite rowers (n = 38) M (19); 25.1 ± 4.8 y; 179.8 ± 7cm; 79.3 ± 8.2 kg F (19); 25.2 ± 4.6 y; 169.2 ± 6 cm; 68.0	Non-competitive: 10 wk concurrent strength (2–6 sets × 4–12 reps, 2 d) and endurance (<4 h/wk, 4 d) training. Descriptive study, no control group for strength intervention	Pre- and post-strength tests: estimated 1RM 45° leg press (90° knee flexion): M 347.8 ± 57.9 kg, F 186.5 ± 50.5 kg Change 2000 m (C2) time: M 426.3 ± 20.0 sec, F 495.9 ± 29.7 sec	Significant improvement ($p < 0.05$) in estimated 1RM (M 1.60% per wk, ES = 1.11 and F 2.28% per wk, ES = 0.61) and 2000 m time (M 31.8 sec faster, ES = 1.04, and F 43.5 sec faster, ES = 1.03)

Study	Rowers level; sex (n); age; height; weight [a,b]	Phase and strength training intervention	Strength tests and rowing performance assessment[c]	Main findings
	± 11.5 kg			
Kramer et al. (1983)	Sub-elite and non-elite; F (24); 19.3 ± 1.0 y; 180 ± 10 cm; 75.0 ± 6.0 kg	Non-competitive: 9 wk concurrent endurance (<4 h/wk, 4 d) and strength (3–5 sets × 4–12 reps, 3 d) or strength with plyometric training (i.e. plus 80–310 jumps). Intervention design for plyometric training with control group	Pre- and post-strength tests: 1RM 45° leg press (100° knee flexion): control 164.2 ± 24.9 kg, plyometric 162.4 ± 36.1 kg Change 2500 m (C2) time: control 606 ± 48 sec, plyometric 614 ± 61 sec	Both control and plyometric groups improved strength ($p < 0.01$; 1.61% per wk, ES = 0.57 and 1.66% per wk, ES = 0.90, respectively) and 2500 m time ($p < 0.05$; 19 sec faster, ES = 0.40 and 22 sec faster, ES = 0.33, respectively) but no differences in change due to plyometric training ($p > 0.05$)
Syrotuik et al. (2001)	Non-elite rowers (n = 22); M (12), F (10); 23.0 y; 176.3 m; 76.8 kg[f]	Non-competitive: 9 wk concurrent strength (3–4 sets × 10RM, 2 d) and endurance training (31–37 km/wk, dispersed over 4 d). Intervention design for creatine monohydrate supplementation with control group. No control for descriptive strength intervention	Pre- and post-strength tests: estimated 1RM 45° leg press (90° knee flexion), creatine 337.7 ± 96.4 kg Control 300.9 ± 100 kg Change 2000 m (C2) time: creatine 458.2 ± 42.4 sec, control 461.4 ± 38.2 sec	Both creatine and control groups improved ($p < 0.05$) estimated 1RM strength (3.37% per wk, ES = 1.23 and 2.04% per wk, ES = 0.59) and 2000-m time (18.2 sec faster, ES = 0.39 and 15.3 sec faster, ES = 0.33, respectively) Creatine no beneficial effect on either test measures ($p > 0.05$)
Tse et al. (2005)	Non-elite; M (34); 20.1 ± 1.0 y; 175 ± 6 cm; 67.3 ± 5.8 kg	Competitive: Concurrent strength (2 sets × 12–15 reps, 2 d) and endurance training.[d] Intervention design for abdominal core training (n = 14) of 30–40 min of muscle transverse abdominus activation endurance (2 d), with control group (n = 20)	Pre- and post-strength tests: isometric abdominal endurance test (60° flexion): control 215.5 ± 62.7 sec, core 176.2 ± 48.9 sec Change in 2000 m (C2) time: control 442.1 ± 9.5 sec, core 452.4 ± 9.8 sec	After 8 wk, no improvement ($p > 0.05$) in isometric abdominal endurance test for either control or core training groups (ES = 0.09 and 0.16, respectively) nor 2000-m time (1.4 sec faster, ES = 0.13 and 2.1 sec faster, ES = 0.18, respectively) Programme too short, tests too unrefined and improvements in incident rate of low back pain overlooked

Study	Rowers level; sex (n); age; height; weight [a,b]	Phase and strength training intervention	Strength tests and rowing performance assessment[c]	Main findings
Webster et al. (2006)	Non-elite rowers (n = 31) M (12); 21.3 ± 2.7 y; 184.3 ± 6.6 cm; 81.5 ± 7.8 kg F (19); 22.8 ± 5.8 y; 173.4 ± 7.2 cm; 70.9 ± 9.7 kg	Non-competitive: 8 wk concurrent strength (2–6 sets × 4–12 reps, 2 d) and endurance (<4 h/wk, 4 d) training; descriptive study, no control group for strength intervention	Pre- and post-strength tests: 1RM 45° leg press (90° knee flexion): M 274.3 ± 80.7 kg, F 172.8 ± 49.0 kg Change 2000 m (C2) time: M 444.8 ± 29.7 sec, F 501.3 ± 32.0 sec	All rowers significantly ($p < 0.05$) increased strength (1.8% per wk, ES = 0.55) and 2000 m time (22 sec faster, ES = 0.65). Duration (i.e. time) and not sex positively affect performance

[a] Sample only (refer to original paper for further details).

[b] Mean ± SD unless otherwise stated.

[c] All data is post-testing.

[d] Load not stated.

[e] Significant difference ($p = 0.002$).

[f] Data for the Syrotuik et al. (2001) study are presented in mean values.

C2 = Concept2 rowing ergometer; **ES** = effect size (pre-, post-test data/SD pre-test data); **F** = female; **M** = male; **max.** = maximum; **RM** = repetition maximum; **rep(s)** = repetition(s).

What is apparent from the literature is that intensive on-water training is unlikely to achieve the mechanical, metabolic and hormonal stimuli required to maintain maximal strength. For example, the isokinetic leg strength of elite oarsmen declined 12–16% by the end of a competition period once strength training was ceased (Hagerman & Staron, 1983). In contrast, at sufficient intensity (i.e. 73.0–79.3% of predicted 1RM), oarswomen were able to maintain maximal strength over a 6-week competition period whether one or two resistance sessions were performed each week (Bell, et al., 1993). Therefore, some element of off-water strength training to maintain maximal strength appears warranted all year round.

An alternative periodization model was to shift the off-season emphasis from maximal strength to local muscle endurance adaptation as a competition phase approaches. Lighter loads (i.e. 40-60% 1RM) coupled with higher repetitions (i.e. ≥15) lead to greater local endurance adaptation, without significant muscle hypertrophy (Campos, et al., 2002). Such adaptations may be preferable for lightweight rowers who need to be cautious of excessive body mass. Local muscle endurance training provides a suitable complement or substitute for endurance rowing, particularly for unskilled novice or injured rowers as very high repetition bench pull and leg press exercise at low intensities (e.g. 50 to 125 repetitions using a 40% of 1RM load) developed blood lactate levels ranging between 6.9±2.2 mmol/L and up to 11.2–11.8±2.5-2.3 mmol/L, respectively (Jürimäe, et al., 2010; Liu, et al., 2004; Simsch, et al., 2002), with mean and peak heart-rate responses ($r = 0.71$–0.77; $p<0.05$), and perceived exertion ($r = 0.76$; $p<0.05$) of leg pressing comparable to 2000-m ergometer rowing (Jürimäe, et al., 2010). After 10 weeks, concurrent strength training and endurance exercise increased left ventricle diastole (10.6%), wall thickness (11.3%) and mass (17.5%), which was contended to be a unique and plausibly favourable anatomical adaption of the heart amongst rowing populations (duManoir, et al., 2007; Haykowsky, et al., 1998).

The effects of maximal strength and local muscle endurance exercise on 2000-m ergometer performance has been compared using novice and sub-elite rowers over 8 weeks of non-competition phase training (Ebben, et al., 2004; Gallagher, et al., 2010). Maximal strength training has consisted of 12RM loads, which were progressively increased to heavier 5RM loads (Ebben, et al., 2004), or 5RM loads, which were progressively increased to sets varying in load between 1RM and 5RM (Gallagher, et al., 2010). In contrast, strength endurance training utilized loads ranging between 15RM and 32RM. Ebben et al. (2004) concluded that rowers with more training experience achieved a greater benefit from maximal strength training, while novice rowers benefited more from strength endurance training; however, the lack of control group or crossover research designs again makes the interpretation of effect sizes and application of findings problematic (see Tables 2.1 and 2.4). Gallagher et al. (2010) found that no significant short-term performance improvements were gained from the inclusion of either low- or high-load strength training, nor were any detrimental outcomes observed when compared with endurance only controls. However, a lack of statistical power (low subject numbers), imprecise assessment of changes in strength and strength endurance, and unequal training volumes between control and intervention groups (extra 2 hours exercise per week) again make the interpretation of effect sizes difficult (see Tables 2.1 and 2.4). Although not statistically significant, the practical significance of the short-term differences in performance improvements between groups (i.e. high load 3.5% or

15 seconds faster; low load 3.1% or 12 seconds faster, and control 2.8% or 11 seconds faster) were noteworthy and equivalent to almost a boat length over a 2000-m race. Nonetheless, longer-term interventions are required to clarify any beneficial prescription of strength training methods and performance outcomes between novice and elite rowers.

To date, strength training research has primarily focused on the effect of maximal strength training on rowing performance. However, explosive power exercise may be more relevant over the competition phase when peak physical fitness performance needs are tuned to the specifics of racing. Compared with off-season maximal strength training, lighter isoinertial loads used for local muscle endurance exercise (40–60% of 1RM) enables the attainment of a faster movement velocity during exercise. While isokinetic strength training gains are specific to the velocity with which training is performed (Bell, Petersen, Arthur Quinney, & Wenger, 1989), moderate and fast velocities with isoinertial loads enhance both strength and motor performance gains more effectively (Kraemer, et al., 2002).

Significant performance benefits from the integration of short-term explosive low-fatigue strength exercise have been reported for highly trained endurance cyclists (e.g. 8.7% increase in 1 km power and 8.1% increase in 4 km power (Paton & Hopkins, 2005) and 7.1% increase in average power over a 1-hour time-trial performance (Bastiaans, Diemen, Veneberg, & Jeukendrup, 2001) and middle-distance runners (e.g. improved running economy ranging from 4.1–8.1% (Yamamoto, et al., 2008). Izquierdo-Gabarren et al. (2010) also found that by reducing the volume of strength exercise (i.e. five repetitions at 75% 1RM) to eliminate fatigue and sustain greater movement velocity, greater strength and power gains were realized than when repetition failure occurred (i.e. ten repetitions at 75% 1RM). Furthermore, significantly greater improvements in average power over ten strokes (3.6–5.0% gain) and 20 minutes (7.6 – 9.0% gain) were achieved during fixed seat ergometer rowing (Concept2 ltd., model D, Morrisville, VT, USA) for the non-fatigue exercise group compared with traditional strength training and control groups.

There is a paucity of research, however, that has examined the effects of explosive power training on rowing performance. Neither sub-elite nor novice rowers achieved any additional performance advantage over traditional strength training after 9 weeks of lower body plyometric training was incorporated into the training programme (Kramer, et al., 1983). Again, the findings of this research are problematic as total training volumes were not equivalent between groups and overtraining may have negated any ergometer performance benefits attributable to the addition of explosive leg exercise.

Strength Training and Rowing Injuries

As mentioned previously in 'alternative applications of strength testing' (section 7.4), strength testing may provide a means to assess musculo-skeletal conditions commonly associated with rowing. Most injuries associated with rowing appear to be related to chronic overuse syndromes affecting soft tissues of the lower back, shoulders, knees and wrists (Hagerman, 1984). However, a less than desirable rowing technique, such as increased posterior tilt during the leg drive action or excessive flexion and rotation of the thoracic spine at the catch (McGregor, Bull, & Byng-Maddick, 2004), may lead to imbalances in muscle development and an associated increase in pain or injury.

While acknowledging limitations with past research, strength training has been used to correct muscle imbalances, which, in specific cases, appeared useful in the reduction of pain associated with rowing. For example, the number of training days lost due to low back pain was reduced once the relatively excessive quadriceps strength (i.e. a knee flexion to extension ratio less than 45%) was addressed by a specific hamstring strengthening programme over 6–8 months (Koutedakis, et al., 1997). In addition, 8 weeks of specific strengthening of the deep abdominal and low back stabilizers of the pelvis and spine, while having no effect on rowing performance, purportedly reduced the incidence of painful rowing for those rowers with a history of low back pain (Tse, et al., 2005). However, it was unclear whether changes in muscle imbalances led to a subsequent improvement in rowing technique, or whether similar outcomes could have been achieved by allocating an equivalent time to practice of a revised rowing technique.

Future Research

On the basis of the evidence reviewed, the clinical relevance and practical significance of positive benefits associated with various strength training modalities cannot be ignored. Importantly, no negative performance outcomes were attributed to the inclusion of various strength-training protocols. However, while the integration of strength training appeared relatively simple, there was an absence of research that clarified the type of overload stimulus required for each distinct phase of preparation of the competition year (i.e. non-competition or competition phase) that was of relevance to various divisions (light or heavyweight), and experience levels (novice or elite). Additionally, few definitive recommendations could be made with respect to essential programme variables of strength programme design. For example, it was unclear what rowing performance advantages were gained when three or more strength sessions a week were integrated over a training phase, whether changes in 2000-m times were attributable to lower or upper body strength development, or in emphasizing one over the other, or whether any particular exercises such as the lateral pulldown, shoulder press or dead-lifts were potentially more beneficial than others. What was apparent was that year-round monitoring, as part of longer–term investigations, rather than intermittent episodic interventions of <10 weeks, was required to better understand performance benefits attributable to various strength-training protocols. Of note, such benefits should be examined in the context of models that incorporate on-water performance data (e.g. 2000-m times or rank of rower) if limitations to the reliability and precision of such data can be overcome.

Conclusions

While strength explained much of the variances in 2000-m ergometer performance and muscle balance assessments derived from strength data appeared useful in the pathological assessment of low back pain or rib injury history associated with competitive rowing, the clinical and practical significance of positive benefits associated with strength training lacked statistical significance, primarily due to an absence of quality long-term controlled experimental research designs.

Chapter 3 – Strength tests for elite rowers: low or high repetition?

Prelude

Champion rowers are stronger than their less successful peers, regardless of the mode of strength testing implemented. Therefore, there does not appear to be any strong reason(s) for rowers to engage in laboratory based isometric or isokinetic testing requiring sophisticated sensors, processor technology, or dynamometers. Indeed, if the purpose of testing is to assist with the setting of (individual) weight-training parameters, there may be advantages to assessments performed in the same mode and field-setting as training. For example, coaches could evaluate individual progress against specific benchmarks for strength in exercises used for circuit or weight-training, and these benchmarks could be based on the achievements of past successful rowers. Given a strong relationship between 2000-m rowing performance and aerobic power, it is not surprising that rowers may perform high-repetition weight training and testing to develop and to assess (local) muscular–endurance. However, while the logical validity of such assessments are appealing, it is unclear whether the protocols used in the determination of high–repetition strength testing data are reliable or even appropriate assessments for rowers. If high–repetition testing proves unreliable, then benchmarks set for muscular–endurance exercise or research utilising such assessments may be constrained by measurement error. Subsequently, the purpose of this study was to determine the reliability of testing strength over a range of low– and high–repetition maximums, using the leg press and arm rowing exercise.

Introduction

Strength testing and training appears relatively ingrained as part of the physical preparation plans of rowers (Gee, Olsen, Berger, Golby, & Thompson, 2011). However, the efficacy and benefits in performance from incorporating various low– and high–repetition strength–training protocols into the training plans of rowers, remains unclear (Bell, et al., 1989; Ebben, et al., 2004; Gallagher, et al., 2010). In part, we believe this has been due to a lack of consideration in past study designs with respect to the specificity and precision of measures used to assess strength–training and associated muscle adaptations.

Previous research in this area constrained strength–training assessments to simple and convenient measures, reporting changes in specific repetition maximums (RM) for each group (Bell, et al., 1989; Ebben, et al., 2004; Gallagher, et al., 2010). However, investigations based on maximal strength data (1RM) have been proven to inadequately evaluate small worthwhile changes in muscular–endurance (30RM or 120RM) and vice versa (Campos, et al., 2002). Including tests that are sensitive to changes in strength and/or muscular endurance is important in rowing, as periodised training plans may seek to sequence strength, muscular–endurance and aerobic power adaptations over successive training phases (Bell, et al., 1991; Bell, et al., 2000). Profiling strength over a range of repetition maximums (e.g. 5RM, 30RM, 60RM and 120RM) may improve the ability to monitor changes in the strength quality of interest following specific interventions, to identify performance differences of interest, both in cross–sectional and longitudinal analysis of data (Reilly, Morris, & Whyte, 2009).

While isometric and isokinetic dynamometry has been utilised (Bell, et al., 1988; Kramer, 1990; Riganas, Vrabas, Papaevangelou, & Mandroukas, 2010; Russell, et al., 1998), strength has been more commonly assessed using weights (i.e. isoinertial exercise) because they offered simple, affordable and practical field assessments of muscle performance, and were easily administered within the weekly training schedule of rowers (Ebben, et al., 2004; Gallagher, et al., 2010; Kramer, et al., 1994). Most strength assessments have involved leg pressing and arm pulling actions (Lawton, et al., 2011). For example, muscular–endurance has been assessed as the maximum repetitions accrued during leg pressing and prone bench pull exercise, with a load at either a fixed percentage of maximum such as 50–70% 1RM (Jürimäe, et al., 2010; Kramer, et al., 1994), or a set absolute load such as a 40 kg in the case of bench pull (Jensen, et al., 1996). A lifting tempo and time constraint for the test is typical for this type of assessment. Furthermore, given differences in muscle mass and qualitative criteria regarding the tempo of exercise, we suspect large systemic measurement errors are associated with the participants' familiarity, learning, fitness or motivation to perform these assessment protocols (Desgorces, et al., 2010; Douris, et al., 2006; Hoeger, et al., 1990; Levinger, et al., 2009; Ritti-Dias, Avelar, Salvador, & Cyrino, 2011; Shimano, et al., 2006). However, such data has not been reported and meaningful changes may have gone undetected if these assessments were neither reliable nor sensitive to small worthwhile differences in muscular–endurance.

Isoinertial tests do not offer the most practical mode for the assessment of strength over a wide continuum of specific repetition maximums (e.g. 5RM, 30RM, 60RM or 120RM), given a trial and error approach to load selection. These tests also overlook important kinematic data, such as displacement and velocity of concentric muscle actions, which may prove useful in the analysis of upper–body performance differences (Cronin, et al., 2007). Rowers may also be concerned about the possibility of (temporary) rowing performance losses and the risk of injury perceived with muscle soreness (Gee, French, et al., 2011) with such assessments. A desirable alternative would measure force and displacement for each repetition similar to isokinetic dynamometry, but instead involve simple, portable, low–cost field based equipment to provide the opportunity to administer tests easily across a broad range of groups with diverse training experiences. The Dynamic Strength Training dynamometer (DYNO, Concept 2 Inc.; Morrisville, USA) provides an accommodating drag–inertia resistance and quantifies average repetition work during concentric only leg pressing and seated arm pulling exercise. The dynamometer has been used to assess rowers in a field setting (Gee, Olsen, et al., 2011), and apart from minimizing soreness, provides a similar leg driving action and drag–inertia encountered during rowing ergometry. Furthermore the dynamometer allows for practical administration to assess strength using a variety of repetition maximums. Subsequently, the purpose of this study was to evaluate the utility of low– and high–repetition tests used to assess rowers.

Methods

Study Design

We analysed within–subject and between–subject variations from repeated–measures data to establish the utility of low– (5RM) and high–repetition (30RM, 60RM and 120RM) tests used to monitor and to assess strength–training. The absolute consistency (percent typical error) and relative consistency (intra–class correlation – ICC) of the tests were determined using leg press and seated arm pull exercise. Over a nine day non–competition training cycle, the National Centre for Rowing Excellence assigned six normally scheduled weight–training sessions (approximately 90 minutes duration) for data collection. On each test occasion, the same rowers and assessors were involved. Participants performed eight tests in total (i.e. 4 x leg press and 4 x seated arm pulls). Subsequently, to eliminate any potentially negative impact from fatigue or pressure to meet time constraints associated with procedures, the 5RM, 30RM and 60RM tests (i.e. 3 x leg press and 3 x seated arm pull exercise) were scheduled on day one, and repeated on days four and day eight. The 120RM tests (i.e. 1 x leg press and 1 x seated arm pulls) were performed on day two, and repeated on days five and day nine. Testing was repeated at the same time of day. A common on– and off–water endurance training program was performed and rowers maintained a similar diet monitored for the duration of the study.

Participants

Twenty elite male heavyweight rowers elected to participate in this project, the testing conducted in the "off–season" (October). These rowers had recently competed in 'A–finals' at World Rowing Championships, and included 16 gold and three bronze medallists. The group ranged in age from 19 to 33 years (average age 23.7 ± 4.0 years), with rowing experiences ranging between 4 and 17 years (average experience 8.7 ± 4.2 years). Institutional review board approval was granted, in the spirit of the Helsinki Declaration and voluntary signed informed consent was attained after rowers attended project information and familiarisation seminars. Rowers who were cleared by medical staff for participation in regular weight–training were allowed to test.

Equipment

A “Dynamic Strength Training” dynamometer (DYNO, Concept 2 Inc.; Morrisville, USA) was used to measure average concentric work produced during leg pressing (lower–body) and seated arm pulling (upper–body) exercise. The dynamometer provides accommodating resistance by flywheel fan inertia combined with air–braking to create drag, comparable in design to a Concept 2 rowing ergometer. A processor chip in the dynamometer console uses changes in flywheel fan motion (acceleration and velocity), measured by a magnetic position transducer, to calculate work (J) each repetition. Since the moment of inertia of the flywheel calibrated at the factory is a known constant, the console calculates the component of work to overcome air–drag as a function of the speed of the flywheel and the air–drag coefficient (or 'load'). The air–drag coefficient is determined at the completion of each repetition from the deceleration of the flywheel. A greater air–drag coefficient setting means that amount of air passing through the flywheel is greater, and therefore the load. For all rowers the load was set at 120 with two air dampeners opened for leg pressing, and at 100 with all dampeners closed for the seated arm pulling. A console displayed the elapsed time and information about the cadence and work performed on completion of each repetition. Ten seconds after the completion of each test, the dynamometer console produced a summary of the average work per repetition. These data were recorded as the test result.

Exercises

Participants adjusted the set–up of leg press and seated arm pulling exercise (or bench pull) exercise on the dynamometer before testing (http://concept2.co.uk/dyno/exercises). To set–up leg press exercise, participants strapped their feet into an adjustable foot–stretcher, kept their back against a seat–rest, and held onto seat handles. Participants commenced the exercise from a flexed leg position (i.e. the shin was vertical to floor), and pressed against the foot stretcher until their knees were fully extended. To set–up seated arm pulling, participants sat astride the bench pull seat and adjusted the height of the handle grips on the vertical post to align with their elbows, when their elbows were flexed and arms adducted. Participants commenced the exercise from a fully extended arm position, and keeping their chest against the support pad and feet positioned on the floor in a forward split–stance at all times, pulled against the handles until the carriage reached the stops at the end of the support beam. The same set–up and technique was used on each testing occasion.

Assessments

The continuum of maximal effort tests differed by the number of repetitions performed. For each test, a repetition was commenced every two seconds (or equivalent to a rating of about 30 repetitions per minute), to ensure tests were performed within a target completion time. Test one involved five maximal effort repetitions (5RM) performed within a target completion time of 10 seconds. Three trials of the 5RM test were performed, with at least three minutes rest between each trial and the best trial result reported. Test two involved one trial of thirty repetitions (30RM) with a target completion time of 60 seconds; test three 60 repetitions (60RM) with a target completion time of 120 seconds; and test four, 120 repetitions (120RM) with a target completion time of 240 seconds. To ensure consistency of the test protocol, data was excluded from the analysis where the time to complete a test varied by more than 5 percent of the target time (seconds ± 5%).

Participants were instructed to maximise the amount of work they could achieve for each test. As work is the product of the displacement and force, participants were advised to think "length" and "strength" for each repetition they performed, and were reminded of this throughout each test. During testing participants had access to results and were actively encouraged by each other to perform to their best ability.

Procedures

All rowers had used the dynamometer equipment as part of their strength exercise for a period of at least three months preceding this present study. During an orientation session, participants were familiarised with the testing protocols and provided technique instruction, given opportunity to practise each test with feedback, and to ask questions. The test procedures were also rehearsed to ensure the appropriate warm up protocol and flow of participants through the test battery was safe and effective.

Participants were physically prepared by light rowing on an ergometer for at least 15 minutes prior to the commencement of testing. If participants wanted to perform dynamic or static stretches, they were instructed to keep them to less than 30 seconds duration, and to repeat such stretches on each test occasion. After the preparation, rowers were randomly assigned to a group of three – this was to ensure the appropriate work to rest ratio to enable sufficient recovery prior to progressing to the next test. A time sheet and timer were used to ensure each individual had a rest interval of at least ten minutes after any 5RM, 30RM or 60RM test; and that at least 20 minutes rest followed a 120RM test. If necessary, participants could notify the researchers if they needed more time to prepare or recover between tests to ensure their best performance was measured. On each day, the order in which participants attempted each test and exercise was randomized. Trials were alternated between participants in a group, until the number of permitted trials for each test was completed. Participants were advised to keep warm and drink fluids throughout the testing session and to move about after each test to keep blood circulating and to assist with the processing of any lactic acid.

Statistical analysis

The reliability of each test was evaluated using log transformed data to quantify percent typical error calculated from within–subject variations (CV) as well as intraclass correlation coefficients (ICC). The unit of measurement for analysis was average work per repetition (J).

Individual best scores were tabulated for each test. Raw data distribution was examined by normal probability plots and Shapiro–Wilks test (samples less than 20), and Levene's test for homogeneity of variances based on competitive level was conducted using log transformed data.

Change in the means between trials, which are inclusive of random (sampling or random error) and systemic change (learning, motivation, fitness or fatigue effects) were calculated and compared using paired t–tests given the same subjects repeated each trial. All statistical analyses were conducted at the 95% level of significance, where $P \leq 0.05$. Data are presented as means ± standard deviation (SD), unless otherwise stated. Within–subject variation was reported as raw typical error (the SD of within–subject differences between trials divided by root 2).

Log transformation was performed to normalise any positive kurtosis or skewing of data distribution (multiplied by 100 to maintain precision) and to avoid heteroscedastic errors associated with ICC calculations. Intraclass correlation coefficients were determined as they provide some sense of within–subject repeat–test rank order. The ICC method was based on a repeat measurement of average work (single value) with the same investigator coordinating all tests. The percentage change in means and typical error expressed as a coefficient of variation (CV) were also calculated after log transformation to allow for a more meaningful interpretation of the magnitude of error, irrespective of calibration or scaling. The lower and upper confidence limits (95%CI) of the above measurements were reported.

This study was constrained to 20 national team members, as these tests were to be used by the National Centre for Rowing Excellence to monitor these same rowers. A test had to have both satisfactory precision (i.e. percent typical error ≤ 5%) and test–retest consistency (ICC ≥ 0.9) to be recommended for inclusion in an assessment battery (Hopkins, Schabort, & Hawley, 2001).

We were also interested whether any low– or high–repetition tests were suitable for control–group research designs involving small sample sizes (i.e. n = 20 rowers). For these purposes, the precision of a test was considered 'satisfactory' if the 'signal' was greater than the noise (i.e. typical error), based on the formula *sample size* = 32*(typical error^2/signal^2) (Hopkins, 2000). As an unknown, the magnitude of the smallest signal was calculated as 0.2 times the SD of the between–subject mean of all trials (log transformed data) (Cohen, 1988). Test–retest reliability was considered satisfactory where ICC ≥ 0.97, based on the formula *sample size* = 800*(1 – ICC) (Hopkins, 2000). Both satisfactory precision and test–retest reliability were required for a test to be recommended. Data were analysed using SPSS (Version 17) and a spreadsheet (Hopkins, 2006).

Results

Shaprio–Wilk's tests confirmed normality of data, although there was a small positive skew and kurtosis to data distribution. After log transformation, Levene's test confirmed homogeneity of the variance from the mean across all tests between elite and elite–under 23 rowers.

The overall group means and mean typical error for each test are reported in Table 3.1. Average work was greater (e.g. >50%) for the lower 5RM tests, with leg pressing work far greater than seated arm pulling tests of equivalent repetition zones. Mean typical error of the raw data for leg press and seated arm pull tests were similar (range 20.9 – 24.4 J and 21.3 – 27.9 J respectively).

Table 3.1 Leg pressing and seated arm pulling means (± SD) and mean typical error (raw data) and 95% confidence intervals (95%CI).

	Leg pressing		**Seated arm pulling**	
	Mean ± SD (J)	*Mean Typical Error (J),* (95% CI)	*Mean ± SD (J)*	*Mean Typical Error (J),* (95% CI)
5RM	883 ± 146	23.2, (18.3 to 33.9)	572 ± 109	27.9, (21.6 to 39.6)
30RM	742 ± 110	24.4, (19.2 to 35.7)	442 ± 84	25.0, (19.7 to 36.5)
60RM	648 ± 92	20.9, (16.3 to 30.2)	365 ± 69	21.3, (16.5 to 30.7)
120RM	566 ± 70	22.9, (16.3 to 39.1)	302 ± 50	22.4, (16.6 to 39.7)

KEY: SD = Standard deviation; RM = Repetition maximum; J = Joules.

Table 3.2 summarises the between trials ICC, percentage change in means and percentage typical error. Pairwise testing indicated no significant systematic bias between trials of leg pressing, with the exception of T2 and T3 of the 120RM test (change in means –4.9%, P=0.05). In contrast, there was statistically significant systematic bias in 30RM and 120RM tests involving seated arm pulling between occasions two and three (e.g. 6.2% and 6.6%, P<0.05 respectively). Consequently, recommended percent typical error, ICC and percentage typical error for these measures were referenced in subsequent tables.

The calculated precision and test–retest reliability for each test are summarised in Table 3.3. Overall, tests involving seated arm pulling exercise had much lower measurement precision when compared to the same test involving leg press. All test–retest measures were on average high (i.e. ICCs ≥ 0.92), with the exception of the 120RM test involving seated arm pulling (ICC=0.71).

Table 3.2 Percent change in test means (Δ% Mean), test–retest reliability (ICC) and typical error expressed as a coefficient of variation (log transformed data) and confidence intervals (95% CI).

	Δ% Mean, (95% CI)		**ICC, (95% CI)**		**Percent typical error, (95% CI)**	
Test	*T2–T1*	*T3–T2*	*T2–T1*	*T3–T2*	*T2–T1*	*T3–T2*
Leg pressing						
5RM	1.2, (-0.9 to 3.3)	1.9, (-0.3 to 4.1)	0.98, (0.94 to 0.99)	0.98, (0.94 to 0.99)	2.5, (1.8 to 4.2)	2.9, (2.1 to 4.5)
30RM	-0.9, (-2.8 to 1.0)	1.6, (-1.3 to 4.6)	0.98, (0.94 to 0.99)	0.95, (0.87 to 0.98)	2.3, (1.6 to 3.8)	3.9, (2.9 to 6.1)
60RM	1.5, (-0.9 to 4.1)	1.3, (-1.5 to 4.2)	0.97, (0.89 to 0.99)	0.95, (0.85 to 0.98)	2.9, (2.1 to 4.8)	3.6, (2.6 to 5.8)
120RM	0.2, (-3.8 to 4.4)	-4.9*, (-9.7 to 0.1)	0.95, (0.73 to 0.99)	0.89, (0.56 to 0.96)	3.2, (2.0 to 7.1)	4.5, (2.9 to 9.3)
Seated arm pulling						
5RM	2.0, (-2.3 to 6.5)	4.1•, (-0.1 to 8.4)	0.95, (0.84 to 0.98)	0.95, (0.87 to 0.98)	5.0, (3.7 to 7.7)	5.1, (3.9 - 7.3)
30RM	0.4, (-4.1 to 5.1)	6.2†, (4.5 to 9.7)	0.93, (0.78 to 0.98)	0.93, (0.82 to 0.97)	5.5, (4.9 to 9.2)	6.2, (4.5 to 9.7)
60RM	2.0, (-1.9 to 6.1)	3.4, (-1.8 to 8.8)	0.94, (0.82 to 0.98)	0.91, (0.76 to 0.96)	4.5, (3.1 to 7.7)	7.0, (5.1 to 11.1)
120RM	3.0, (-10.4 to 18.4)	6.6**, (0.0 to 13.5)	0.71, (-0.23 to 0.95)	0.88, (0.56 to 0.96)	11.2, (7.1 to 26.4)	6.0, (4.0 to 11.8)

KEY: RM = Repetition maximum; • (P=0.06), *(P=0.05), ** (P=0.04) and † (P=0.01) indicate statistically significant difference between trials.

High–repetition tests (30RM, 60RM and 120RM) involving seated arm pulling exercise were not recommended for inclusion in an assessment battery of rowing performance, as they had unsatisfactory measurement precision (percent typical error > 5%). In contrast, low–repetition tests (5RM), and high–repetition tests involving leg press exercise, offered satisfactory precision and reliability (percent typical error ≤ 5% and ICC ≥ 0.9). The only assessment recommended to contrast strength–training outcomes between small sample interventions was the 5RM test involving leg press exercise (percent typical error = 2.7%, ICC = 0.98).

Table 3.3 Summary of mean test precision [i.e. typical error expressed as a coefficient of variation (CV%)] and mean test re-test reliability [intraclass correlation coefficients (ICC)] over the continuum of repetition maximum (RM) assessments (N = 20; log transformed data).

Test	**Precision (%), (95% CI)**	**Test–retest reliability (ICC), (95% CI)**
Leg pressing		
5RM‡	2.7%, (2.1% to 4.0%)	0.98, (0.95 to 0.99)
30RM‡	3.3%, (2.6% to 4.8%)	0.96, (0.91 to 0.98)
60RM‡	3.3%, (2.6% to 4.8%)	0.95, (0.89 to 0.98)
120RM**	3.2%, (2.0% to 7.1%)	0.95, (0.73 to 0.99)
Seated arm pulling		
5RM‡	5.0%, (3.9% to 7.7%)	0.95, (0.88 to 0.98)
30RM**	5.5%, (4.9% to 9.2%)	0.93, (0.78 to 0.98)
60RM‡	6.1%, (4.7% to 8.9%)	0.92, (0.81 to 0.97)
120RM**	11.2%, (7.1% to 26.4%)	0.71, (0.23 to 0.95)

KEY: RM = Repetition maximum; Data derived from: ‡ average of all trials; ** Based on T2–T1

Discussion

Although various strength tests have been used to examine variances in 2000–m ergometer performance, the main finding of this study was that high–repetition assessments (30RM, 60RM and 120RM) involving upper–body exercise had poor measurement error, which necessitates careful consideration for the use of such tests in the monitoring of individual performance changes. The lower reliability of high–repetition leg pressing and seated arm pulling measures proved inadequate for most inferential research involving small samples sizes (<20 subjects) where small performances differences may be expected (i.e. lower percentage typical error). Subsequently, in terms of the continuum of assessments used in this study, only low–repetition tests (5RM) had the degree of precision and reliability required to assess elite rowers (percent typical error ≤ 5% and ICC ≥ 0.9); however, only the leg press exercise (percent typical error = 2.7%, ICC = 0.98) met the recommended criteria to compare small squads of elite rowers (n = 20).

High–repetition assessments involving seated arm pulling exercise were not recommended in this study, because the percent typical errors calculated from within–subject data were greater than 5% (e.g. 120RM: 11.2%; 95%CI = 7.1% to 26.4%) and were far greater than any calculated smallest worthwhile signals (0.2*SD 120RM mean = 3.9%). Subsequently, estimates recommended for confidence of a 'true' change in performance, using a factor of 1.5 and 2.0 multiplied by the coefficient of variation (Hopkins, 2000), were considerable (e.g. 120RM = +22.4%). This would imply a large proportion of progress over a typical training phase e.g. ~15% over ~9 weeks (duManoir, et al., 2007; Haykowsky, et al., 1998; Kennedy & Bell, 2003; Webster, et al., 2006) may be due to systematic bias with the execution of higher repetition testing (i.e. familiarity, learning experiences and/or motivation).

While no individuals were injured from any testing, participants were more likely to alter their technique during high–repetition seated arm pulling assessments. The main observable fault was modest extension of the trunk away from the chest plate, which reduced the contribution of arm flexion during the test. Subsequently, more frequent technique prompts were provided. The systematic bias was in part attributed to participant's fatigue with the technique (e.g. change in means 120RM = +6.6%, see Table 3.2), and additional test constraints may have improved precision and re–test reliability of the seated arm pulling exercise (e.g. using a belt or tie to reduce movement of the upper body), attaining figures closer to leg pressing data.

The greater CVs associated with high–repetition testing, resulted in some doubt as to the suitability of the seated arm pulling exercise as an assessment task. However, the 5RM test offered comparable reliability and precision (ICC = 0.95; CV = 5.4%) as reported for seated cable row (ICC = 0.99; CV = 3.4% to 5%) (Cronin, et al., 2007; Levinger, et al., 2009). Similarly, ICCs reported for peak isokinetic leg extension torque (Bell, et al., 1993; Kramer, 1990; Kramer, et al., 1991) ranging from 0.82 to 0.94 and for 1RM leg pressing (ICC = 0.99) with percent typical error of 3.3% (Levinger, et al., 2009), offered no better precision or reliability over the 5RM leg press data acquired using the dynamometer in this study (ICC = 0.98 and CV = 2.7%).

As stated, we were unable to ascertain the reliability for typical high–repetition muscular–endurance tests used in rowing. Data from the present dynamometer confirmed high–repetition tests were less reliable compared to briefer maximal strength assessments, and we suspect this was in part due to the need to standardize lifting tempos, test durations and enforce qualitative technical criteria associated with fatigue, in the determination of data. However, the exclusion of high–repetition tests involving leg pressing exercise were borderline in context to the margins for precision and test–retest reliability required for small sample reliability (i.e. 20 subjects). Furthermore, the systematic bias associated with 120RM tests were in part attributed to differing 'pacing strategies' (i.e. variations in effort for each repetition), as well as varying levels of fatigue from endurance rowing preceding testing (e.g. change in mean leg pressing 120RM T3–T2 = –4.9%, P = 0.05). Subsequently, it may be the case that high–repetition testing requires greater attention to the rest and recovery strategies deployed around the administration of testing.

It may also be the case that for tests lasting longer than two minutes (60RM and 120RM), given the linear decay in muscle force from commencement of a maximal effort test (Gerdle, et al., 1998), there may be greater merit in allowing a 'free–rating' where both force and tempo of repetitions were allowed, so that total muscle work (thus repetitions) was maximized for a period of assessment (e.g. 4 minutes), rather than averaged for a specific RM. Peltonen and Rusko (1993) used a modified rowing ergometer to assess changes in force and power production during maximal leg pressing action over 2, 6 and 12 minutes. Periods greater than two minutes were determined to test power endurance rather than average force generation, with greater aerobic capacity, blood bicarbonate and lactate concentration on anaerobic threshold associated with performance results (total work). Similarly, the main discomfort experienced by our participants during high–repetition tests was a mild burning sensation in the active muscles, along with some heavy or laboured breathing, both attributed to the buildup of lactic acid. As with training, the degree to which this occurred varied depending on the level of exertion, current fitness and personal tolerance to lactic acid. It may also be the case that such symptoms were better tolerated in performance of leg press than seated arm pulling exercise, which in turn affected judgments in pacing of exercise intensity.

The low precision and reliability of seated arm pulling dynamometer tests raised some doubt about the utility of other upper–body high–repetition tests commonly used in rowing. For example, Jurimae et al. (2010) reported that the number of repetitions performed in leg pressing at 50% 1RM was closer (reps = 173.5 ± 11.8) to the number of average strokes taken to complete a 2000–m time trial (n = 194.2 ± 19.5) than bench pulling (reps = 122.6 ± 17.7). Leg pressing ($r = -0.68$, $P < 0.05$) and not bench pulling (r = –0.2, $P > 0.05$), was correlated with ergometer performance. On the basis of our data, poor test–retest reliability of high repetition upper–body assessments (e.g. 120RM seated arm pulling, ICC = 0.71) might explain the poor relationship between bench pulling and ergometer performance. However, we were unable to establish the rationale for the sub maximal loads used in previous research to quantify muscular–endurance (Jürimäe, et al., 2010; Kramer, et al., 1994; Liu, et al., 2003). Muscular–endurance tests resulting in comparable repetitions between lower– and upper–body exercises would arguably be of greater logical validity in the examination of common variances shared with rowing performance. It seems from the data in our study that the average work performed during 120RM seated arm pulling was approximately half (53%) that of the 5RM test, whereas the leg pressing ratio was almost two thirds (64%), noting the precision of such ratios was highly prone to error.

Finally, on the basis of our data, we recommend research utilizing high–repetition (upper–body) tests incorporate more than three repeated–measures into the design of a study, to explore familiarization, motivation and learning biases associated with such testing. Furthermore, it would appear that interventions incorporating high–repetition strength–training exercise may necessitate large study samples (n > 40 rowers), or the need to consider interventions of longer duration (> 9 weeks) into the study design, to ensure the magnitude of differences between groups can be interpreted with certainty from measurement error.

In summary, this study attempted to quantify the utility of low– and high–repetition tests used to assess rowers, in terms of the precision and retest reliability when used with upper– and lower–body exercise for a variety of purposes (i.e. monitoring or research).

The dynamometer enabled the assessment of strength using a continuum of repetition maximums. Our data indicated measurement error varied for each test and between lower– and upper–body exercises. Overall, tests involving leg press were found to be more precise and reliable than the same test involving seated arm pulling. High–repetition tests involving seated arm pulling were not recommended as assessments for elite oarsmen. Therefore, low–repetition tests (5RM) offered greater utility as assessments of upper– and lower–body strength; however, only the 5RM test involving leg press has sufficient precision and reliability to contrast strength training outcomes between small squads of elite rowers.

Chapter 4 – Anthropometry, strength and benchmarks for development: a basis for junior rowers' selection?

Prelude

Surprisingly, muscular endurance tests involving leg pressing or arm pulling (rowing) exercise have not been used to compare junior and senior elite rowers. Muscular-endurance tests are relatively simple to perform and therefore allow participants to assess their maximum ability, regardless of their rowing ability or experience. In comparison to high–repetition exercise, it was observed from Chapter 3 that low–repetition strength tests were briefer in administration and offered greater testing precision and reliability. However, it is likely that junior rowers that are strong, but who have performed low volumes of muscular-endurance exercise, do not excel at a 2000–m time trial. Therefore, juniors who are selected on the basis of strength and familial anthropometrical attributes for rowing, may not do too well on–water if such attributes favour rowing ergometry, given the negative effect on boat buoyancy and drag–velocity associated with body mass. Muscular-endurance performance by way of contrast is not as dependent on muscle mass and differences between junior and senior rowers are likely to be large, overcoming issues associated with measurement error. Subsequently, the purpose of this investigation was to establish whether low- or high-repetition strength tests explain performance differences and thus priorities associated with training, between junior and senior rowers.

Introduction

In order to improve international competitiveness, the early identification of potentially talented rowers, through anthropometrical testing, is of interest to scientists, rowers and coaches alike (Hahn, 1990; Mikulic & Ruzic, 2008; Slater, et al., 2005; Vaeyens, Lenoir, Williams, & Philippaerts, 2008). After allowing for a population trend of increasing standing height of 0.03 m, the 21st century elite rower is some 0.06 m taller [1.94 ± 0.05 m (males) and 1.81 ± 0.05 m (females)] and between 6.4 kg and 12.1 kg heavier [94.3 ± 5.9 kg (males) and 76.6 ± 5.2 kg (females)] when compared to Olympic rowers from two decades earlier (Kerr, et al., 2007). Standing height ($r = -0.81$, $p<0.001$), body mass ($r = -0.85$, $p<0.001$), as well as fat free mass ($r = -0.91$, $p<0.001$) are some of the simplest measures and well established correlates of 2000-m rowing ergometer performance (Yoshiga & Higuchi, 2003b). Furthermore, research has clarified that successful senior rowers were on average significantly taller (+5.4 cm $p<0.01$) and heavier (+11.1 kg, $p<0.05$) than juniors (Mikulic, 2008), with longer arm span and greater sitting height than junior rowers (Kerr, et al., 2007). However, selecting 'talent' on the basis of anthropometry alone has limitations, due to the physiological (aerobic and anaerobic power), technical (stroke to stroke consistency, crew synchronicity, etc.) and tactical (pacing, competition level etc.) requirements of racing on-water; not to mention the potentially negative effects of body mass on boat velocity (Millward, 1987; Nevill, et al., 2010; Secher, 1993; Shimoda, et al., 2009; Smith & Spinks, 1995).

While acknowledging that there are limitations to single factor performance models, some of the key physiological predictors of success in rowers of varying competitive ability have been identified as isokinetic quadriceps strength (e.g. $r = -0.41$, $p < 0.05$) as well as VO_{2max} (e.g. $r = -0.43$, $p < 0.05$), in addition to lean body mass (e.g. $r = -0.40$, $p < 0.05$) (Russell, et al., 1998; Shimoda, et al., 2009). Subsequently, strength testing of the major muscle groups, along with tests of aerobic power, have been used to compare the differences between elite and non-elite, irrespective of rowing experience or skill (Hahn, 1990; Smith & Spinks, 1995). Nationally ranked rowers were stronger (~11%) when comparisons of isometric rowing strength were made to rowers of lower competitive standing (Secher, 1975); they also performed better (e.g. 850 ± 70W vs. 610 ± 70W) in tests of arm cranking power (Koutedakis & Sharp, 1986). There are measures of muscular strength which have emerged as moderate to strong predictors of 2000-m ergometer ability (e.g. leg pressing 1RM (kg): $r = -0.68$, endurance (repetitions): $r = -0.68$ or power (W): $r = -0.68$, $P < 0.05$) (Jürimäe, et al., 2010; Russell, et al., 1998; Shimoda, et al., 2009; Yoshiga & Higuchi, 2003a), but when examining rowers of varying experience levels, it remains unclear which is of greater relevance to monitoring performance over the various phases of preparation in build up to competition. In particular, low measurement precision, combined with trivial differences in performance outcomes, has made the interpretation of benefits associated with the short-term inclusion of various strength interventions on 2000-m rowing ergometer performance, problematic (Lawton, et al., 2011). However, establishing meaningful differences in performance outcomes within short duration interventions of eight weeks or less, particularly with high performing athletes, is difficult (Hopkins, 2000). It may simply be the case that such a void in the literature, stands in stark contrast to longer-term empirical data or experience, as embodied in modern rowing training practices or beliefs (Gee, Olsen, et al., 2011).

Over the past 30 years endurance training volumes have increased by more than 20% in many countries (Fiskerstrand & Seiler, 2004). However, to the knowledge of these authors, recent data quantifying differences in strength and muscular endurance between junior and senior rowers has not been reported. Furthermore, given the paucity and currency of comparative data, the average time (or average annual development rate) required to attain strength attributes or recommended targets (e.g. 1RM dead lift equivalent to 1.9 times body mass) for senior rowers (McNeely, et al., 2005), or the magnitude of benefits associated with such changes as rowers progress through levels of competition, remain unclear. In context of individual training responses, some sense from normative (longitudinal) data of typical progression rates would be of use not only for planning, sequencing and evaluation of strength and endurance adaptations over the longer term; but as critical benchmarks on which to gauge or predict an individual's future potential of success. Subsequently, given these limitations in the existing literature, the purposes of this study were twofold: to establish whether anthropometry, muscle strength and endurance accounted for differences between junior and senior rowing ergometer performance and, to determine annual development (progression) rates for juniors associated with strength and endurance training.

Methods

Participants

Twenty six junior (8 females, age 18.0 ± 0.3 years and 18 males, age 17.9 ± 0.2 years) and 30 senior heavyweight rowers (12 females, 23.7 ± 3.0 years and 18 males, 24.0 ± 3.9 years), selected as national representatives, provided data for this descriptive research analysis. Senior rowers had competed in 'A-finals' at World Rowing Championships, and included 14 gold and two bronze medallists, while the juniors included four gold and four bronze medallists. Subject characteristics are summarised in Table 4.1.

The study protocol was approved by the AUT University Ethics committee. Informed voluntary signed consent was attained after rowers attended project information and familiarisation seminars. Rowers who were cleared by medical staff for participation in regular training were by allowed to test.

Equipment

Stature and arm span measures were assessed using wall mounted stadiometers, with body mass measured using calibrated electronic scales (Tanita HD-316, Tanita Corporation, Tokyo, Japan). All skinfolds were measured using a Slim Guide calliper (Creative Health Products, Plymouth, USA).

All rowing performance tests were performed with an air-braked rowing ergometer (Model D, Concept 2 Ltd, Illinois, USA) with the drag factor setting to 110 for females and 130 for males. During testing participants had access to the console information, which included the elapsed distance (meters), test time (minutes and seconds), 500-m interval time/splits (minutes and seconds) and average stroke–rate per minute.

A "Dynamic Strength Training" dynamometer (DYNO; Concept 2 Ltd, Illinois, USA) was used to measure average concentric work produced during leg pressing and seated arm pulling exercise. The dynamometer provided resistance by flywheel inertia combined with air braking fans to create drag, comparable in design with a Concept 2c rowing ergometer. The drag factor was set with two air dampeners opened for leg pressing and with all dampeners closed for the seated arm pulls. A console displayed information about the force (kg) and work (J) performed on completion of each repetition. Ten seconds after the end of each trial, the dynamometer console produced a summary of the average work per repetition (J) for the completed set. These data were recorded as the test result.

The isometric pull test was performed within a power rack (Fitness works Pty. Ltd, Auckland, New Zealand). During the test, the rower stood on a force platform (400 Series Performance Plate, Fitness Technology, Adelaide, Australia). Vertical ground reaction force data were collected at 200 Hz then analyzed via the Ballistic Measurement System software (version 2009 1.4, www.innervations.com, Australia).

Assessments

Anthropometry

Anthropometrical measurements included body mass, stature (standing height), sitting height, and sum of five skinfold sites (triceps, subscapularis, abdominal, supraspinale, and iliac crest). All anthropometrical measures were performed and measured as per the International Society for the Advancement of Kinanthropometry (ISAK) guidelines (Norton, et al., 2004).

2000-m time-trial

The 2000-m test was a one-off maximal-effort self–paced time–trial, with the test result reported as the total elapsed time (s). This test was conducted as part of national selection criteria, supervised by examiners (selectors) and performed at various rowing centres of excellence.

Isometric pull

The isometric pull was used to assess the strength of the legs, torso and arms. The isometric pull involved pulling against an immovable barbell adjusted to the height of the rower's knee. Rowers performed 4 x 5 seconds trials, progressing from 50% to 100% of their anticipated maximum, with up to 2 min rest between trials. Rowers were observed to ensure each attempt was performed without flexion of the lumbar spine. The greatest peak force (N) of any trial was reported as the test result. Previous test-retest reliability reported for this test was: coefficient of variation (CV) 3.5% and Intra-class correlation (ICC) ≥ 0.96 (McGuigan, Newton, Winchester, & Nelson, 2010).

Muscle strength and endurance dynamometry

Muscle strength and endurance were assessed using the dynamometer. For each test, a repetition was commenced every two seconds (or equivalent to a rating of about 30 repetitions per minute). Test one required five maximal effort repetitions performed within 10 seconds. Three trials of each test were performed, with at least three minutes between attempts; with the best result of the three trials recorded as the test result. All five repetition leg press trials were performed before five repetition seated arm pull trials. Test two involved one trial of 120 maximal effort repetitions, completed within a target completion time of four minutes. Again, the 120 repetition leg press test was performed before the 120 repetition seated arm pulls. To ensure consistency of the test protocol, data was excluded from the analysis where the time taken to complete the test was more than 5 percent of the target time (target time ± 5%). Previous test-retest reliability of these dynamometer strength and endurance tests in our laboratory were CV = 2.5% to 9.6%; ICC ≥ 0.89 to 0.99.

Test procedures

Rowers aiming for national team selection, elected to participate in a 2000-m ergometer time trial held at various national rowing centres of excellence. After successful selection and commencement of a national training scholarship, rowers performed the muscular strength (isometric pull, five repetition leg press and five repetition seated arm pulls) and endurance tests (120 repetition leg press and 120 repetition seated arm pulls) and were anthropometrically measured. Rowers were assigned to a group of three – this allowed the appropriate work to rest ratio to enable sufficient recovery prior to progressing to the next test. However, participants could notify the researchers if they needed more time to prepare or recover between tests to ensure their best performance was measured. These results, and the earlier performed 2000-m ergometer time trial data, were used for the present study.

Statistical analysis

Individual best scores were tabulated and represented as a mean ± standard deviation (SD); percent difference (annualised), and respective significance (one-way ANOVA) in differences for all strength and rowing ergometer performance measures were calculated.

To compare junior and senior rowers, standardised mean differences in strength and rowing ergometer performance, and standardised differences between performances adjusted by the average level of strength for all rowers as a covariate, along with respective p-values and 90% confidence limits, were calculated using a spreadsheet (Hopkins, 2007). The adjustment was performed by fitting a simple linear model to the relationship between the change scores and strength covariate in each group, to determine the extent to which the effect of the training was due to strength. The linearity and homoscedasticity of data were examined by visual inspection of bipolar plots with least squares regression analysis, and the distribution and normality of data were assessed using histograms, probability plots and Shapiro—Wilks' test on SPSS (version 17). All data were log-transformed prior to analysis to reduce non-uniformity of error. Magnitudes of standardised effects (ES) were calculated by dividing the appropriate between-rower standard deviation and using a modified Cohen scale defined as: <0.2 = trivial, 0.2 to 0.59 = small, 0.6 to 1.19 = moderate, 1.2 to 1.99 = large, >2.0 = very large (Hopkins, Marshall, Batterham, & Hanin, 2009). The effect was deemed unclear if its confidence interval overlapped the thresholds for small positive and negative effects.

To determine the relative importance of each strength measure on rowing ergometer performance (that is, for each unit increase in ES in strength, the relative change in adjusted 2000-m ergometer performance ES), the ratio of various standardised differences in strength (denominator) and associated change in rowing ergometer performance ES were equated.

Results

Anthropometrical characteristics of rowers are summarized in Table 4.1. There were no significant group differences between junior and seniors in standing height, arm span or 5-site skinfold sum (body fat). Senior females had greater body mass (6.7%; ±4.1%, P = 0.01) than junior females (77.2 ± 5.9 kg and 70.5 ± 4.6 kg respectively) that was attributable to lean tissue mass after controlling for standing height and body fat in the analysis. Senior females were also of greater sitting height than juniors.

Table 4.1 Mean anthropometrical characteristics of junior and senior rowers (±SD)

	Females		**Males**	
	Junior	*Senior*	*Junior*	*Senior*
Standing height (cm)	174.6 ± 6.6	178.8 ± 3.8	187.8 ± 4.9	190.0 ± 5.4
Arm Span (cm)	177.6 ± 8.4	179.9 ± 5.5	192.1 ± 6.1	193.9 ± 6.0
Sit Height (cm)	89.8 ± 2.2	92.2 ± 2.7†	96.9 ± 2.7	97.9 ± 2.6
Body mass (kg)	70.5 ± 4.6	77.2 ± 5.9*	85.5 ± 6.3	90.5 ± 9.6
Sum of skin folds (mm)**	62.0 ± 13.5	52.4 ± 7.8	51.7 ± 14.9	42.4 ± 13.4‡

‡P = 0.06, †P = 0.04 and *P = 0.01, **5-sites = Triceps, subscapularis, iliac crest, suprailiac, and abdominal.

Average 2000-m time, isometric pull and dynamometer measures are reported in Table 4.2. In all cases, senior rowers were significantly faster and stronger than their junior counterparts. The annualised development rate (i.e. compounding growth rate) estimated over five years for juniors to attain the rowing ergometer performance of seniors was 1.0% and 1.5% for males and females respectively. Greater annual development rates were estimated for all strength and endurance measures (2.5% to 6.0% pa).

Table 4.2 Mean (±SD) 2000-m time, isometric pull, muscular strength and endurance dynamometer measures, and estimated 5-year development rates (%) for junior rowers

	Females			**Males**		
	Juniors	*Seniors*	*%#*	*Juniors*	*Seniors*	*%#*
2000 m (s)	442 ± 8.5	411 ± 6.3*	1.5%	382 ± 5.0	366 ± 9.3*	1.0%
Isometric pull (N)	1654 ± 143	1875 ± 206*	2.5%	2254 ± 208	2678 ± 229*	3.5%
Leg Press						
5 reps (J)	536 ± 55	631 ± 70*	3.5%	781 ± 81	921 ± 118*	3.5%
120 reps (J)	357 ± 49	404 ± 46†	2.5%	514 ± 61	581 ± 77*	2.5%
Seated arm pulls						
5 reps (J)	267 ± 41	342 ± 54*	5.0%	469 ± 60	617 ± 95*	6.0%
120 reps (J)	153 ± 16	204 ± 46*	6.0%	257 ± 28	339 ± 66*	6.0%

†P = 0.01, *P < 0.01; # % = 5 year annualized development rate (i.e. compounding rate); reps = repetitions; J = Joules.

Table 4.3 summarises the standardised differences in strength, and differences in effects on rowing ergometer performance. The standardised differences in strength between junior and senior by magnitude of effect sizes were moderate to very large for five repetition seated arm pulls, five repetition leg press, and 120 repetition seated arm pulls for females, and moderate to very large for the isometric pull, five and 120 repetition seated arm pulls in the case of males. After adjustments for levels of strength were made for each measure, associated reductions in ergometer performance ES differences were observed, with the magnitude of change marginally greater for males (e.g. greatest adjusted 2000-m ES for females: -0.6, and males: -0.7). After ratios of standardised differences in effects were calculated, increases in 120 repetition seated arm pull lead to greater performance adjustments for females (0.46) whereas for males, greater effects were associated with five repetition seated arm pull (0.37).

Table 4.3 Standardized difference (ES; ±90%CI) in 2000-m and muscular strength and endurance covariates, associated adjusted 2000-m performance standardized differences, and ES ratios (log transformed data)

	Females			**Males**		
	ES	*Adjusted 2000-m ES*	*ES Ratios**	*ES*	*Adjusted 2000-m ES*	*ES Ratios*
2000-m	3.8; ±0.8			2.0; ±0.6		
Isometric Pull	1.2; ±0.7	3.4; ±1.1	0.35	1.9; ±0.6	1.5; ±0.8	0.24
Leg Press						
5 reps	1.4; ±0.7	3.3; ±1.2	0.36	1.4; ±0.6	1.6; ±0.7	0.27
120 reps	0.9; ±0.8	3.7; ±0.9	0.13	0.9; ±0.6	1.7; ±0.6	0.30
Seated arm pulls						
5 reps	1.5; ±0.7	3.7; ±1.2	0.07	1.8; ±0.6	1.3; ±0.8	0.37
120 reps	1.4; ±0.8	3.2; ±1.2	0.46	1.5; ±0.6	2.0; ±0.7	0.03

† P<0.05; *P<0.01; *ES ratios = change in standardized 2000-m ergometer performance after adjustment for covariate/standardized differences in muscular strength or endurance covariate.
Notes: CI = Confidence Interval; reps = repetitions.

Discussion

Anthropometrical characteristics associated with improved on- and off-water rowing performance, which are dependent on growth and maturation rates (e.g. greater standing and sitting height and arm span), cannot be influenced by training. Subsequently, after a number of years of training and high-level competition, coaches and/or sport scientists alike, might question whether a junior rower of the right physical build, has the physiological capacity to be competitive internationally. The main finding of this study was that 2000-m performance differences between junior and senior rowers could be explained by differences in muscular strength and endurance. Furthermore, given the relative simplicity of dynamometer testing, attainment and development rates in muscle strength and endurance could be used to identify those juniors who possess the physiological attributes to potentially excel at rowing.

When considering the anthropometry of a rower, not all possess the necessary attributes to excel at rowing. For example, senior females were of greater body mass (70.5 ± 4.6 kg and 77.2 ± 5.9 kg, $P = 0.01$), and sitting height (89.8 ± 2.2 cm and 92.2 ± 2.7 cm, $P = 0.04$) compared to the juniors. After controlling for standing height and body–fat, these differences in body mass were attributed to greater lean tissue mass; a strong anthropometrical predictor of rowing ergometer performance. Additionally, senior rowers differed only slightly on average to past data reported on 2000 Olympic champions' for standing height (males: -0.04 m; females: -0.02 m) and body mass (males: -4.0 kg and females: +0.6 kg). Whereas by way of contrast, junior rowers were on average shorter (male standing height: -0.06 m; females: -0.06 m) and lighter (around -9.0 kg and -6.0 kg respectively). Therefore, it would appear likely that with particular regard to the greater apparent heterogeneity of junior females, only rowers of greater body mass and/or sitting height possessed the necessary attributes to succeed beyond national age-based competition. Alternatively, factors such as strength, skill and efficiency or mental aptitude (motivation) must enable rowers with slight variations in the familial anthropometric profile, to succeed.

To the knowledge of these authors, this is the first investigation to report leg pressing and arm pulling strength of rowers using the Concept 2 dynamometer (DYNO). While comparative results may not yet be published, the trends in dynamometer data means were consistent with past research. That is, irrespective of the type of equipment (e.g. leg press, prone bench pull etc.) or assessment (e.g. maximum repetitions with 50% 1RM or 1RM), senior rowers of greater competitive level, perform better than their junior or lesser ranked counterparts in rowing specific measures of strength or muscular endurance – Table 4.2 (Koutedakis & Sharp, 1986; Kramer, et al., 1994; Russell, et al., 1998; Secher, 1975; Shimoda, et al., 2009; Yoshiga & Higuchi, 2003a, 2003b). However, the present dynamometer data provide not only more currency on which to 'benchmark' juniors against the modern elite senior rower; but given the relative simplicity, portability and ease of administering tests (in comparison to racing 2000-m), they appear ideal in conjunction with anthropometric assessment, for testing and identification of individuals who possess muscular strength and endurance qualities to excel at rowing.

Average annualised (or compounding) development rates in strength and endurance for junior rowers (allowing for a five year training investment) ranged from 2.5% for lower body endurance (120 repetition leg press) up to 6.0% pa for upper-body measures (five repetition seated arm pulls and 120 repetition seated arm pulls) – Table 4.2. In the interpretation of strength data on rowing ergometer performance, the common variances shared between strength and muscle mass, cannot be overlooked. That is, any increase in upper or lower–body strength and/or lean tissue mass, is likely to have a subsequent 2000-m performance benefit in general, given rowing is a whole-body strength and endurance sport. Nonetheless, after adjusting for mean level of strength/endurance as a covariate (i.e. juniors had greater strength/endurance or conversely seniors' less), the associated effects of compounding these small annual differences on rowing ergometer performance were small to moderate and in general, slightly greater for males (i.e. largest adjusted 2000-m ES for males: 0.7 and females: 0.6).

On further analysis of data, large differences in upper-body strength (five repetition seated arm pulls) and endurance (120 repetition seated arm pulls) between junior and senior rowers were observed (e.g. ES = 1.4 to 1.5 females; 1.5 to 1.8 males; see Table 4.3). Given that the contribution of the upper-body during the whole-body generation of total propulsive stroke-power is limited (e.g. ~15%-20%) (Kleshnev & Kleshnev, 1998; Tachibana, et al., 2007), it may simply be the case that training methods of senior rowers emphasize or are constrained by, the muscular strength and endurance capacity of the upper-body. Nonetheless, although subtle differences by order of standardised differences in strength by gender were observed [e.g. females: five repetition seated arm pulls (1.5), 120 repetition seated arm pulls (1.4), and five repetition leg press (1.4); and males: isometric pull (1.9), five repetition seated arm pulls (1.8) and 120 repetition seated arm pulls (1.5)], in the first instance upper–body assessments may prove the more useful tests in the initial identification of potential talent.

When changes in strength and performance outcome effects were equated on the assumption of equal adaptation rates to overcome any bias associated with previous training histories (e.g. swimming, cycling or running), equal unit increases in upper-body endurance were associated with larger adjustments in 2000-m ergometer performance outcomes for females (120 repetition seated arm pull ES ratio = 0.46) while in the case of males, upper-body muscular strength showed larger associations (five repetition seated arm pull, ES ratio = 0.37). Subsequently, with consideration of past evidence involving the weight-training of novices (Ebben, et al., 2004), junior female rowers might do better to prioritize the upper-body muscular endurance, while junior males strength. However, given the differences observed in all muscular strength and endurance covariates, it may more logically be the case that the programming of novices is best addressed by an evaluation of each individual's 'strengths' and 'weaknesses' against the established benchmarks of seniors.

Over the longer term, there may be limitations to using strength or endurance 'benchmarks' in the identification of potentially talented rowers. For example, the junior and senior males recruited for this study, were on average stronger during isometric testing (~2250N and 2680N respectively) than comparable data reported on senior males circa 1975 (~2000N) (Secher, 1975). Thus, unless indexed accordingly, the present benchmarks of strength and endurance may prove inadequate in context of international rowing competition standards within the next decade.

By way of contrast, annualised development rates may prove more useful in the confirmation of 'talent', particularly as training adaptations become more marginal over the longer-term. For example, relatively untrained rowers may improve strength in excess of 2.5% each week, for as many as ten weeks (Lawton, et al., 2011). Thus all other factors remaining equal, individuals that show greater capacity for change above and beyond the desirable benchmarks on entry into a training program (including those attributable to the retraining phenomenon), may have greatest potential for success in rowing.

Given a paucity of serial or longitudinal evidence, these authors caution the reader to consider factors unable to be adequately accounted for in the determination of associated effects of strength or endurance on differences in performance outcomes. For example, Hagerman (1984) reported after reviewing test data of three rowers over seven consecutive years (1972 – 1980), that even though maximal aerobic capacity (VO_{2max}) did not improve, annualized gains in a 6-minute ergometer test that ranged from 3.0% up to 4.1% pa were observed and associated with changes in mechanical efficiency from approximately 16% to 23% (or 3.3% to 5.1% pa). Furthermore, the typical error of measurement associated with any performance monitoring cannot be overlooked in the interpretation of annualized development rates. That is, given the annualized development rates for the 2000-m ergometer time trial was 1.5% and 1.0% pa respectively for females and males, the odds of establishing differences in performance outcomes over any twelve month intervention appear particularly low, should rowers close in age to the seniors (i.e. ~ 24.0 years) be recruited, given a typical error as a coefficient of variation (CV) of around 2.0% (Schabort, Hawley, Hopkins, & Blum, 1999). Finally, the superiority of early maturing rowers accounted for in terms of strength, aerobic power or lean body mass, should not be used to discourage or deny any opportunity for advancement of later maturing individuals (Mikulic, 2010).

In conclusion, differences in muscular strength and endurance, particularly of the upper body (i.e. five and 120 repetition seated arm pulls), may prove useful for the identification of individuals who possess the physiological characteristics to excel at rowing. Additionally, while rowing is a whole-body strength and endurance sport, rowers that exhibit individual development rates greater than the estimated five-year average, could be targeted by programmes willing to invest in their longer-term competitiveness in the sport.

Chapter 5 – Strength, power and muscular endurance determinants of elite rowing ergometer performance

Prelude

Exercise benchmarks that provide robust diagnostics about an individual's strengths and weaknesses are of interest to coaches and rowers. As on-water environmental conditions such as ambient air and water temperatures, currents, swells or wind speed cannot be controlled, most diagnostic tests in rowing are performed indoors using an ergometer. The 'gold-standard' test for rowers is the 2000-m time-trial, although coaches and sport scientists may use a range of other tests to evaluate rowers (e.g. peak stroke-power, 500-m, 5000-m or 60-minute trials), as the goals and adaptations from training vary according to the training history and available time for competition preparations. Given the diversity of physiological demands apparent in these ergometer assessments, it seems logical that low– and high–repetition strength tests may be strongly correlated. Ideally, strength tests that are highly correlated with rowing performance can be used as exercise for weight training, to identify individual needs and short-term targets associated with training, or even to select rowers for crews. Since it was observed in the previous chapter that juniors lack the strength and muscular-endurance of seniors, it may be that upper-body strength tests share greater common variances with tests of rowing performance. The purpose of this study therefore, was to establish which strength, power and muscular-endurance exercises for weight training, which when periodically used for testing, are strong determinants of specific performance measures used to assess elite rowers.

Introduction

The advent of rowing ergometry has facilitated not only environmentally controlled training and monitoring of rowers, but more critically, the establishment of important physiological determinants of 2000-m on-water performance (Ingham, Whyte, Jones, & Nevill, 2002). Logically, ergometry testing cannot account for differences in boat speed associated with crew-number, oar-blade surface area (sculling or sweep-oar rowing), synchronicity or effectiveness of work performed with the oar-blade (feathering, entry, work-slip arcs, stroke rate and consistency) (Baudouin & Hawkins, 2004; Hofmijster, et al., 2008; Kleshnev & Kleshnev, 1998; Millward, 1987). However, all such factors remaining equal, rowers who sustain greater average net propulsive power, achieve faster boat speeds (Hofmijster, et al., 2007; Smith & Spinks, 1995). Therefore, in the quest to maximize average boat velocity over a 2000-m race, various rowing ergometer protocols are deployed to evaluate individual physiological needs and to detect changes in performance capacities (Ingham, et al., 2002; Kendall, Smith, Fukuda, Dwyer, & Stout, 2011; Maestu, et al., 2005; Mikulic, 2009; Nevill, Allen, & Ingham, 2011; Riechman, Zoeller, Balasekaran, Goss, & Robertson, 2002).

Acknowledging that there are limitations to single factor performance models, the strongest ‘determinants’ of an elite rower’s 2000-m ability, identified from multiple regression models (R^2 ~96%, standard error ~1.5%) are the power at VO_2max ($r = 0.84$ to 0.93, $p<0.001$) and the peak stroke-power ($r = 0.82$ to 0.88, $p<0.001$) (Ingham, et al., 2002; Nevill, et al., 2011). Given these determinants are, physiologically, relatively polarized, and considering a strong correlation between muscle strength and rowing peak stroke-power (e.g. $r = 0.8$ to 0.9; $p<0.05$) (Bell, et al., 1989; Ingham, et al., 2002; Nevill, et al., 2011), it is not surprising that weight training and benchmarks for strength testing are commonly prescribed as part of preparation plans in rowing (Gee, Olsen, et al., 2011; Hay, 1968; McNeely, et al., 2005).

Absolute maximal strength (kg, N or W), but not relative maximal strength (i.e. kg, N or W per kg of body mass), is a strong discriminator of rowing ability (Koutedakis & Sharp, 1986; Kramer, et al., 1994; Lawton, et al., 2011; Russell, et al., 1998; Secher, 1975; Shimoda, et al., 2009). Peak isokinetic quadriceps strength ($r = -0.41$ to -0.68, $p < 0.05$), along with VO_2max ($r = -0.43$ to -0.61, $p < 0.05$) and lean body mass ($r = -0.40$ to -0.73, $p < 0.05$), has been reported as a key (multiple regression) 'determinant' of 2000-m performance (Russell, et al., 1998; Shimoda, et al., 2009). However, given a large aerobic energy contribution in 2000-m racing (around 70% to 85%) (Hagerman, 1984; Maestu, et al., 2005; Shephard, 1998; Steinacker, 1993), some debate exists as to whether testing and training using weight-room exercises should be directed at local muscle-endurance, rather than maximum strength adaptations (Ebben, et al., 2004; Gallagher, et al., 2010).

Muscular-endurance adaptations have been assessed using the maximum repetitions attained with a 50% 1RM load (Jürimäe, et al., 2010) or the absolute quantity of work (i.e. mass x vertical distance x repetitions = total joules per exercise) performed with a 70% 1RM load (Kramer, et al., 1994) during weight-room exercise. Researchers utilizing absolute leg press muscular-endurance exercise results report strong to modest correlations with ergometer time ($r = -0.68$ and -0.51 respectively, $p<0.05$) (Jürimäe, et al., 2010; Kramer, et al., 1994). By way of contrast, poor correlations were associated with rowing performance and absolute upper-body muscular-endurance testing (e.g. prone bench pull, $r = -0.25$; $p > 0.05$) (Kramer, et al., 1994). This is somewhat surprising, given rowing involves all the major muscle groups and the proven usefulness of upper-body muscular-endurance benchmarks in differentiating rowers of varying competitive ability (Koutedakis & Sharp, 1986).

Given the relatively small muscle mass of the arms and limited contribution to rowing power (Kleshnev & Kleshnev, 1998; Tachibana, et al., 2007), it may be that absolute upper-body muscular-endurance testing is relevant only when considered as part of multiple-regression models of performance; however such analysis has not been explored. Alternatively, absolute upper-body muscular-endurance tests may be 'determinants' of rowing performance measures other than 2000-m (e.g. 5000-m time) but to the knowledge of these authors such data has not been reported. In terms of weight training, some sense of the relationships between upper- and lower-body exercises and various ergometer tests used to assess rowers would prove useful for the development and assessment of strength and conditioning programs. However, information addressing such contentions is limited. Subsequently, the purpose of this study was to establish strength, power and muscular-endurance exercises for weight-room training, which are strong determinants of success in performance measures used to assess elite rowers.

Methods

Experimental approach to the problem

We developed a cross-sectional research design in collaboration with the national centre for rowing excellence to determine strong common variances between weight-room exercises used as part of preparations (predictor variables) and measures of rowing performance (dependent outcomes). The national squad of heavyweight male rowers was invited to participate in this study conducted early off-season (i.e. October) in place of normally scheduled endurance rowing and weight training. Over twelve days of investigation we assessed each rower's repetition maximum loads for a range of dynamometer and 'free weights' exercises (predictor variables) and performance in a range of rowing ergometer tests (dependent outcomes). Rowers were familiar with all exercises and testing protocols as they were used regularly as part of national team preparations.

Pearson correlation moments and stepwise multiple linear regression calculations were used to establish strong common variances shared between predictors and outcomes. We anticipated marginal differences in testing results given training histories and competitive rankings and given the small sample size we selected measures with robust intra-class correlations (ICC $\geq$ 0.95) or coefficients of variation (CV ~5%). For the purposes of this study, predictors that shared strong common variances with rowing ergometer performance were recommended as exercise combinations for weight-room training.

Subjects

Nineteen heavyweight male rowers volunteered for this study conducted 'off-season' (October). These elite open age and elite under-23 age (U23) rowers had recently competed in 'A finals' at Rowing World Championships, and included fourteen gold and two bronze medallists. The mean ± standard deviation (SD) characteristics of these rowers were: age 24.3 ± 4.0 years; rowing experience 9.4 ± 4.1 years; height 189.7 ± 5.3 cm; arm-span 193.4 ± 6.2 cm; sitting height 97.8 ± 2.5 cm and body mass 87.3 ± 10.1 kg.

Institutional Review Board (IRB) approval for the study protocol was gained from the AUT University Ethics committee. Written (signed) informed voluntary consent was attained from rowers after project information and familiarisation seminars were attended. Rowers who were cleared by medical staff for participation in regular training were allowed to test.

Assessments

Rowing ergometer performance measures

All rowing performance measures were utilized an air-braked rowing ergometer (Model D, Concept2 Inc., Morrisville, VT, USA) with the drag factor setting to 130. Rowing performance measures included a *500-m, 2000-m* and *5000-m time-trials* (s); *a one-hour trial* (m); and greatest *peak stroke-power* (W) attained over 15 maximal-strokes. The *aerobic condition* was assessed using a seven–stage incremental test. At the completion of each six–minute stage the workload was increased by 15W by increasing stroke rate, until blood lactate equalled or exceeded 6 mmol/L. The blood lactate response was determined using a Yellow Spring Instruments 2300 blood lactate analyser (Ohio, USA) from a 25µl pipette sample drawn from the earlobe within 30 s of the commencement of the one-minute rest interval allowed between stages. From these data, average power at 4 mmol/L was determined using scatter plot graphing (MS Excel). Previous test-retest reliability reported for these tests were Coefficient of Variation (CV) = 2.0% - 3.1%; Intra-class Correlation Coefficient (ICC) ≥ 0.96) (Hopkins, et al., 2001; Schabort, et al., 1999).

Leg pressing and seated arm pulling dynamometry

A "Dynamic Strength Training" dynamometer (DYNO, Concept 2 Inc.; Morrisville, USA) was used to measure average concentric work produced during leg pressing and seated arm pulling exercise. The dynamometer provides accommodating resistance by flywheel fan inertia combined with air–braking to create drag, comparable in design to a Concept 2 rowing ergometer. A processor chip in the dynamometer console uses changes in flywheel fan motion (acceleration and velocity), measured by a magnetic position transducer, to calculate work (J) each repetition. Since the moment of inertia of the flywheel calibrated at the factory is a known constant, the console calculates the component of work to overcome air–drag as a function of the speed of the flywheel and the air–drag coefficient (or 'load'). The air–drag coefficient is determined at the completion of each repetition from the deceleration of the flywheel. For all rowers the load was set at 120 with two air dampeners opened for leg pressing, and at 100 with all dampeners closed for the seated arm pulling.

Participants adjusted the set–up for leg pressing and seated arm pulling (or bench pull) exercise on the dynamometer before testing (http://concept2.co.uk/dyno/exercises). During horizontal leg pressing participants strapped their feet into an adjustable foot–stretcher, kept their back against a seat–rest and held onto seat handles. Leg pressing repetitions were commenced from a flexed knee position (i.e. the shin was vertical to floor) and completed at full extension. For seated arm pulling participants sat astride the bench pull seat and adjusted the height of the handle grips (attached to the vertical carriage rail post of the machine) to align with their elbows during flexion. Repetitions were commenced at full elbow extension and by keeping their chest against the support pad and feet positioned on the floor in a forward split–stance at all times, completed when the handles carriage rail reached the stops at the end of the support beam.

A console displayed the elapsed time and information about the cadence and work performed on completion of each repetition. As work is the product of the displacement and force, participants were advised to maximise the "length" and "strength" of each repetition effort they performed. Ten seconds after the completion of each test, the dynamometer console produced a summary of the average work per repetition. These data were recorded as the test result.

Test one involved 120 repetitions (120RM) of leg pressing within a target completion time of 240 seconds. All subsequent tests involved both leg pressing and seated arm pulling. Test two involved five repetitions (5RM, target time 10 s) with the best of three trials (three minutes rest between attempts) recorded as the result. Test three involved one trial of thirty repetitions (30RM, target time 60 s) and test four, 60 repetitions

(60RM, target time 120 s). A time sheet and timer were used to ensure each participant had a rest interval of at least ten minutes after any 5RM, 30RM or 60RM test; and that at least 20 minutes rest followed a 120RM test. Previous test-retest reliability trials associated with these methods established using a repeat measures design (same assessors and participants) in our laboratory were: CV = 2.5% to 6.2% and ICCs ≥ 0.96.

Free weight exercises

A one repetition maximum (1RM) load (kg) for the *power clean* was determined using free weights (Fitness Works Pty. Ltd, Auckland, New Zealand) within three sets (3 sets x 1RM) after warm up (3 sets, 75% to 90% of anticipated maximum), allowing three minutes rest and increments of 2.5 kg per attempt. A six repetition maximum (6RM) load (kg) for the *prone bench pull* (Fitness Works Pty. Ltd, Auckland, New Zealand) was determined within three sets after a warm up (3 sets, 70% to 85% anticipated 6RM), allowing three minutes rest and increments of 2.5 kg per attempt. *Bench pull power* was assessed by connecting and aligning a linear position transducer (IDM instruments Pty. Ltd, Hallam, Victoria Australia) to the path of the bar. Data was sampled at 200 Hz with the force time series processed by the Ballistic Measurement System software (version 2009 1.4, www.innervations.com, Australia) to compute peak concentric power (W). Previous test-retest reliability trials associated with these methods established using a repeat measures design (same assessors and participants) in our laboratory were CV = 2% to 5% and ICC ≥ 0.96.

Test Procedures

A common on– and off–water endurance taper (~50% reduced training volume) was performed by rowers, who maintained a similar diet and hydration status monitored throughout the duration of the twelve days of the investigation. On all test occasions, rowers were physically prepared by 'easy' rowing on an ergometer for at least 20 minutes prior to any initial test (apart from the aerobic condition test) to ensure maximal efforts were attained during assessment and to reduce measurement errors associated with procedures.

The five rowing ergometer tests were distributed over three consecutive days in place of regular endurance rowing (Day 1: 5000-m time-trial; Day 2: 60-minute distance–trial, and Day 3: 2000-m time–trial in morning, with 500-m time-trial and peak stroke power test scheduled in the afternoon). Five days later, the ten weight-room exercises were distributed over two training days, in place of normally scheduled strength and conditioning (Day 8: power clean (1RM), prone bench pull (6RM) and 120RM leg pressing, and Day 9: prone bench pull power (W), 5RM, 30RM and 60RM leg pressing and seated arm pulling Concept 2 DYNO tests). Finally, after two and one half days of rest, the seven-stage incremental power aerobic condition test with blood lactate response was performed (Day 12).

Statistical Analysis

All weight-room exercises (predictors) and rowing ergometer performance measures (dependent variables or outcomes) were determined and data presented as means ± SD.

Pearson correlation moments and respective 95% confidence intervals (95% CI) were calculated to determine the common variances shared between predictors and dependent variables. The determination and interpretation of correlation coefficients was dependent on fulfilment of statistical criteria, namely the assumption of normality, linearity and homoscedasticity in the distribution of data. These criteria were examined using SPSS histograms, normal probability plots, a Shapiro—Wilks' test, and bi-polar plots and least squares regression analysis. The interpretation of correlation moments was: r = 0.0 to 0.09 (trivial); 0.1 to 0.29 (small); 0.3 to 0.49 (moderate), 0.5 to 0.69 (strong); 0.7 to 0.89 (very strong); 0.9 to 0.99 (nearly perfect) and 1.0 (perfect) (Hopkins, 2002). A paired t-test was used to establish significant correlations between predictors and outcome variables (where $P \leq 0.05$). The magnitude of differences in correlations was taken to be significant where the 95% CIs did not overlap, or where $P \leq 0.05$ of the z-score transformation.

Simple linear and two-factor multiple-regression models of dependent variables were computed to determine predictors or combination of two predictors provided greater explained variances (i.e. $R^2 > 50\%$) for each rowing performance measure of interest. Co-linearity between predictors was assessed initially by cross-examination and exclusion from entry to regression models of highly correlated co-predictors (i.e. $r \geq 0.8$). Using SPSS (Version 17), stepwise and then staged backward-removal of the strongest predictors were computed against each dependent variable of interest. The probability of the change in explained variance (R^2 change) F-value for entry was ≤ 0.05, and for removal ≥ 0.10.

The strength of each model fit to the data (R of Model) was compared to use of the means by ANOVA, and considered satisfactory where $P \leq 0.05$. Selected models had lower standard error of the estimates (SEE) along with narrowly dispersed 90% CI for each of the b-value coefficients (i.e. did not include positive and negative values). To evaluate two-factor predictor models, partial and part correlations were examined to assess the common variance between each predictor and the outcome variable, and between each predictor and outcome variable while controlling for effect of other variables (i.e. the unique relationship of assessed variable). Selected models had Durbin-Watson values of around 2.0 in order to confirm the assumption that errors in regression were independent, variance inflation factors (VIF) less than 10 with average VIF values substantially less than 1.0 and tolerance estimates above 0.2 to ensure that multi co-linearity between predictors was eliminated. Models were excluded if the plot of predicted and the residual of the estimate and observed data displayed skewness, heteroscedasticity and non-linearity to plots.

Predictors identified in each selected regression models were tabulated against dependent outcomes with respective R^2 and SEE reported. For purposes of this study, these predictors were recommended by equipment type (i.e. dynamometry or ‘free weights’) as exercises or combinations of exercises for weight-room training.

Results

The mean ± SD for weight-room exercises and rowing ergometer performance data are reported in Table 5.1. 5RM Concept 2 DYNO tests resulted in greater average work than 30RM (leg pressing: +23%, and seated arm pulling: +30%), 60RM (leg pressing: +39%, and seated arm pulling: +51%) and in the case of leg pressing only, the 120RM test (+59%).

Table 5.1 Descriptive group means and standard deviations (SD) for Concept 2 DYNO, free-weights exercises and rowing ergometer measures (N = 19 males).

Tests	**Mean (SD)**		**Mean (SD)**
Concept 2 DYNO			
Leg pressing		Seated arm pulling	
5RM	921 (119) J	5RM	617 (95) J
30RM	748 (70) J	30RM	476 (63) J
60RM	665 (58) J	60RM	410 (47) J
120RM	581 (77) J		
Free-weights			
6RM Bench pull	81.6 (9.4) kg	Bench pull power	815 (117) W
1RM Power clean	92.3 (10.3) kg		
Rowing ergometer			
Peak stroke-power	892 (131) W	500-m	82.7 (3.8) s
2000-m	367.4 (10.4) s	5000-m	976 (27.6) s
60-min	17108 (521) m	Aerobic condition	322 (34) W

KEY: *J = Joules; s = Seconds; W = Watts; m = meters; kg = kilograms; RM = repetition maximum load.*

Highly correlated co-predictors were identified as 5RM, 30RM and 60RM Concept 2 DYNO tests (leg pressing range r = 0.9 to 0.96, and seated arm pulling r = 0.79 to 0.84), and prone bench pulling 6RM and power (r = 0.82; 95% CI = 0.57 to 0.94, P<0.01). A very strong correlation was found between 5RM leg pressing and 5RM seated arm pulling ($r = 0.78$; 95% CI = 0.46 to 0.92, $p<0.01$), and between the 60RM seated arm pulling and 120RM leg pressing ($r = 0.77$; 95% CI = 0.4 to 0.92, $p<0.01$). Given the observed magnitude of correlations, these co-predictors were not entered together in two-factor regression models of rowing performance.

The 1RM power clean was very strongly correlated to 6RM bench pull ($r = 0.77$, $p<0.05$) and strongly with bench pull power ($r = 0.66$, $p<0.05$). Power clean and Concept 2 DYNO correlations (leg pressing and seated arm pulling) were strong and ranged from $r = 0.59$ to 0.62 ($p<0.05$). Seated arm pulling assessments were strongly associated with 6RM prone bench pulling (range $r = 0.60$ to 0.66, $p<0.05$), but lower correlations were noted to prone bench pull power (range $r = 0.36$ to 0.5, $p>0.05$).

Significant correlations were observed between weight-room exercises and measures of rowing ergometer performance – Table 5.2. 5RM leg pressing ($r = 0.51$ to 0.69, $p<0.05$) and 6RM prone bench pulling tests ($r = 0.57$ to 0.75, $p<0.05$) and the higher repetition 60RM seated arm pulling ($r = 0.51$ to 0.66, $p<0.05$), were frequently observed predictors of rowing ergometer performance. Observed differences in correlation coefficients between predictors and performance factors of interest lacked statistical significance after z-score transformation.

Table 5.2 Correlations (95% Confidence Interval) between Concept 2 DYNO leg pressing (LP) and seated arm pulling (SAP) repetition maximum (RM) dynamometry, free weights exercises and rowing ergometer tests.

	PSP	**500-m**	**2000-m**	**5000-m**	**60-min**	**Aerobic condition**
LP 5RM	0.63** 0.20 to 0.86	-0.53* -0.81 to -0.05	-0.69** -0.88 to -0.30	-0.51* -0.80 to -0.02	0.50 0.01 to 0.8	0.58* 0.12 to 0.84
LP 30RM	0.56* 0.09 to 0.83	-0.54* -0.82 to -0.06	-0.60* -0.84 to -0.15	-0.47 -0.78 to 0.03	0.47 -0.03 to 0.78	0.42 -0.10 to 0.76
LP 60RM	0.43 -0.08 to 0.76	-0.42 -0.76 to 0.10	-0.54* -0.82 to -0.06	-0.48 -0.79 to 0.02	0.47 -0.03 to 0.78	0.42 -0.10 to 0.76
LP 120RM (N = 14)†	0.19 -0.38 to 0.65	-0.19 -0.65 to 0.38	-0.32 -0.73 to 0.25	-0.21 -0.67 to 0.36	0.20 -0.37 to 0.66	0.29 -0.28 to 0.71
SAP 5RM	0.54* 0.06 to 0.82	-0.53* -0.81 to -0.05	-0.58* -0.84 to -0.12	-0.30 -0.69 to 0.23	0.32 -0.21 to 0.7	0.50 0.01 to 0.8
SAP 30RM	0.47 -0.03 to 0.78	-0.59* -0.84 to -0.13	-0.59* -0.84 to -0.13	-0.39 -0.74 to 0.13	0.39 -0.13 to 0.74	0.46 -0.05 to 0.78
SAP 60RM	0.49 -0.01 to 0.79	-0.58* -0.84 to -0.12	-0.66** -0.87 to -0.24	-0.46 -0.78 to 0.05	0.51* 0.02 to 0.8	0.61* 0.16 to 0.85
1PC	0.72** 0.35 to 0.90	-0.78** -0.92 to -0.46	-0.63** -0.86 to -0.20	-0.43 -0.76 to 0.08	0.24 -0.29 to 0.66	-0.3 -0.69 to 0.23
6BP	0.75** 0.40 to 0.91	-0.78** -0.92 to -0.46	-0.68** -0.88 to -0.28	-0.57* -0.83 to -0.10	0.42 -0.10 to 0.76	-0.17 -0.61 to 0.36
BPP	0.82** 0.55 to 0.94	-0.74** -0.90 to -0.39	-0.53* -0.81 to -0.05	-0.37 -0.73 to 0.15	0.28 -0.25 to 0.68	-0.21 -0.64 to 0.32

KEY **P<0.05; **P<0.01; PSP = Peak stroke power; 1PC = 1RM Power clean; 6BP = 6RM Bench pull; BPP = Bench pull power*

Table 5.3 summarizes weight-room exercises that shared greater variances (R^2 = 46% to 68%) with elite rowing peak stroke-power, 500-m and 2000-m ergometer performance with a comparison shown to rowing ergometer tests alone (R^2 = 75% to 83%). Single factor regression models using weight-room exercises were not useful to predict aerobic condition, 5000-m or 60-min ergometer tests (R^2 < 33%)

Table 5.3 Summary of weight-room exercises (predictors) for rowers by equipment type that shared greater explained variances with elite rowing ergometer performance measures (all ANOVA of models P < 0.05).

	Peak stroke-power	**500-m**	**2000-m**
Concept 2 DYNO	Leg Pressing 5RM (J) R^2 = 39%, SEE = 85.9 W	Seated Arm Pulling 30RM (J) R^2 = 35%, SEE = 2.5 s	Leg Pressing 5RM (J)$^{\Delta}$ R^2 = 47%, SEE = 6.8 s
Free weights	Bench Pull Power (W)$^{\Delta}$ R^2 = 68%, SEE = 62.8 W	1RM Power Clean (kg)$^{\Delta}$ R^2 = 61%, SEE = 1.9 s	6RM Bench Pull (kg) R^2 = 46%, SEE = 6.9 s
Rowing ergometer (comparison)	NA	Peak stroke-power (W) R^2 = 83%, SEE = 1.27 s	500-m (s)† R^2 = 75%, SEE = 4.7 s

KEY: J = Joules; s = Seconds; W = Watts; m = meters; kg = kilograms; RM = repetition maximum load; SEE = Standard error of the estimates; $^{\Delta}$ = *recommended exercise combination..* † When 500-m and aerobic condition was regressed on 2000-m time, R^2 increased from 75% to 92% (SEE = 2.8 s).

The recommended combinations of weight-room exercises for program prescription and/or assessment (monitoring) of elite rowers which explained greater variances in rowing peak stroke power, 500-m or 2000-m time performances are summarized in Table 5.4. Two-factor multiple regression models using weight-room exercises were not useful (R^2 < 33%) to predict aerobic condition, 5000-m or 60-minute outcomes. Combinations including power cleans (kg) and bench pull power (W), 5RM leg pressing (J) and 6RM bench pull load (kg) were identified as the main weight-room exercises recommended to predict specific measures of rowing performance. On the basis of coefficient estimates (B-values), the greater explained variance of two-factor predictor models (R^2 = 59% to 73%) lacked significance ($P > 0.05$) to population groups other than the specific sample of elite rowers examined in this investigation.

Table 5.4 Recommended combinations of weight-room exercises (predictors) for program prescription and assessment of rowers in context of specific measures of elite rowing ergometer performance (all ANOVA of models $p < 0.05$).

	Peak stroke-power	**500-m**	**2000-m**
Weight-room exercise predictors only	Bench Pull Power (W) + 1RM Power Clean (kg)$^{\Delta}$ R^2 = 73%, SEE = 59.6 W	1RM Power Clean (kg) + Bench Pull Power (W)$^{\Delta}$ R^2 = 70%, SEE = 1.75 s	LP 5RM (J) + SAP 60RM (J) R^2 = 57%, SEE = 6.40 s LP 5RM (J) + 6RM Bench Pull (kg)$^{\Delta}$ R^2 = 59%, SEE = 6.3 s
Rowing ergometer test and **weight-room predictors** (comparative)	NA	PSP (W) + SAP 30RM (J) R^2 = 87%, SEE = 1.18 s	500-m (s) + LP 5RM (J)* R^2 = 82%, SEE = 4.15 s PSP & SAP 60RM* R^2 = 79%, SEE = 4.5 s

* Beta and b-value of factor entry significant ($p < 0.05$). KEY: J = Joules; s = Seconds; W = Watts; m = meters; kg = kilograms; RM = repetition maximum load; LP = Leg Pressing; SAP = Seated Arm Pulling; SEE = Standard error of the estimates; $^{\Delta}$ = *recommended exercise combination.*

Discussion

Exercises used during weight-room training that can provide robust diagnostics about an individual's strengths or weaknesses as a rower are of interest to coaches and rowers alike. This study identified strength, power and muscular-endurance weight-room exercises were strong predictors of rowing peak stroke-power, 500-m and 2000-m performance. Therefore, practitioners who wish to select exercises for training, which periodically could be used as assessments indicative of potential success in these rowing performance measures, should consider including (1RM) power cleans, (6RM) bench pulls, (5RM) leg presses or (60RM) seated arm pulling as part of strength and conditioning plans.

In this study, no single weight-room exercise emerged as a 'universal determinant' of the various rowing performance measures. That is, predictors varied in accordance with the specific rowing ergometer performance measure of interest, highlighting the diverse range of muscular requirements to excel at rowing (Table 5.4). Including a range of strength (5RM leg press and 6RM bench pull), power (1RM power clean and bench pull power) or muscular-endurance (60RM seated arm pulling) exercises year-round would therefore seem good strength and conditioning practice. Alternatively, these recommended exercises might periodically be used as tests to evaluate training efficacy, which may facilitate a better understanding of effect-mechanisms between weight-room training and rowing performance. However, the balance between time required, information gained, energy demands or risks in administering a range of weight-room exercises as tests, should not be overlooked. For example, very strong correlations indicated a high degree of common variance was shared between 5RM, 30RM and 60RM seated arm pulling Concept 2 DYNO tests (range $r = 0.79$ to 0.84); thus, any small advantages in terms of explained variance gained on including a 60RM, could be outweighed by the extra duration and effort required, when compared to the briefer 30RM ($r = 0.84$, $P<0.05$).

Unsurprisingly, linear regression analysis confirmed the greater specificity of ergometer data (R^2 range 75% to 83%) over weight-room dynamometer data (R^2 range 35% to 47%) or free weights exercise (R^2 range 46% to 68%) in the determination of rowing peak stroke-power, 500-m and 2000-m performance. Coaches might therefore consider ergometer tests as better measures for rowers, negating any need for weight-room testing other than for the assignment of loads for strength exercise. However, from this study, it was observed that ergometer and weight-room exercises in combination were better determinants of rowing performance together, than either measure in isolation. For example, peak stroke-power with either 30RM or 60RM seated arm pulling, accounted for 87% of 500-m time and 79% of 2000-m time, respectively (Table 5.4). It is also worth considering that, unlike ergometer testing, weight-room exercise data may prove useful determinants for rowers unable to participate fully in rowing testing, due to injury (e.g. low back).

Weight-room exercises shared little common variance with aerobic condition (five repetition leg pressing, $r = 0.58$, $r^2 = 34\%$), 5000-m (6RM prone bench pull: $r = -0.57$, $r^2 = 33\%$) or 60-minute rowing performances (60RM seated arm pulling: $r = 0.51$, $r^2 = 26\%$). This is not unexpected, given the ability to sustain stroke-power and stroke-rating is more strongly associated with the ability to aerobically metabolize fuel substrates (Hagerman, 1984; Secher, 1993; Shephard, 1998). However, we were surprised that the 120RM (four-minute) leg pressing test was not found to be a predictor of rowing endurance performance (e.g. 60-minute $r = 0.20$, 95%CI = –0.37 to 0.71), given previous research. Elite rowers are likely to have similar aerobic power (Ingham, et al., 2002; Maestu, et al., 2005; Nevill, et al., 2011); thus, we suspect within this elite group, differences in 60-minute ergometer performance were not adequately explained by muscular endurance. It may also be the case that specific tapering was required for the 120RM test.

In terms of the 'gold-standard' 2000-m time-trial, 5RM leg pressing in combination with either 60RM seated arm pulling or 6RM bench pull exercise, were found to be strong co-predictors of performance (R^2 = 57%; SEE = 6.4 s, and R^2 = 59%; SEE = 6.3 s, respectively) and thus recommended for weight-room exercise or assessment. It may be that intensive lower-body strength exercise, in combination with either high- or low-repetition upper-body exercise provides a training stimulus of equal relevance to 2000-m performance, for rowers of comparable aerobic power (Ebben, et al., 2004; Gallagher, et al., 2010). Maximal loads (1RM power clean (kg), r^2 = 61%) and upper-body power (bench pull power (W), r^2 = 52%) tests were also very strong determinants of 500-m time (R^2 = 70%, SEE = 1.8 s; see Tables 5.3 and 5.4). In this study, approximately equal shared variances in 2000-m ergometer performance could be explained using either 500-m time (r = 0.87) or aerobic condition (r = 0.82); which together, account for up to (R^2) 92% of 2000-m performance. Therefore, if rowers have no technique or injury concerns, we recommend power cleans (1RM) and prone bench pulls (using 6RM loads) are included as part of weight training and/or strength testing.

Isoinertial exercises like prone bench pulls do not offer the most practical mode for the assessment of strength qualities over a wide continuum of repetition maximums (e.g. 6RM, 30RM, 60RM or 120RM) given a trial and error approach to load selection. Rowers may also be concerned about the possibility of (temporary) rowing performance losses or the risk of injury perceived with muscle soreness associated with such assessments (Gee, French, et al., 2011). In contrast, the dynamometer (DYNO, Concept 2 Inc.; Morrisville, USA) provided an accommodating concentric only drag–inertia resistance to quantify average repetition work readily during leg pressing or seated arm pulling exercise. While the dynamometer has been used to assess rowers in a field setting (Gee, Olsen, et al., 2011) we were unable to find any published research to justify dynamometer testing protocols. We observed from our study that, apart from minimizing muscle soreness, specific RM dynamometer protocols appeared to be both reliable and valid measures (i.e. shared strong common variances with specific measures of rowing performance) for rowers (see Tables 5.3 and 5.4). Indeed, the dynamometer made the administration of tests both practical and efficient for the assessment of strength qualities using an array of repetition maximums. As the dynamometer was simple to operate, was portable and in the opinion of the authors, proved robust for testing or training, it may provide sport scientists and rowing coaches with the opportunity to administer tests efficiently to a broad range of individuals with diverse training histories for sport selection purposes.

Without doubt, the validity of any strength or muscular endurance weight-room exercise should be evaluated in context of models incorporating on-water performance data (2000-m time or rank). That is, efficiency on an ergometer is only a rough estimate of on-water rowing performance. Research indicates 2000-m ergometer times appear only useful for performance models which are constrained to small boat crews, such as singles, doubles or pairs, and even then, only modest predictive certainty of on-water performance is attained (R^2 = 0.60 to 0.55, SEE 4.3 – 5.4 s) (Mikulic, et al., 2009). Moreover, while allometric scaling to normalize 2000-m ergometer times improved prediction of single sculling rowing speed (R^2 = 59.2%, error 3.1%), the significant effect of body mass on boat drag cannot be overlooked

(Nevill, et al., 2010). However, there are limitations to the reliability and precision of such on-water testing due to large standard error of the estimates of data (Mikulic, et al., 2009). Accordingly, sport scientists and coaches will continue to use an array of physiological data considered important in the monitoring and assessment of the rower's physical development off-water (500-m time-trial, power at 4 mmol lactate, or one-hour distance challenge) (Maestu, et al., 2005) while on-water trials continue to be used to determine combinations and seat positions of rowers within crews (i.e. seat racing).

In summary, a range of strength, power and muscular endurance measures from weight-room exercises seemed to be strong predictors of specific ergometer tests used to assess elite rowers, notably the 2000-m or 500-m time-trial or a peak stroke-power test. Therefore, practitioners who wish to select exercises for weight-room training or researchers seeking assessments for training interventions indicative of rowing strength qualities, should consider (1RM) power cleans, (6RM) bench pulls, (5RM) leg presses or (60RM) seated arm pulling as part of strength and conditioning plans.

Practical Applications

This study examined an array of weight-room strength, power and muscular endurance exercises involving knee extension (leg pressing), shoulder adduction (seated arm pulling and prone bench pulls), and whole-body activities, such as the power clean. These activities are commonly prescribed as part of the weight-room training of rowers and therefore could also be used periodically as valid assessments of development. However, due to the level of skill and perceived potential risk of injury associated with traditional free weights such as delayed on-set of muscle soreness and/or acute muscle damage (Gee, French, et al., 2011), isoinertial exercises may not be as easily administered with ‘novice’ or ‘untrained’ individuals. Subsequently, the portable air-braked concentric only accommodating resistance provided by the Concept 2 DYNO, appears highly suitable for testing rowers who are not performing weight-room training (e.g. as part of controlled research designs) or more particularly, individuals participating in testing as part of ‘talent identification’ programs for rowing.

Chapter 6 – Does extensive on-water endurance rowing increase strength and muscular-endurance?

Prelude

In the previous chapter, the attainment of greater strength, power and muscular-endurance was found in part, to explain variances in rowing (ergometer) performances of superior rowers. The strongest correlates and best two-factor strength determinants of 2000-m were the 5RM leg press and 6RM bench pull tests. Subsequently, unless a coach is intent on developing peak stroke-power or 500-m speed, it is recommended these strength tests are used to assess and monitor the progress of rowers. However, if benchmarks are to be set for strength testing or training, a coach or rower must be convinced that the attainment of such targets from weight training has good odds of improving performance. A strong correlation between strength testing and rowing performance data does not imply there is a 'cause' and 'effect' for weight training. It may be that increases in strength are steadily acquired over a number of years, as endurance training volumes gradually raise. In other circumstances, a coach must be informed of any risks on substituting weight-training for rowing if inclement weather, injury or pain associated with rowing (e.g. low back) necessitate cross-training. For example, coaches may be concerned that rowers risk compromising their aerobic condition or gain undesirable body–mass on commencing weight training. However, there are constraints in the current knowledge and it remains unclear whether any compromises in aerobic condition, strength or body mass are realised on substitution of weight-training for rowing, hence the purpose for the following investigation.

Introduction

Periodisation of training is believed to enhance performance (Bell, et al., 1991; Bell, et al., 1993; Ingham, Carter, Whyte, & Doust, 2008; Ingham, et al., 2002; Nevill, et al., 2011). Over the past 30 years, increases in training volume of more than 20% have resulted in polarizing views about physical preparation models (Fiskerstrand & Seiler, 2004). In particular, some doubt has been raised with respect to the benefits of resistance (or weight) training as part of the integrated training plans of amateur and professional rowers (Gee, Olsen, et al., 2011; Gee, French, et al., 2011).

Considering the range of impulses required to change boat inertia from the start to the finishing stroke-rating burst of a typical 2000-m race (Hartmann, et al., 1993), the inclusion of weight training might be beneficial for a range of strength, power or endurance 'adaptation windows'. Senior elite rowers are stronger than their less successful peers, whether through genetic endowment, successive years of rowing, or the diligent pursuit of weight training (Hahn, 1990; McNeely, et al., 2005; Secher, 1975). Maximal strength training has consisted of 12RM loads progressively increased to heavier 5RM loads (Ebben, et al., 2004) or 5RM loads progressively increased to sets varying in load between 1RM and 5RM (Gallagher, et al., 2010). In contrast, strength endurance training has utilized loads ranging between 15RM and 32RM. Ebben et al. (2004) concluded that rowers with greater training experience benefited from maximal strength training, while novice rowers benefited from strength endurance training. Gallagher et al. (2010) reported no significant short term performance improvements from the inclusion of either low or high load strength training, nor were any detrimental outcomes observed when compared to endurance only controls. However, low subject numbers, imprecise assessment of changes in strength and strength endurance and unequal training volumes between control and intervention groups (extra two hours exercise per week), make the interpretation of effect sizes in these studies problematic.

Given the marginal performance changes observed (e.g. <3.5% over 8 weeks), known pacing strategies and errors of measurement associated with 2000-m racing (e.g. typical error as a coefficient of variation ~2.0%) (Kennedy & Bell, 2003; Schabort, et al., 1999; Webster, et al., 2006), it seems unlikely that benefits attributable to strength training could be differentiated within short duration interventions, yet alone on recruitment of highly trained rowers. The aerobic condition (e.g. ventilation breaking point or estimated power at blood lactate of 4 mmol/L) has been suggested to be a sensitive measure of (individual) change, and argued to be a proxy of the on-water performance ability of rowers (Maestu, et al., 2005; Nevill, et al., 2010; Secher, 1993).

Concurrent maximal strength and aerobic endurance training however, appears somewhat counter–productive in the development of strength (Garcia-Pallares & Izquierdo, 2011; Izquierdo-Gabarren, et al., 2010). It may be the case that, regardless of the inclusion of weight training, the attenuation of strength adaptations over the shorter term, marginalized any differences in performance outcomes (De Souza, et al., 2007). The purpose of this study was to compare changes in the aerobic condition, strength and muscular-endurance of elite rowers, following 8-weeks of extensive on-water endurance rowing only or in combination with weight training.

Methods

Participants

Twenty two elite rowers (males = 12, females = 10) volunteered for this study conducted "off-season" (Table 6.1). Five weeks earlier, these rowers had competed in 'A finals' at World Rowing Championships, and included six gold and two bronze medallists and 10 gold and one bronze medallists in the under-23 age category.

Institutional review board approval was granted, in the spirit of the Helsinki Declaration and voluntary signed informed consent was attained after rowers attended project information and familiarisation seminars. Rowers who were cleared by medical staff for participation in regular training were allowed to test.

Table 6.1 Rower characteristics (means ± SD)

	No. of participants	**Age (years)**	**Rowing experience (Years)**	**Height (cm)**	**Body Mass (pre-kg)**	**2000-m (s)[a]**
Rowing plus weights:	12 (9 males, 3 females)	24.7 ± 4.2	9.8 ± 4.4	186.6 ± 7.0	84.7 ± 8.4	380.6 ± 20.2
Rowing only:	10 (3 males, 7 females)	24.0 ± 3.6	8.2 ± 2.9	184.1 ± 7.9	83.3 ± 13.7	392.4 ± 29.4

[a] Data from National Rowing Centre of Excellence. *Note*: No differences between groups (P<0.05).

Design

A pre post study design was used to establish differences in performance measures of interest, with participants assigned by national selectors to squads that performed on-water endurance rowing either with or without the addition of weight training.

Assessments

Aerobic condition

The aerobic condition was assessed using a seven–stage incremental test performed on an air-braked rowing ergometer (Concept 2 Model D, Concept 2 Inc, Morrisville, Vermont, USA) with the drag factor set to 110 for females and 130 for males. Participants had access to the console information, which included the elapsed distance (meters), test time (minutes and seconds), 500-m interval time/splits (minutes and seconds) and average stroke–rate per minute. At the completion of each six–minute stage the workload was increased by 15 Watts by increasing stroke rate, until blood lactate equalled or exceeded 6 mmol/L. The blood lactate response was determined using a Yellow Spring Instruments 2300 blood lactate analyser (Ohio, USA) from a 25µl pipette sample drawn from the earlobe within 30 s of the commencement of the one-minute rest interval allowed between stages. From these data, average power at 4 mmol/L was determined using scatter plot graphing (MS Excel). Previous test-retest reliability was (Coefficient of Variation (CV) = 2.0% - 3.1%; Intra-class Correlation Coefficient (ICC) $\geq$ 0.96) (Hopkins, et al., 2001; Schabort, et al., 1999).

Leg pressing and seated arm pulling dynamometry

A "Dynamic Strength Training" dynamometer (Concept 2; Illinois, USA) was used to measure average concentric work produced during leg pressing and seated arm pulling exercise. The dynamometer provided resistance by flywheel inertia combined with air braking fans to create drag, comparable in design with a Concept 2c rowing ergometer.

The drag factor was set with two air dampeners opened for leg pressing and with all dampeners closed for the seated arm pulling.

Muscle strength and endurance were assessed over a number of repetitions. For each test, a repetition was commenced every two seconds. Test one required five maximal effort leg press repetitions and lasted approximately 10 seconds. Three trials of the five repetition leg press test were performed, with at least three minutes between attempts, with the best result recorded. Test two involved one trial of thirty maximal effort leg press repetitions and lasted approximately 60 seconds, while test three involved one trial of 60 maximal effort seated arm pulling repetitions and lasted approximately 2 minutes.

Rowers were familiar with the equipment and test protocols, and attempted to maximise the amount of work they could achieve for each test. To ensure consistency of the test protocol, data were excluded from the analysis where the time taken to complete the test was more than 5 percent of the target time (target time ± 5%). Previous test-retest reliability of these tests in our laboratory were CV = 2.5% - 6.2%; ICC ≥ 0.96.

Isometric pull

The isometric pull was used to assess the strength of the legs, torso and arms. The isometric pull involved pulling against an immovable barbell adjusted to the height of the rower's knee and held in place by the adjustable safety bars within in a power rack (Fitness works Pty. Ltd, Auckland, New Zealand). Rowers performed 4 x 5 seconds trials, progressing from 50% to 100% of their anticipated maximum, with up to 2 min rest between trials. Rowers were observed to ensure each attempt was performed without flexion of the lumbar spine.

During the test, the rower stood on a force platform (400 Series Performance Plate, Fitness Technology, Adelaide, Australia). Vertical ground reaction force data were collected at 200 Hz then analyzed via the Ballistic Measurement System software (version 2009 1.4, www.innervations.com, Australia. The greatest peak force of any trial was reported. Previous test-retest reliability of these tests were CV = ~3.5%; ICC ≥ 0.96 (McGuigan, et al., 2010).

6RM Bench pull

The prone bench pull (or row) assesses the pulling (shoulder adduction) strength of the upper torso and arms. A specifically manufactured raised bench was used for this test (Fitness works Pty. Ltd, Auckland, New Zealand). The bench height was adjusted so that the prone rower could not rest the plates of the barbell on the floor, when the rowers' hands were spaced about shoulder width apart using a pronated (overhand) grip. A repetition was invalid if during the test the bar failed to make contact with the bench, or the bar ascended unevenly (i.e. lateral tilt). A trial was terminated if two invalid repetitions were performed in sequence. Three warm up sets of three repetitions were performed, with loads progressing from 75%, to 83% and 90% of the anticipated maximum. The six repetition maximum (6RM) load (kg) was determined within five attempts, with up to three minutes rest between progressively increased loads (around 2.5 kg per attempt). Previous reliability of this method of testing in our laboratory was CV = 2%-3%; ICC > 0.96.

Training interventions

All endurance rowing exercise was performed on-water in single sculls, double sculls or sweep-oar pairs. Rowing was performed between 18 and 20 strokes per minute in order to attain an average boat velocity of between 80%-85% of world record pace for respective boats class, with individual target training zones for heart rate (~70-80% maximum heart rate) and lactate levels (~1-1.8 mmol/L) moderated, in accordance to fat-substrate energy 'utilisation zone two' (U2) training parameters.

Weekly training volume was progressed using a four-week step cycle (~5%-10% weekly increases in training distance), with a three-day loading pattern (2 x double sessions and 1 x single session) repeated twice each week (Table 6.2). Training distance ranged between 16 and 28 km a session, with total common weekly volumes between intervention groups ranging from ~190 to 210 km/wk. A coach accompanied each squad of rowers, to monitor training intensity and volume, and to provide instruction in execution of their technique.

In addition to the endurance rowing, the group assigned weight training performed two sessions to develop strength (6 exercises, 3–4 sets of 6–15 reps) and two sessions to develop muscular endurance (8 exercises, 3–4 sets of 25–50 reps). The intensity of strength exercise was progressively increased so that by the eighth week, fewer exercises and repetitions were performed (Table 6.3), in contrast, only the volume of muscular endurance exercise was progressed. In strength or endurance programmes, no repetitions were performed to 'failure' (i.e. repetition maximum load) (Izquierdo-Gabarren, et al., 2010).

Table 6.2 On-water endurance rowing template and schedule of intervention activities

	Training day						
	1	2	3	4	5	6	7
Early morning	20-28 km U2 (~16k U2 if strength training)	~20 km U2	AT 'pieces': 2000-m/ 5000-m time-trial 1-5 repetitions	20-28k U2 (~16 km U2 if strength training)	20-28 km U2 (~16 km U2 if strength training)	AT 'pieces': 5000-m/8000-m time-trial 1-3 repetitions	Rest
Mid-morning	INTERVENTION: Weight training (strength) or, ~16-18 km U2	INTERVENTION: Circuit weight training (endurance) or, ~16-18 km U2		INTERVENTION: Weight training (strength) or, ~16-18 km U2	INTERVENTION: Circuit weight training (endurance) or, ~16-18 km U2		
Mid-afternoon	~16 km U2	~16 km U2 More technique focus	Rest	~16 km U2	~16 km U2 More technique focus	Rest	

Note: AT = Anaerobic threshold (i.e. ventilation 'breaking point'); U2 = Utilization energy zone 2 (heart rate ~70-80% maximum)

To match training volumes (i.e. total weekly minutes of exercise), the group assigned to endurance rowing only performed additional U2 training on-water, for the equivalent on-water time to the group assigned weight training (~60-90 minutes), increasing total training volumes from ~250 to 270 km/wk.

Test procedures

At the beginning of the training and after two and one half days of rest (taper), the seven-step incremental aerobic condition work test with blood lactate response was performed, in place of normally scheduled endurance rowing. The following day, five maximal effort strength tests (i.e. isometric pull; 6RM bench pull: five repetition leg press, 30 repetition leg press and 60 repetition seated arm pull) were performed in place of normally scheduled strength training.

For the strength testing, rowers were assigned to a group of three – this allowed the appropriate work to rest ratio to enable sufficient recovery prior to progressing to the next strength test within the 90 minute session. However, participants could notify the researchers if they needed more time to prepare or recover between tests to ensure their best performance was measured. At the completion of the eight-week training intervention and commencement of the ninth training week following two and one half days rest, the aerobic conditioning and maximal effort strength tests were repeated.

Statistical analysis

All data are presented as means ± standard deviation (SD), unless otherwise stated. An independent t-test was used to compare differences in baseline measures. All pre and post intervention data were analysed using a spreadsheet for analysis of 'pre-post controlled trials' (Hopkins, 2006). Individual best scores were tabulated for all strength and aerobic condition measures and normalized by dividing by body mass (ratio scaling). All data were log-transformed prior to analysis to reduce non-uniformity of error, and adjusted for the gender of each rower as a covariate.

Percent and standardised mean changes in performance and differences between the changes were calculated, along with 90% confidence limits (CL) and respective p-values. Magnitudes of standardised effects were calculated by dividing the appropriate between-rower standard deviation and using a modified Cohen scale defined as: <0.2 = trivial, 0.2 - 0.59 = small, 0.6 - 1.19 = moderate, 1.2 – 1.99 = large, >2.0 = very large (Hopkins, 2006). The effect was deemed unclear if its confidence interval overlapped the thresholds for small positive and negative effects.

Results

There were no differences between rowing plus weights and rowing only groups in average age, rowing experience, height, arm-span, sitting-height, or body mass at commencement of the study.

In Table 6.4 reductions in body mass and improvements in aerobic condition, 6RM bench pull and 60 repetition seated arm pull were observed in both groups. The between groups standardized effect–size differences were trivial for body mass (ES [; ±90%CI] = 0.03; ±0.14, p=0.75), aerobic condition (ES = 0.15; ±0.28, p=0.37) and 6RM bench pull

(ES = 0.27; ±0.33, p=0.18), although a moderate positive benefit in favour of the rowing only group was observed for 60 repetition seated arm pull (ES = 0.42; ±0.4, p=0.08).

Only the rowing plus weights group improved isometric pull, five repetition leg press and 30 repetition leg press. The interpretation of the standardised effect sizes indicated these gains were moderate for isometric pull (ES = 0.66; ±0.44, p=0.02), moderate for 30 repetition leg press (ES = 0.4; ±0.33, p=0.05), and small but unclear benefits for five repetition leg press (ES = 0.18; ±0.26, p=0.25).

Table 6.3 Weight training strength and muscular endurance circuit programme

Weeks 1-4:	**Weeks 5 – 8:**
Strength Programme	
Two sessions a week 3-4 sets x 10-15 reps (progressively increased weight)	*Two sessions a week 3-4 sets x 6-10 reps (progressively increased weight)*
Dumbbell swings Alternate lunges One arm Dumbbell rows Incline bench Dumbbell press (alternate) Leg press Seated CB row Back extensions Lateral bends	Deadlifts Front or back squats Romanian deadlifts or prone bench rows Chin ups or lateral pulldowns
Muscular endurance circuit	
Two sessions a week *3 circuits x 25-35 reps (progressively increased repetitions)*	*Two sessions a week* *2 circuits x 35-50 reps (progressively increased repetitions)*
Supine pull-ups Alternating lunges Lateral pulldowns Step ups onto box (60cm) Press ups Squatting onto a box (30cm) Back extensions Calf raises (single leg at a time)	Activities unchanged.

Table 6.4 Percentage change in performance (± SD) and differences between group outcomes (log transformed data), adjusted for gender as a covariate

	Body mass	**Aerobic condition**	**IP**	**6BP**	**LP5**	**LP30**	**SAP60**
Rowing plus weights:	-2.8 ± 1.5%*	9.8 ± 4.4%*	12.4 ± 8.9%*	10.9 ± 6.5%*	4.0 ± 5.7%†	2.4 ± 5.4%†	8.5 ± 13.9%†
Rowing only:	-3.1% ± 2.7%*	11.6 ± 3.0%*	1.0 ± 8.8%	6.7 ± 5.3%*	1.4 ± 3.4%	-2.9 ± 5.2%	20.0 ± 6.9%†
Adjusted difference in group outcomes	0.3%	1.6%	-10.1%†	-3.8%	-2.6%	-5.2%†	10.6%
90% CL	-1.5% to 2.2%	-1.4% to 4.8%	-16.3% to -3.5%	-8.3% to 0.9%	-6.2% to 1.2%	-9.3% to -1.0%	0.7% to 21.4%

Note: IP = isometric pull; 6BP = 6RM bench pull; LP5 = 5-repetition leg press; LP30 = 30-repetition leg press; SAP60 = 60-repetition seated arm pulling; 90% CL = 90% confidence limits. † $p<0.05$, * $p<0.01$

Discussion

After factoring for technique and experience, the critical determinants of rowing ability encompass a range of well-developed physiological attributes including aerobic and anaerobic power, strength and muscle endurance. However, it remains unclear whether any benefit(s) over endurance rowing itself may be gained from the inclusion of weight training during the off-season training of elite rowers. The main finding of this study was that greater upper-body muscular endurance adaptations were observed following eight weeks extensive on-water endurance rowing, than with the addition of weight training. By contrast, even though almost half the total propulsive rowing stroke power is generated by the legs (Kleshnev & Kleshnev, 1998; Tachibana, et al., 2007), increases in lower body endurance and maximal strength were observed only with the inclusion of weight training.

In context of yearly planning, coaches or sport scientists may have concerns that a small compromise in one aspect of development in trade-off for gains in another may be detrimental to the performance outcomes of the modern elite rower. Subsequently, within the ‘off-season’ training ‘mix’ of the present study, we chose to evaluate whether concurrent sessions of strength and aerobic endurance exercise were counter-productive in the development of the other, and furthermore, whether the addition weight training exercise provided any benefit(s) to the development of lower and upper-body strength and muscular endurance of highly trained rowers.

Bell et al. (1988) reported that in sequencing five weeks of strength training (12 stations, 2-3 x 20 s, 4d/wk) prior to five weeks aerobic endurance training (40-60 min Concept 2 rowing ergometer, 5d/wk), greater increases in maximal aerobic power (i.e. 7.3% compared to 5.7%, $P < 0.05$) were observed in the strength-aerobic training group as compared to the alternate model (i.e. aerobic endurance prior to strength training). However, it was unclear whether any differences in adaptations in the upper-body occurred after the inclusion of hydraulic strength training. Similarly, Ebben et al. 2004 and later Gallagher et al. 2010 had limited success in separating benefits from strength (1RM-12RM) or endurance (15RM-32RM) weight training on 2000-m ergometer performance after eight weeks of intervention, but concluded that advanced rowers may do better to perform higher intensity strength exercise. However, the interpretation of benefit(s) from the inclusion of weight training was problematic, given training volumes and differences in strength adaptations between rowing and weight training groups were not reported.

We found only trivial gains in aerobic condition were attained (1.6%; 90%CL: -1.4% to 4.8%, P = 0.37) on substitution of four weight training sessions for an equivalent volume of endurance rowing. Nevertheless, given the negative effect on velocity of drag associated with boat buoyancy, an additional rationale for the exclusion of weight training may be to reduce any risk of gains in (lean) body mass associated with strength development. However, the differences observed in body mass changes following the avoidance of weight training in the present study were also trivial (0.3%; 90%CL: -1.5% to 2.2%, P = 0.75). Subsequently, there did not appear to be any argument for the exclusion of weight-training for additional endurance rowing, given equivalent gains in aerobic condition (rowing plus weights: 9.8% ± 4.4% and rowing only: 11.6% ± 3.0%) and reductions in body mass (rowing plus weights: -2.8% ± 1.5% and rowing only: -3.1% ± 2.7%) were observed after eight weeks training of elite rowers. For example, the endurance rowing only group had moderately reduced leg muscular endurance (30 repetition leg press: -5.2%; 90%CL: -9.3% to 1.0%, P = 0.05) and strength (isometric pull: -10.1%; 90%CL: -16.3% to -3.5%, P = 0.02) development when compared to rowers who also performed weight training (Table 6.4). Leg strength and muscular endurance are strong determinants (r = -0.5 to -0.7, P < 0.05) of 2000-m ergometer performance (Jürimäe, et al., 2010; Kramer, et al., 1994; Russell, et al., 1998; Shimoda, et al., 2009), and although limitations exist in past intervention research (e.g. absence of control group comparisons), increases in strength (i.e. 1RM leg press) with concurrently performed low-volume endurance exercise (<5 h/w), have been associated with improvements in 2000-m ergometer performance in novice and sub-elite rowers (Kennedy & Bell, 2003; Kramer, et al., 1983). Thus, it may be that on average the weight training group attained a slight off-water performance benefit.

However, it may also be that leg muscular-endurance and strength development might only benefit extensive endurance training or racing 2000-m on-water on attainment of sufficient upper-body endurance. Alternatively, on-water strategies that load the initial phase of the stroke (such as ‘half slide’ rowing) without proportional increase in load to the finish (i.e. shoulder adduction) in latter phases of preparation in build up to competition, may provide a surrogate training stimulus akin to the benefits attributable to weight training of the lower-body.

Nonetheless, it appears that a limitation to endurance rowing training may be the capacity of the individual’s upper-body muscular-endurance. That is, in comparison to weight training, the endurance rowing group demonstrated moderately greater upper-body muscular endurance trends (adjusted between group difference in 60 repetition seated arm pull: 10.6%; 90%CL: 0.7% to 21.4%, $P = 0.08$); with only trivial losses in maximal strength (adjusted between group difference in 6RM bench pull: -3.8%; 90%CL: -8.3% to 0.9%, $P = 0.18$). Greater gains in muscular endurance (60 repetition seated arm pull: 20.0% ± 6.9% compared to 8.5% ± 13.9%) would be due to the greater volume of shoulder and arm adduction repetitions performed during on-water rowing. For example, during weight training endurance circuits, approximately 200 repetitions of arm adductions were executed each session (Table 6.2), whereas at 20 strokes per minute for 60 minutes, the same muscle group performed some 1200 repetitions during on-water rowing. Of greater interest, was that large volumes of rowing exercise lead to comparable gains in upper-body strength (6RM bench pull:

6.7% ± 5.3% and 10.9% ± 6.5% for rowing only and rowing plus weights respectively). This may provide evidence that strength gains, rather than attenuated by extensive endurance exercise, may be equally well developed by high volume/fatiguing rowing.

In order to match training volumes between groups, the rowing only group spent a greater time 'on-water' and subsequently there was a greater exposure risk to rowing conditions (e.g. blisters, low-backache, chest-wall pain, heat-stroke or sunburn). Along with lower motivation to attain required training parameters (correct intensity or training pace), dehydration, time constraints for rest and/or personal hygiene issues (e.g. more regular bathing and washing of training clothes), any benefits associated with additional rowing, may be outweighed by benefits attained through weight training. Subsequently, large volumes of endurance rowing, while resulting in favourable upper-body adaptations, may not be sustainable for phases of greater than eight weeks in duration.

Practical applications

Weight training permits the distribution of training loads to targeted areas of the muscular system. Elite rowers or coaches might consider the incorporation of the occasional leg strength or endurance exercise (e.g. cycling or running) during the off-season, with recognition however, that such activities are less likely to improve strength relative to body mass as effectively as weight training. On the one extreme, should on-water or ergometry rowing not be possible due to inclement weather or injury, off-water 'cross-training' should consist of both extensive repetitious and intensive upper and lower body exercise to simulate muscular adaptations attained from extensive aerobic endurance rowing.

Conclusion

In conclusion, while gains in aerobic condition and upper-body strength after eight-weeks were comparable to extensive endurance rowing alone, weight-training lead to moderately greater gains in lower-body muscular-endurance and strength.

Chapter 7 – Does on-water resisted rowing increase lower-body strength?

Prelude

The majority of international regatta events in rowing are competed as crews. Therefore, closer to competition and in order to optimise boat speed, a coach must balance training for ‘fitness’ (i.e. strength, aerobic power or muscular endurance) against time required to refine the rowing ‘finesse’ of a crew (i.e. skill with the oar-blade, body technique and synchronicity of the crew). In the previous chapter, it was observed that after a fixed 8-week off-season training ‘window’ (October to December), lower-body strength and muscular-endurance gains were only attained on inclusion of weight–training. However, it may be the case that rowing ‘finesse’ and lower-body strength can be improved concurrently as a crew, on-water. Specific strategies such as towing ropes in the water to increase the drag acting on the boat are believed to develop the strength of the leg–drive. At present there is no evidence to support such claims. Therefore, this chapter investigates whether weight-training is indeed necessary closer to competition, when preparation plans for rowing are intensified.

Introduction

In context of yearly planning in rowing, coaches and sport scientists may balance small compromises in one aspect of physical development in trade off for gains in another. For example, strength or weight training has been traditionally emphasized during the 'off season', sequenced prior to the development of aerobic power (Bell, et al., 1988). Over recent decades (1970 to 2001), endurance volumes have increased by approximately 20% and total training time to more than 1100 hours a year among the rowing elite (Fiskerstrand & Seiler, 2004). With this increase in volume, emphasizing phases of strength over aerobic endurance has become problematic. Informed decisions about the value of weight training over other possible training activities in periodised plans for rowing need to be made.

Researchers have concluded that high volume (2-3 sessions for >16 weeks) non-fatiguing (i.e. prescribing fewer repetitions) heavy resistance [≥ 75% 1 Repetition Maximum (RM)] weight training concurrent to high volume endurance exercise, can lead to enhanced longer term (>30 min) and shorter term (<15 min) endurance performance gains, both in well trained and top level endurance athletes (Aagaard & Andersen, 2010; Bell, et al., 1993; Garcia-Pallares & Izquierdo, 2011; Izquierdo-Gabarren, et al., 2010). With regards to rowing, the leg drive and trunk swing provide almost 80% of total propulsive stroke power (Kleshnev & Kleshnev, 1998; Tachibana, et al., 2007). Furthermore, lower body strength has been reported as a strong predictor of 2000-m ergometer speed (e.g. leg pressing, $r = -0.69$, $P < 0.01$) (Jürimäe, et al., 2010; Kramer, et al., 1994; Yoshiga & Higuchi, 2003b) and positive benefits, of clinical and practical significance, have been associated with strength development of rowers (Bell, et al., 1991; Bell, et al., 1993; Ebben, et al., 2004; Gallagher, et al., 2010; Lawton, et al., 2011). However, 8 weeks of extensive endurance rowing (i.e. 250–270 km per week) was insufficient exercise alone to increase lower body strength in elite rowers, when compared to the gains made on inclusion of weight training [e.g. leg pressing (dynamometer): -2.9 ± 5.2%; P>0.05 and +2.4 ± 5.4%; P<0.05, respectively] (Lawton, Cronin, & McGuigan, 2012). Thus, some element of lower body weight training might be warranted to improve performance in preparation for competition, where practical.

Weight training however, may be excluded from rowing plans on the rationale of eliminating any risk of unnecessary body mass gains, which can negatively affect the drag velocity associated with boat buoyancy (Millward, 1987; Nevill, et al., 2010). If this is the case, alternative strategies to develop or maintain strength need to be employed in rowing. In terms of the lower body, strategies used to emphasize the 'leg drive' such as the towing of ropes ('resisted rowing') or rowing in pairs within a four person crew, are thought to provide a surrogate strength training stimulus highly specific to rowing. However, to the knowledge of these authors, the efficacy of such strategies to develop or to maintain lower body strength in comparison to weight training has not been reported. The purpose of this study therefore was to quantify changes in lower body strength following intensive resisted on-water rowing, either incorporating weight training or rowing alone.

Methods

Experimental approach to the problem

A pre-post cross over research design was developed to compare changes in lower body strength (dependent measures) from intensive resisted rowing alone or in combination with weight training (independent variable). A small population of elite rowers volunteered to participate in this 32-week study as part of their preparations preceding international competition (i.e. 2010 World Cup 2 and then 2010 World Championships). Given the small sample size, we selected dependent measures with very high intra-class correlation (ICC) moments to achieve satisfactory statistical power for investigation (i.e. ICC $\geq$ 0.96). We anticipated small differences in changes in the dependent measures [i.e. standardized differences in change of mean as an effect size $\leq$ 0.2 (Cohen) units] given the advanced training history and competitive level of participants. Therefore, the duration for each training intervention and thus independent variable was maximized (14 weeks) for the period rowers were available for study (i.e. 32 weeks). Rowers were randomly assigned by national selectors to an initial training intervention. After a 4-week 'washout' period, the alternate training method was performed (by the same rowers). Changes in lower body strength tests (dependent measures) were used to compare adaptations from resisted rowing practices alone, to weight training.

Subjects

Ten international elite (all 'A' finals bronze medallists at World Championships) female heavyweight rowers volunteered to participate in this study conducted 'pre-competition'. The characteristics mean (SD) of these rowers were: age and rowing experience 23.3 (4.1) and 7.0 (3.9) years; height 178.5 (4.2) cm; body mass 74.6 (5.3) kg, and 2000-m ergometer time 412.2 (7.6) s.

Institutional Review Board (IRB) approval for the study protocol was gained from the AUT University Ethics Committee. Written (signed) informed voluntary consent was attained from rowers after project information and familiarisation seminars were attended. All rowers were cleared by medical staff for participation in training and testing.

Assessments

Leg pressing dynamometry

A "Dynamic Strength Training" dynamometer (Concept 2 DYNO, Concept 2 Inc., Morrisville, VT, USA) was used to measure average concentric work (J) produced during five repetitions of leg pressing. The dynamometer provided resistance by flywheel inertia combined with air braking fans to create drag, comparable in design with a Concept 2c rowing ergometer. The drag factor was set with two air dampeners opened for leg pressing. For each test, a repetition was commenced every two seconds (or equivalent to a rating of about 30 repetitions per minute) to ensure all repetitions were performed within a target completion time (approximately 10 seconds). Three trials of each test were performed, at least three minutes between attempts, with the best score recorded as the test result. Previous test-retest reliability of this dynamometer strength test was: coefficient of variation (CV %) = 2.5%; ICC ≥ 0.97 (Lawton, et al., 2012).

Isometric pull

The isometric pull was used to assess the strength of the legs, torso and arms as previous research has shown successful national level rowers demonstrated superior strength in this exercise (Jensen, et al., 1996; Secher, 1975). The isometric pull involved pulling against an immovable barbell adjusted to the height of the rower's knee and held in place by the adjustable safety bars within in a power rack (Fitness works Pty. Ltd, Auckland, New Zealand). Rowers performed the isometric pull for 5 seconds, progressively building to their maximum effort, and up to 3 minutes rest was allowed between the 3 trials permitted for assessment. Rowers were observed to ensure each attempt was performed without flexion of the lumbar spine.

During the test, the rower stood on a force platform (400 Series Performance Plate, Fitness Technology, Adelaide, Australia). Vertical ground reaction force data was collected at 200 Hz then analyzed via the Ballistic Measurement System software (version 2009 1.4, www.innervations.com, Australia). The greatest peak force of any trial was reported as the test result. Previous test-retest reliability was CV = 3.5%; ICC ≥ 0.96 (McGuigan, et al., 2010).

Test Procedures

At the beginning of each training intervention dependent strength measures (leg pressing and isometric pull) were performed. During testing, rowers were assigned to a group of three – this allowed the appropriate work to rest ratio to enable sufficient recovery between trials. However, participants could notify the researchers if they needed more time to prepare or recover between tests to ensure their best performance was measured. Up to three trials were permitted for each test, with the maximum result reported. At the completion of the repeated 14 week training intervention, dependent strength measures were repeated (**Table 7.1**). All testing was repeated at the same time of day. A common on– and off–water endurance taper (~50% reduced training volume) was performed three days prior to testing and rowers maintained a similar diet and hydration status, monitored for the duration of the study.

Training Interventions

All on-water rowing exercise was performed in single, double or quadruple sculls. Endurance rowing was performed between 18 and 20 strokes per minute (spm) with a target average boat velocity of approximately 80% ± 5% of world record pace for respective boat classes. Individual target training zones for heart rate (~70-80% maximum heart rate) and lactate levels (~1-1.8 mmol/L) were moderated in accordance to 'utilisation two' (U2) energy substrate training parameters.

In addition, two intensive boat races were conducted each week that varied in distance from between 8000 m and 2000 m, and were either fixed (e.g. 24 spm) or free rating. Races were handicapped based on estimated completion time, and timed with rowers ranked by performance expressed as a percentage of world record times for each respective boat class.

Table 7.1 Pre-post crossover groups study design (n = 10)

Crew trials 1 week	Baseline strength measures	**Training intervention (14 weeks)**	Post strength measures	Competition (World Cups) 4 weeks	Baseline strength measures	**Training intervention (14 weeks)**	Final strength measures
Group A (N=5)	X	RO	X	Wash out	X	WT	X
Group B (N=5)	X	WT	X	Wash out	X	RO	X

KEY: X = testing conducted; WT = weight training phase; RO = rowing only phase.

Weekly training volume was progressed using a four week step cycle (~5% weekly increases in training distance), with a three day loading pattern repeated twice each week. Endurance rowing training distances ranged between 16 and 28 km a session, with total weekly volumes ranging from 190 to 210 km/wk (including warm up and cool down phases performed as part of interval and resisted rowing sessions). A coach accompanied each squad of rowers to monitor training intensity and volume, and to provide technical instruction in the execution of their rowing technique.

Resisted-rowing

On-water 'resisted rowing' was achieved by use of 'bungees' (elasticized straps wrapped around the hull attached to the gunnels) or partnered rowing (only two of the four person crew row the boat). Resisted rowing was performed twice each week. Work intervals varied from one to three minutes of resisted rowing, followed by three to six minutes of conventional rowing, repeated between seven and nine times. Stroke rating varied each repetition between 28 and 32 spm and the total interval session running up to one hour, with an additional 15 minutes warm up and cool down row.

Weight-training

Weight training consisted of one session of maximal strength (4 exercises, 3–4 sets x 6–15 reps) and muscular power (7 exercises, 3–4 sets x 15–30 reps) each week (Table 7.2). The intensity of strength exercise was progressively increased so that by the final week, fewer repetitions were performed, although no sets were performed to repetition failure.(Garcia-Pallares & Izquierdo, 2011; Izquierdo-Gabarren, et al., 2010) To equate for additional volumes (total time) when weight training was incorporated into the interventions, two endurance rows were shortened in duration or distance (e.g. less than 60 minutes or <16 km). All other on-water training remained consistent between training phases, including resisted rowing practices.

Table 7.2 Strength training interventions

Day 1: Strength Program	**Day 2: Power Program**
One session a week	*One session a week*
Deadlifts or power cleans	Hang cleans (40-45kg)
Back squats or leg press	Jump Squats (30-40kg)
Romanian deadlifts or prone bench rows	Prone Bench Rows (30kg-45kg)
Seated cable rows	Air-brake leg pressing (DYNO)
	Elastic cord seated rowing
Exercises performed in series. Injury and/or experience dictated actual exercise selection.	Hurdle jumping (15-30 jumps per set)
	Supine pull-ups
	Jump up onto box (30-60cm)
	Two exercises alternated (“super-setting”)
Weeks 1-5:	**Weeks 1-5:**
3-4 sets x 10-15 reps (increase weight) @90% of equivalent RM (i.e. 90% 10RM).	2 sets x [10-10-10] with 20 seconds rest between sub-sets using the lower suggested load.
Week 6 – 9:	**Week 6 – 9:**
3-4 sets x 6-10 reps (increase weight) @90% of equivalent RM (i.e. 90% 6RM).	3 sets x [5-5-5 reps] with 10 seconds rest between sub-sets, at the higher suggested load.

Statistical Analysis

All dependent strength measures data (leg pressing and isometric pull) was presented as means ± standard deviation (SD). Data was analyzed using a spreadsheet designed for 'analysis of pre-post crossover trials', with confidence limits (CL) set at 90% and smallest worthwhile difference or change in dependent strength measure means in standardized (Cohen) unit set to 0.2 (Hopkins, 2006). Individual best scores were tabulated for all dependent strength measures and normalized by dividing by body mass (ratio scaling). All data was log transformed prior to analysis to reduce non uniformity of error and adjusted for the pre test scores of each rower as a covariate.

Percent and standardized mean changes in dependent strength measures and differences between the changes were calculated, with P-values interpreted as significant where $P \leq 0.05$. Magnitudes of standardized effects were calculated by dividing the appropriate between rower standard deviation and using a modified Cohen scale defined as: <0.2 = trivial, 0.2 - 0.59 = small, 0.6 - 1.19 = moderate, 1.2 – 1.99 = large, >2.0 = very large (Hopkins, 2002; Hopkins, et al., 2009). An effect trend was deemed unclear if confidence intervals for standardized effects overlapped the thresholds for small positive and negative effects (i.e. 0.1 Cohen units).

Results

The percentage change in group means (± SD) and differences in dependent strength measures following 14 weeks of weight training or rowing alone, adjusted for pre-test scores can be observed in Table 7.3. Differences in body mass changes observed following weight training (0.5% ± 2.8%, P = 0.78) and resisted rowing alone (-0.6% ± 4.8%, P = 0.78) were trivial (ES = 0.17 ± 0.61, P = 0.61). After resisted rowing alone, leg pressing (-1.0% ± 5.3% P = 0.51) did not change (i.e. was maintained); in contrast, after weight training a moderate increase (+9.1% ± 8.5%, P = 0.01) in leg pressing strength was observed (ES = 0.72; ± 0.62, P = 0.03). Isometric pulling strength, while showing a trend to increase, was maintained on average whether 14 weeks of resisted rowing alone (+5.3% ± 13.4%, P = 0.28) or in combination with weight training (+12.3% ± 8.6%, P = 0.10) was performed. The likelihood that observed trend increases in isometric pulling was moderately greater after weight training was unclear (ES = 0.56; ±1.69, P = 0.52).

Table 7.3 Percentage change in group means (± SD) and differences in performance outcomes adjusted for pre-test scores (log transformed data).

	Body mass	**LP5**	**IP**
Rowing and weight-training:	0.5% ± 2.8%	9.1% ± 8.5%*	12.3% ± 8.6%
Rowing only:	-0.6% ± 4.8%	-1.0% ± 5.3%	5.3% ± 13.4%
% adjusted difference in performance outcomes	-1.1%	-9.3%	-6.2%
90%CL	-5.2% to 3.0%	-15.1% to -3.0%	-22.9% to 14.1%
P-value	0.61	0.03	0.52

KEY: *P = 0.01, IP = Isometric pull; LP5 = 5 repetition leg press; 90%CI = 90% confidence interval; 90%CL = 90% confidence limits.

Discussion

After a period of prioritization over the off–season, a rower may have little time or sufficient energy to commit to further strength training. In these circumstances, weight training might be ceased and replaced with intensive resisted on-water training practices such as towing ropes or paired crew rowing. Dependent on total volumes, resisted rowing may offer the potential for increased muscular strength, power or endurance. Additionally, any gains in lean body mass or strength would logically seem highly specific to the kinetic and kinematics requirements of rowing. Such practice may also be beneficial in terms of ensuring any lower body strength believed to enhance performance gained off-water may continue to improve or at the very least, be maintained. However, the main finding of the present study was that without the inclusion of weight training, the lower body strength development of individual rowers ceased (-1.0% ± 5.3% P = 0.51). In other words, resisted rowing resulted in maintenance of lower body strength at best. Conversely, the inclusion of two weight training sessions each week, resulted in a moderately greater increase (9.1% ± 8.5%, P = 0.01) in lower body strength (ES = 0.72; ± 0.62, P = 0.03). Therefore, rowers seeking further gains in lower body strength as part of preparations for competition should not rely on resisted on-water rowing practices for such adaptations.

To the knowledge of these authors, strength, power or muscular endurance adaptations following intensive on-water resisted rowing have not previously been published. Past intervention studies involving parallel trials with weight training contrasts in rowing, have not published strength data for non weight trained controls (Gallagher, et al., 2010). However, what was apparent from the literature was that on–water rowing was unlikely to achieve the mechanical, metabolic and hormonal stimuli required to maintain strength for extended periods (Kraemer, et al., 2002). For example, the isokinetic leg strength of elite oarsmen had effectively declined 12 – 16% by the end of a competition period after weight training was ceased for eight months (Hagerman & Staron, 1983).

In contrast, at sufficient intensity (i.e. 73.0 – 79.3% of predicted 1RM), oarswomen were able to increase leg pressing maximal strength development around 10 – 20% over 6 weeks, whether one or two weight training sessions were performed each week (Bell, et al., 1993). That is, weight training need not be too time-consuming or physically demanding, in build up to competition.

In terms of the present cross-over study, significant lower body strength gains (scaled relative to body mass) were observed when rowers performed weight training (leg pressing: +9.1% ± 8.5%, P = 0.01). In contrast, for a period of equal training volumes, rowers were unable to improve leg strength (leg pressing: -1.0% ± 5.3%, P = 0.51). Therefore, if it is believed a crew or rower may benefit from increased lower body strength relative to their body mass, they would be moderately worse off using on-water rowing techniques after 14 weeks, on omission of weight training (adjusted difference: -9.3%; 90%CL = -15.1% to -3.0%, P = 0.03). Furthermore, it was postulated that off-water strength training may be excluded from training or closer to competition on the rationale of eliminating any risk of unnecessary body mass gains, which can negatively affect the drag velocity associated with boat buoyancy in rowing (Millward, 1987; Nevill, et al., 2010). Our results suggested that differences in body mass changes were trivial (ES = 0.17 ± 0.61, P = 0.61) and there was no advantage gained from on-water resisted rowing alone (change body mass: -0.6% ± 4.8%, P = 0.78) on omission of weight training (0.5% ± 2.8%, P = 0.78). We concluded these variations in body mass were more likely to be associated with a rower's hydration status or dietary energy balance.

Interestingly, coaches have reported to the authors, acute improvements in the distance attained for a set number of strokes (at an equivalent fixed rating) for the work interval immediately subsequent to the resisted rowing, than without the use of such strategies. The benefits associated with these modest improvements observed on-water however, did not amount to any chronic change in lower body strength. While there may be acute performance benefit(s) associated with such observed trends, on the basis of the present data, we could only conclude that specific on-water resisted rowing practices were inadequate to develop leg strength.

In order to elicit a sufficient training stimulus to develop strength concurrent to technique development, it may be that the external work performed and thus physiological responses to resisted rowing, necessitate greater overload. For example, our investigations with force gates (Powerline™, Peach Innovations Ltd., Cambridge UK.) used to monitor the training of these rowers, confirmed increases in average propulsive stroke forces during resisted rowing. However, given a faster rate of energy utilisation associated with higher intensity work intervals (in comparison to steady state extensive endurance rowing), total session training volumes (duration) were reduced. Thus, we suspect any potential advantage associated with chronic strength development was limited with resisted rowing due to the inability to sustain any real net increase in either intensity (power) or volume of exercise.

Greater drag loads (i.e. more bungees) and/or training volumes may be required to develop maximal strength, should that be the intent of training. However, consideration must also be given to any increased risk(s) of injury to the low back (e.g. vertebral segments) given the trends we observed in isometric pull strength from rowing (+5.3% ± 13.4%, P = 0.28). Rowing involves repeated flexion cycles of the spine that exacerbate the risk of disc injury (Caldwell, McNair, & Williams, 2003; McGregor, et al., 2002; McGregor, et al., 2004; Reid & McNair, 2000). It may be the case that any further increase in training intensity (drag load) or volume (number of work intervals) over exposes rowers to the risk of low back injury.

In conclusion, on the basis of this study, 14 weeks of intensive on-water training including resisted rowing, maintained but was not able to increase the lower body muscle strength of rowers, which was in contrast to the effective integration of weight training.

Practical applications

Elite rowers or coaches might consider the incorporation of high intensity non-fatiguing weight training exercise as part of periodised training plans, if an increase in the lower body strength of a rower is desired, without any change in body mass. Furthermore, weight training permits the distribution of training loads to targeted areas of the muscular system such as the lower body, overcoming potential limitations associated with rowing exercise when injured (e.g. low back). However, lower body strength can be maintained but not increased over 14 weeks by the use of intensive on-water training and resisted rowing.

Chapter 8 – Factors which impact on selection of elite women sculling crews

Prelude

Although there may be great diversity in methods of preparation for competition, these philosophical differences in training are somewhat irrelevant, unless proven to develop specific attributes associated with rowing success. For example, on the basis of the findings from this research, clearly weight-training offers greater efficacy over rowing for the acquisition of lower–body strength and/or muscular–endurance gains. Given more than half the total propulsive power in rowing is developed by the leg-drive, it may be that rowers with superior leg strength perform better (faster) as a crew. As part of current selection policy in New Zealand, a 2000-m qualifying standard (i.e. < 7 minutes) is required for heavyweight women who wish to be considered for national crew selection. Differences between 2000-m ergometer times are therefore on average quite trivial (i.e. less than the typical error of measurement ~2%). It may be that leg strength testing may prove useful in refining crew selections. The purpose of this concluding study therefore, was to determine the relationship between lower–body strength and the on-water performance of crews.

Introduction

Based on world best times and dependent on crew size, boat type, and weather conditions, an Olympic 2000-m rowing event lasts somewhere between 5:20 and 7:28 minutes on-water. However, no common theory exists on criteria to appropriately select crew-rowers in pursuit of small performance gains as little as 0.3% in order to improve final rankings at World Cup or Championship regattas (Smith & Hopkins, 2011; Steinacker, Lormes, Lehmann, & Altenburg, 1998). Sport-science selection strategies are common and typically consider some aspect of anthropometry. Olympic female heavyweight rowers were significantly taller (1.81 ± 0.05m), heavier (76.6 ± 5.2 kg, $p<0.01$) and of greater sitting height (93.7 ± 3.1 cm) than non-rowers, and when compared to their less successful competitors, had lower skinfold sum for 8-sites (82.1 ± 23.2 mm vs. 99.8 ± 20.4 mm) (Kerr, et al., 2007). Successful senior rowers were also on average significantly taller (+5.4 cm), heavier (+11.1 kg) (Mikulic, 2008), and had longer arm span and greater sitting height than junior rowers (Kerr, et al., 2007). Height ($r = -0.81$), body mass ($r = -0.85$), as well as fat free mass ($r = -0.91$) are some of the simplest measures and strongest correlates of 2000-m rowing ergometer performance (Yoshiga & Higuchi, 2003b). However, such differences within elite crew-boats may be less likely; and as stature characteristics are genetic and dependent on maturation rates, they cannot be influenced by training.

In terms of possible physiological selection criteria, Hay (1968) reported that a 6-min rowing ergometer test was the strongest correlate of rank-orders of twenty rowers based on ‘rowing-ability’ agreed on by five experts (Spearman’s rho = 0.89). Similarly, Kramer et al. (1994) established the best two-factors to reflect overall ‘rowing-ability’ (as determined by coach rank-order) from a suite of descriptive, field and laboratory tests, were 2500-m ergometer speed (rho = –0.86) and competitive experience (rho = –0.91). In both cases, given knowledge of past performance in testing and competition, such strong interrelationships between factors indicated bias in expert judgments existed in the ranking of rowers.

Various protocols to assess individual physiological relationships between rowing ergometry and rowing ability have been utilized (Ingham, et al., 2002; Kendall, et al., 2011; Kramer, et al., 1994; Mikulic, et al., 2009; Nevill, et al., 2011). Yet, ergometry assessments are only a rough guide of on-water crew performance outcomes (Mikulic, et al., 2009; Nevill, et al., 2010). Many ‘boat–stoppers’ are argued to have found their way into crews when assigned on the basis of such data (Hay, 1968). Annual 2000-m ergometer performance improvements are also likely to plateau on reaching champion-elite status in ‘A–final’ regattas (i.e. ± 0.3%) (Mikulic, 2011). Given pacing strategies and errors of measurement associated with 2000-m ergometer assessment (e.g. typical error as a coefficient of variation ~2.0%) (Kennedy & Bell, 2003; Schabort, et al., 1999; Webster, et al., 2006), establishing meaningful performance differences (e.g. ≤1.0%) between highly-trained rowers would be difficult and therefore problematic for crew selection purposes.

Gallagher et al. (2010) proposed that the practical significance of differences in 2000-m ergometer performance gains associated with strength were noteworthy, and equivalent to almost a boat length or 4 s on-water. In particular, lower-body strength appears to account for performance differences between individuals of varying rowing ability, with strong, possibly curvilinear associations reported with 2000-m ergometer performance and simulated 6-minute on-water racing (Bell, et al., 1989; Hahn, 1990; Jensen, et al., 1996; Jürimäe, et al., 2010; Kramer, et al., 1994; Pyke, et al., 1979; Yoshiga & Higuchi, 2003a). In practical terms, relatively large differences in lower-body strength may be required to account for comparatively small although important performance outcomes between elite rowers. However, the role of strength and particularly leg strength in predicting crew performance and the selection of individual rowers is unknown.

Given the preceding information, the purpose of this study was to establish whether lower-body strength, anthropometry, or rowing ergometry accounted for performance differences observed between 'selected' and 'non-selected' rowers contesting representation in national sculling crew-boats. Current national crew-boat selection strategy in New Zealand is based on each rower's ability to contribute to on-water boat-speed, methodically determined by 'seat-racing'. Seat–racing trials involve head-to-head races between two crews, after which rowers are switched between boats. Seat–racing trials overcome most standard error of the estimates (SEM) associated with comparing boat speed (s) (Mikulic, et al., 2009), as contrasts are based on finish-order (crews) then (individual) rankings between rowers under identical environmental conditions. Therefore, once crew combinations have been 'trialed', objective factors thought to differentiate between 'faster' and 'slower' crews can be examined. To the knowledge of these authors, this is the first study to investigate factors influencing actual crew selection outcomes.

Methods

Study Design

This study compared mean (± SD) differences in anthropometry, 2000-m ergometer time and lower-body strength between 'selected' and 'non-selected' crew-scullers, subsequent to national selection seat-racing trials. Twelve elite females performed a 2000-m ergometer time-trial, a five repetition leg-pressing dynamometer test, were anthropometrically profiled, and participated in on-water national crew 'seat-racing' trials conducted at the commencement of a four month competition phase. Log transformed data were analyzed to compare percent (± SD) and standardized differences in group means [ES; ±90% Confidence Interval (CI)] between selected and non-selected oarswomen, with adjustments for covariates as appropriate.

Subjects

Twelve elite females age 23.1 ± 3.8 years with an average rowing experience of 7.6 ± 3.5 years were retrospectively investigated in this study. All oarswomen were crew-scullers (e.g. double scull) and had previously competed in 'A-finals' at world cup and championship regattas. Selected crews from the respective boat classes examined in this study went on to achieve bronze medals at world championships. The study protocol was approved by the AUT University Ethics committee. Informed voluntary signed consent was attained after rowers attended project information and familiarisation seminars. Rowers who were cleared by medical staff for participation in regular training were allowed to test.

Test Procedures

Scullers aspiring for national selection participated in a 2000-m time-trial held at the various rowing centres of excellence and then attended the national championships regatta. Top-ranked national scullers (i.e. 'premier finalists') were invited by national selectors to participate in 'seat-racing' trials. After the announcement of crews, all scullers were anthropometrically measured and strength tested. The entire selection and testing protocol was completed within four weeks.

Assessments

2000-m time-trial

A stationary air-braked rowing ergometer (Model D, Concept 2 Inc., Morrisville, VT, USA) with the drag factor setting to 110, was used for the 2000-m self-paced time–trial. During testing participants had access to the console information, which included the elapsed distance (meters), test time (minutes and seconds), 500-m interval time/splits (minutes and seconds) and stroke rate expressed in strokes per minute. This test was performed as part of national selections at various rowing centres of excellence.

National selection trials (crew seat-racing)

Seat-racing trials involved head-to-head races over 1500-m between two crew-boats, fitted with standardised rigger spans and oar gearing, and in this study involved selection of national sculling crew-boats (e.g. double-scull). Based on 2000-m time-trials rank-orders (e.g. fastest versus slowest rowers), the starting combinations for the initial crew-boat trials were announced by national selectors. An initial 1500-m trial was held and finishing order (rank) established, with the margin between race times (expressed as a percentage) assigned to the winning crew (e.g. margin win of 0.8% assigned to crew 'A'). Using no pre-determined order, selectors announced which two scullers were to switch seats between crew-boats, and after approximately 20 minutes, a subsequent 1500-m trial was held. Finish margins were again determined and compared to trial one, with the winning 'seat-race' assigned to the rower in the now faster crew (e.g. rower 'A' retrieved 0.5% of the 0.8% margin between crews and was therefore ranked higher than rower 'B'). Switching between boats was continued until all scullers were ranked by changes in boat margins (thus boat speed). Previously assessed trials were on occasion repeated, and although rowers were able to observe differences in boat lengths (as crews crossed the finish line); they were not made aware of final margin(s) or individual rankings.

No more than eight trials were performed on a particular day (i.e. four trials in each morning and afternoon sessions). Weather conditions (air temperature and wind speed) were monitored throughout trials and seat-racing was suspended or discontinued when weather conditions became inclement (e.g. head or tail wind >1.5 m/s). On establishment of rankings, the fastest ranked crew-scullers were raced against the slower-ranked crew. If necessary, further trials or switches between seats were made, if in the opinion of selectors, performance margins were negligible (e.g. < the average % margins won) or boatmanship was poor, until a favoured crew-combination was announced by selectors.

Anthropometry

Standing height (stature), sitting height and arm span measures were assessed using wall mounted stadiometers, with body mass measured using calibrated electronic scales (Tanita HD-316, Tanita Corporation, Tokyo, Japan). Skinfolds were measured using a Slim Guide calliper (Creative Health Products, Plymouth, USA), at 8 sites: biceps, triceps, subscapularis, supraspinale, iliac–crest, abdominal, mid–thigh and calf. All anthropometrical measures were performed and measured as per the International Society for the Advancement of Kinanthropometry (ISAK) guidelines (Norton, et al., 2004).

Leg pressing dynamometry

A "Dynamic Strength Training" dynamometer (DYNO, Concept 2 Inc., Morrisville, VT, USA) was used to measure average concentric work (i.e. force x distance) produced during five repetitions of leg pressing exercise. The dynamometer provided resistance by flywheel inertia combined with air braking fans to create drag, comparable in design with a Concept 2c rowing ergometer. The drag factor was set with two air dampeners opened. A repetition was commenced every two seconds (or equivalent to a rating of about 30 repetitions per minute) to ensure tests were performed within a target completion time (approximately 10 seconds). Three trials were performed, with at least three minutes between attempts, and the best score recorded as the test result. All rowers had previously used the dynamometer and were familiar with the leg press technique. Previous test-retest reliability of the dynamometer five repetition leg press strength test in our laboratory was CV = 2.5%, ICC $\geq$ 0.99.

Statistical Analysis

Individual scores were tabulated and represented as a mean ± standard deviation (SD) for ‘selected’ and ‘non-selected’ sculling crews (groups).

A one-way ANOVA was used to establish differences between groups, with respective p-values and 90% confidence limits (CL) reported (Hopkins, et al., 2009). Mean, percent mean and standardised differences in 2000-m ergometer and five repetition leg press data, adjusted for by body mass as a covariate, were calculated using a spreadsheet (Hopkins, 2007). Differences in body mass were adjusted for by standing-height as a covariate. Adjustments were performed by fitting a simple linear model to the relationship between the change scores and anthropometrical covariate in each group. The linearity and homoscedasticity of data were examined by visual inspection of bipolar plots with least squares regression analysis, and the distribution and normality of data were assessed using histograms, probability plots and Shapiro—Wilks’ test on SPSS (version 17). All data were log-transformed prior to analysis to reduce non-uniformity of error. Magnitudes of standardised effects (ES) were calculated by dividing the appropriate between-rower standard deviation and using a modified Cohen scale defined as: <0.2 = trivial, 0.2 to 0.59 = small, 0.6 to 1.19 = moderate, 1.2 to 1.99 = large, >2.0 = very large (Hopkins, 2006). Differences were deemed significant where P ≤ 0.05, but given a small participant sample, unclear if the confidence intervals for ES overlapped the thresholds for smallest positive and negative effects (i.e. 0.2*SD).

Results

Selected crew-boats were 4.6 ± 0.02% faster and won by an average margin of 13.5 ± 0.7 s over the final 1500 m seat-race. In Table 8.1 no significant differences in height, arm-span sitting-height, body–mass or 8-site skinfold sum were observed between selected and non-selected rowers (all $P > 0.05$).

Table 8.1 Mean ± standard deviation (SD) anthropometrical characteristics and differences (one-way ANOVA) between selected and non-selected crew-scullers (females = 12)

	Height (cm)	**Arm-span (cm)**	**Sit-height (cm)**	**Body-mass (kg)**	**8-site skinfold sum (mm)**
Selected (n = 6)	178.9 ± 5.1	182.7 ± 10.0	92.2 ± 3.3	73.5 ± 3.8	82.0 ± 7.6
Non-selected (n = 6)	177.1 ± 2.2	179.5 ± 3.1	92.8 ± 2.9	73.8 ± 4.2	85.0 ± 15.8
P-value:	P = 0.36	P = 0.39	P = 0.71	P = 0.88	P = 0.38

The mean 2000-m ergometer time was 412.2 ± 7.6 s and five repetition leg pressing strength 648 ± 65 J. Mean differences in 2000-m ergometer times between selected and non-selected scullers were trivial and unclear (ES = 0.2, 90%CL = -0.6 to 1.1, P = 0.63). In contrast, significant and clearly greater leg strength was found in selected scullers (ES = 1.1; 90%CL = 0.3 to 1.9, P = 0.03) – Table 8.2.

Table 8.2 Means ± standard deviation (SD) and differences (one-way ANOVA) in 2000-m ergometer and five repetition leg pressing adjusted for body-mass selected and non-selected scullers (females = 12)

	2000-m ergometer time-trial (s)	**5 repetition leg-pressing dynamometry (J)**
Selected (n = 6)	413.2 ± 6.3*	686.5 ± 77.4‡
Non-selected (n = 6)	411.2 ± 8.9	608.5 ± 52.0

* the probability that selected scullers were 0.5% slower was not significant and unclear (90%CL = -1.3% to 2.3%, P = 0.63), ‡ the probability that selected scullers were clearly 11.8% stronger was significant (90%CL = 3.1% to 21.3%, P = 0.03).

Discussion

While there is general agreement that a number of physiological, psychological and technical factors are important to perform, the extent to which each factor contributes in the assignment of rowers to crews is seldom quantified (Kramer, et al., 1994). Individual technique and crew boatmanship are difficult if not intangible factors to replicate off-water. Nonetheless, specific criteria to select a replacement, to set goals to monitor progress or to assess the possible impact of any crew-change involving individual rowers are desirable off-water. In the present study, we examined whether anthropometry, 2000-m ergometry or leg strength factors were such suitable criteria. Our main finding was that neither height, arm-span, sitting-height, body-mass, 8-site skinfold sum, nor 2000-m rowing ergometer data was different between successful or unsuccessful elite crews. However, all other factors remaining equal, selected oarswomen who were faster in sculling crews had greater lower-body strength.

In a practical sense, oarswomen differed in stature and body-fat sum as individuals. These relatively small variations did not amount to any meaningful difference in the assignment of oarswomen to crews (Table 8.1). Similarly, selected crews who went on to become successful at international regattas (i.e. bronze medallists at World Rowing Championships) were only marginally shorter (–2.0 cm) and lighter in body–mass (–3.0 kg), but were otherwise comparable in sitting–height and body–fat sum to data reported of champion rowers at Olympic Games (2000). On the basis of these data, we conclude moderate differences (standardised effect size ~0.8) of about 18 mm of body–fat (or around 1–2 kg) would be more likely to influence selection outcomes. Additionally, although our oarswomen were relatively homogeneous in stature and body–fat, future research might investigate whether the distribution of lean body–mass differed in segments critical to the development of rowing power (i.e. anterior thigh, posterior chain complex and erector spinae muscle groups of the legs and trunk) by use of ultra-sound or magnetic resonance imaging (Tachibana, et al., 2007). The greater strength and performance standards of elite rowers can in part be attributed to a greater lean body-mass and muscle hypertrophy (Bourgois, et al., 2001; Clarkson, et al., 1984; Kerr, et al., 2007; Mikulic, 2008, 2009).

Although rowing ergometry can discriminate between rowers of competitive ability (Hay, 1968; Kendall, et al., 2011; Kramer, et al., 1994), a 2000-m time trial was not a significant discriminator in the assignment of elite oarswomen to crews in the present study. It may be that the technique used to maximise ergometer results do not relate to, or is in contrast to, on-water crew rowing techniques. For example, counterproductive habits on-water, such as rushing into the catch, pulling the oar-handle to the neck, or excessive body swing at the finish, have little negative and perhaps greater beneficial performance outcomes in rowing ergometry. Additionally, rowing ergometry utilises a very stable base of support has little requirement for balance, consideration or reaction to crew mates, weather conditions or skill with the oar (Mikulic, et al., 2009; Nevill, et al., 2011). Hill et al. (2002) suggested the dynamics of stroke-force and synchronicity were of equal if not greater importance in the performance of larger crews. That is, the only real way to rank rowers is on the basis of their ability to contribute to a crew's performance in terms of actual boat-speed. Therefore at best, the prediction of on-water performance on the basis of rowing ergometry data appears constrained to the setting of competitive benchmarks for standards of performance attained by oarswomen in preparation for international competition. It may be however, that ergometer tests which are explicit measures of aerobic power or condition, provide more useful data to differentiate candidates vying for crew selection (Ingham, et al., 2002; Mikulic, et al., 2009; Nevill, et al., 2011).

Gallagher et al. (2010) postulated that the greater gains observed in the rate of 2000-m rowing ergometry improvement from strength development, may amount to gaining almost one boat-length on-water. If this were the case, then oarswomen assigned to the selected crews in our study should have attained faster 2000-m ergometer times on average. In fact, 2000-m times did not differ between crews as overall, our sample of oarswomen were relatively homogenous (412.2 ± 7.6 s, coefficient of variation = 1.8%). More to the case, elite oarswomen assigned to faster crews had moderately greater lower-body strength (i.e. +11.8%; 90%CL = 3.1% to 21.3%, P = 0.03). That is, amongst oarswomen of comparable ergometer ability, it was the attainment of greater leg strength that accounted for a 13.5 + 0.7 s difference in 1500-m on-water performance between selected (686.5 ± 77.4 J) and non-selected (647.5 ± 64.7 J) crews. Given the greater heterogeneity in our sample (648 ± 65 J, CV = 10%), lower-body strength emerged as the only useful data on which to predict the on-water 1500-m performance outcome (win/loss) between crews.

While differences in lower-body strength were clear, due to the small sample size of this investigation, the reader must remain cognizant of Type II error in the determination of differences in other data (i.e. a 'true' difference was not detected). There may also be differences in upper-body strength unaccounted for in the present study, that impact on performance, or individuals who have varying rowing styles that reflect the strength requirements of particular boats (e.g. eights) or seat positions (e.g. bow or stroke seats). We therefore conclude that techniques to assess strength, concurrent to on-water rowing endurance and technique should be considered in the selection and/or preparation of elite oarswomen for sculling-crews.

Practical Applications

In the absence of crew seat-racing trials and where homogeneity of 2000-m ergometer scores is evident (e.g. CV < 2.0% or < 8 s), lower-body strength differences (ES > 0.8 or 10%) may provide meaningful insight for the objective refinement of crew selections or preparations. On attestation of on-water boatmanship, coaches might consider techniques to emphasize the leg-drive and increase lower-body strength in preparation for competition or selection trials. Finally, coaches might consider benchmarks for aspiring national representatives that incorporate lower-body strength along side of anthropometric and 2000-m ergometer time-trial criteria.

Chapter 9: Conclusions

General summary

In the quest to maximize average propulsive stroke-power over 2000-m racing, testing and training of various strength parameters has been incorporated into the physical conditioning plans of rowers. There were, however, methodological inconsistencies identified on review of the literature, which lead to the design of the experimental studies that shape this thesis. In particular, given the rowing stroke involves all major muscle groups, it was surprising that leg pressing and not bench pulling muscular-endurance tests were correlated with 2000-m ergometer times. However, the reliability of high-repetition tests used to assess muscular-endurance had not been investigated. Positive rowing performance benefits of practical significance had been claimed subsequent to concurrent endurance and weight-training over the off-season. However, interpreting the standardised differences in effects of these previous studies was problematic, due to an abundance of quasi-experimental research omitting control (contrast) designs, poorly equated training volumes or use of performance measures lacking the measurement precision required for short-duration small-sample investigations. Subsequently, it was unclear whether weight-training for rowers should involve predominately lower– or upper–body exercise and the effect of specific on-water strength training practices such as towing ropes had not been examined. Furthermore, the ecological validity of variances in strength and its training had not been related to the on- and off-water performance of the rowing elite. Therefore, this thesis sought to investigate such matters in order to establish the benefits for elite (crew) rowers associated with integrating strength testing and training over various phases of preparation for competition.

The utility of low– and high–repetition maximum (RM) strength tests to assess rowers were evaluated using a repeated–measures study (Chapter 3). High–repetition tests (30RM, 60RM and 120RM) involving seated arm pulling exercise are not recommended as assessments, as it was found they had unsatisfactory measurement precision (percent typical error > 5% or ICC < 0.9). The greater typical error was attributed to a rower's inability to correctly pace and tolerate fatigue during testing. Therefore, if high–repetition testing is to be used, it was recommended that endurance training volumes are tapered in close proximity of testing (3 days), more than three repeat-test occasions are included after collection of initial test data and, that these tests are used only if large differences in data are anticipated. In contrast, low–repetition strength tests (i.e. <5RM), and in particular leg press exercise, offer greater test precision and re-test reliability (e.g. percent typical error = 2–5% and ICC = 0.96–0.98) to assess small squads of elite rowers (n = 20), with little apparent need for repeated trials.

In chapter four, moderate to very large differences in strength and muscular-endurance tests were observed when comparing junior to senior elite rowers (effect size range 0.9 – 1.9; see Table 4.3). Greater annual development rates (5.0% to 6.0% per annum), and adjusted 2000-m performance, were associated with upper-body strength (males, change ES = 0.7) and muscular-endurance (females, change ES = 0.6). Subsequently, selection and monitoring of training of potentially talented junior rowers could, in the first instance, be based on upper–body testing. Furthermore, these benchmarks and/or development rates could be used by practitioners to assist with the design of weight training programs for juniors, and the evaluation of individual progress for selection review (see Table 4.2).

In Chapter 5, the common variances shared between strength, power and muscular–endurance exercises used in weight training and specific rowing ergometer assessments used to assess elite rowers, were explored with nineteen senior heavyweight males. A combination of lower– and upper–body exercises emerged as strong determinants of 2000-m and 500-m time, and rowing peak stroke-power (R^2>50%, $P<0.05$), however weight training exercises were not, unsurprisingly, correlated with the aerobic condition, 5000-m or 60-minute endurance performance of rowers. In terms of the 'gold standard' 2000-m ergometer time–trial, the work (J) performed during a 5RM leg press in combination with either a 6RM bench pull (kg) or a 60RM seated arm pulling test emerged as the best (two-factor) determinants from multiple regression analysis (R^2 = 59%; SEE = 6.3 s and R^2 = 57%; SEE = 6.4 s, respectively), and thus, were recommended for exercise and assessment purposes. Additionally, because power cleans (1RM) and bench pull power (W) were strong determinants of rowing peak stroke-power and 500-m performance (R^2 = 73%; standard error of the estimates (SEE) = 59.6 W and, R^2 = 70%; SEE = 1.75 s, respectively) practitioners should also consider use of these exercises in weight training.

The second phase of this thesis involved two controlled intervention studies to compare adaptations attained from (on-water) rowing alone to rowing with the addition of weight-training, because correlation research cannot explain the inter-play or effect mechanisms at work within these strength and rowing performance relationships.

In the first intervention study (chapter 6), participants were assigned to either rowing only (n=10, 250-270 km/week) or rowing plus four weight-training sessions each week (n=12, 190-210 km/week). After eight weeks of endurance training, the standardized differences between groups in aerobic condition (watts @ 4 mmol/L blood lactate: ES [; ±90%CI] = 0.15; ±0.28, P=0.37) and upper-body strength [6RM prone bench pull: (ES = 0.27; ±0.33, P=0.18)] were trivial, although a moderate positive benefit in favour of rowing only was observed in upper-body muscular-endurance [60RM seated-arm-pull (ES = 0.42; ±0.4, P=0.08)]. Only rowers who performed weight-training improved their lower–body strength (isometric pull: 12.4 ± 8.9%, P<0.01, and 5RM leg press: 4.0 ± 5.7%, P<0.01) and muscular-endurance (30RM leg press: 2.4 ± 5.4%, P<0.01).

The purpose of the second intervention study (chapter 7) was to quantify changes in lower–body strength following 14-weeks of intensive pre-competition training, incorporating resisted rowing practices (e.g. two sessions of 'towing-ropes', 8 x 3 minutes). After a four-week washout phase, the same program was repeated with the addition of two weight-training sessions (e.g. 6 exercises, 3-4 sets x 6-15 reps). Although resisted-rowing is believed to improve lower–body strength, from this study it was observed that at best, strength was only maintained (e.g. 5RM leg press: -1.0% ± 5.3%; P = 0.51, and isometric pull: +5.3% ± 13.4%; P = 0.28). In contrast, moderately greater increases in 5RM leg press strength was attained on inclusion of weight-training (ES = 0.72; ±0.49, P = 0.03). However, while differences in isometric pull strength were unclear (ES = 0.56; ±1.69, P = 0.52), it was suggested that resisted rowing may expose rowers to greater flexion loads in the spine (low–back) and thus exposure risk of injury.

From these two intervention studies, it was concluded that the main benefit of weight-training for elite rowers (concurrent to endurance rowing exercise) over short-term periods of preparation for competition, was clearly greater gains in leg strength and muscular-endurance. However, the link between greater leg strength and the on-water rowing performance of crews remained unclear. Therefore, the purpose of the final study in this thesis (chapter 8) was to establish whether anthropometry, rowing ergometry or lower-body strength tests were suitable criteria from which differences between 'selected' and 'non-selected' elite sculling-crews could be adequately explained. Selected crew-boats 'won' by an average margin of 13.5 ± 0.7 s over 1500-m. There were no differences between heavy-weight crews in standing-height, arm-span, sitting-height, body-mass or 8-site skinfold sum (body fat). Difference in 2000-m ergometer times were also trivial (ES = 0.2, 90%CL = -0.6 to 1.1, P = 0.63) however, selected oarswomen had greater leg strength (ES = 1.1; 90%CL = 0.3 to 1.9, P = 0.03).

In summary, the authors suggest that elite rowers, who possess desirable anthropometric characteristics and have attained benchmarks for 2000-m ergometer performance, consider weight training as part of preparations for national crew selection trials to increase the strength of their leg-drive.

Limitations

Success in competitive rowing is extremely multi-factorial. While these authors developed research designs and methods of analysis to control for covariates, there may have been group characteristics, dynamics, environments or other confounding factors associated with training at the national centre for rowing excellence that remain unaccounted for in the analysis (e.g. competitiveness of rowers or influence of coaching personnel). Furthermore, any benefit associated with strength and its training for rowers should be contextualised with respect to the training histories, boat types (e.g. pairs or eights), disciplines (sculling or sweep oar), and somatotypes (i.e. stature and/or body mass) of rowers who volunteered in our investigations. That is, individual results will vary from mean trends and conclusions observed on analysis of group level data.

Rowers of equivalent competitive ability (i.e. senior elite) but from other countries were not recruited in order to improve the inferential power of this investigation to ensure any competitive advantage believed to exist in the training of national rowers was not lost. Readers must therefore remain cognizant of the possibility of Type II error in the determination of differences in data (i.e. a 'true' difference was not detected) due to the small and relatively 'homogenous' group of elite rowers who participated in our research. Therefore, the findings from the series of studies undertaken in this thesis should not be overly 'generalized' in application, as this study is of greatest relevance for the population for whom it was intended to benefit.

Finally, the magnitude of strength changes observed in the interventions was influenced by the duration or window of training assigned between initial testing and re-test occasions. Strength training was of lower priority when ranked by volume (frequency and time) of exercise. For example, individuals may find that performance results differ if greater gains in strength are achieved by prioritising weight training (e.g. more than two sessions each week) or conversely, on reduction of total aerobic exercise volumes. Nonetheless, the findings from these series of studies should assist rowers and coaches decide whether any benefit for elite rowers might be gained from the integration of strength testing and weight training as part of preparations.

Conclusions and practical applications

The purpose of this thesis was to establish whether any benefit for elite rowers could be gained on integration of strength testing and training over various phases of preparations for international regattas. While success in rowing is dependent on a multitude of factors, the main conclusion of this study was that for intensive training periods of 8 or 14 weeks, clearly greater lower–body strength and/or muscular endurance gains were acquired from integrating weight-training as part of rowing preparations for competition. Importantly, no negative effects were observed such as losses in aerobic condition and/or gains in lean body mass on introduction of weight-training. Lower–body strength was found to be a strong predictor of 2000–m rowing ergometer performance and heavyweight females, who were faster on-water as a crew, were considerably stronger in the legs. Therefore, coaches might wish to consider using strength testing to compare rowers vying for crew selection; or to evaluate the progress of rowers against desirable benchmarks associated with training (with knowledge that such benchmarks must be 'indexed' over time), or to make informed decisions as to whether a crew could increase boat speed by incorporating weight-training. Subsequently, the following guidelines are provided to assist practitioners with the applications of these conclusions.

Strength training guidelines

Strength training is appealingly suited to the preparation of younger rowers (e.g. Under–23 elite) who are generally weaker and less likely to undertake (at their stage of development) high volumes of endurance rowing. However, this is not to overlook the importance of weight–training for senior rowers, and in particular females, who may find maintaining (lean) body mass difficult and strength losses excessive after tapering for (national) competition, or for whom gains in strength (relative to their body mass) is difficult to improve from rowing alone. Therefore, if it is to be integrated as part of preparations, it may be wise to prioritise weight-training over the domestic competition phase (October to January), as senior rowers are likely to cease strength training when travelling to compete at various world cups in build up to world championships.

In terms of rowing performance, strength training need not be too time-consuming, as overload should primarily be targeted to the lower–body. Ideally, these sessions should be scheduled after a rower has had sufficient recovery from any preceding endurance exercise (e.g. 3–4 hours rest). As a minimum, the authors recommend at least two sessions each week to develop strength, scheduled 72 hours apart (e.g. Monday and Thursday), involving at least 2–3 lower-body exercises for 3–4 sets x 6–15 repetitions. In this study, the experience, technical proficiency and injury concerns of each individual was used to guide exercise selection as leg presses, lunges and step–ups, squats, power–cleans, dead–lifts and derivatives of these exercises, including jump exercises (e.g. jump up onto a box) are all suitable choices for rowers.

Readers need to be cognizant of the loading parameters used in this study, which allowed participating rowers to avoid repetition failure and to maintain technique during weight training, until a desired volume and intensity (tonnage) of exercise was attained to develop strength. Over the various phases of preparation investigated (e.g. October to January), the volume of weight training exercise was gradually reduced and intensity increased (e.g. month 1: 15RM, month 2: 10RM, and month 3: 6RM) to manage fatigue as the demands of competitive rowing and training at the national training centre, became progressively greater. Weight training loads were also managed each session and gradually, the average weight as proportion of the assigned RM was raised (e.g. average intensity week 1: ~70% of 6RM, week 2: ~85% of 6RM, week 3: ~95% of 6RM, and week 4: ~100% of 6RM). Furthermore, inter–repetition rest, or the 'clustering' of repetitions (e.g. instead of six consecutive repetition using a 6RM load, 3 repetitions are performed, then after 30-60 seconds rest, an additional 3 repetitions) was deployed, if muscle fatigue was evident during strength training.

Muscular-endurance guidelines

It was observed that extensive endurance rowing alone was more likely to develop moderately greater upper-body muscular-endurance, compared with rowing and weight training in combination. Therefore, if muscular-endurance exercise is to be included (i.e. cross-training), or performed in place of rowing in the case of injury (e.g. low back) or inclement weather, it was recommended that greater volumes of exercise in weight-training be targeted towards the upper–body. For example, practitioners might consider allocating twice the volume of exercise to the upper–body (4–6 exercises) than lower–body (2–3 exercises). Furthermore, a modest reduction in muscular-endurance exercise for the lower-body (e.g. 1–2 exercises) could be considered if similar adaptations are expected elsewhere from the endurance training programme for a rower (e.g. running or cycling).

Suitable upper–body exercises for muscular-endurance include prone bench rows, barbell and dumbbell rows, seated cable or elastic cord rows, supine (inverted) pull ups, chin ups or lateral pull downs, and including variants of these exercises. However, assigning loads for these activities can be difficult for high-repetition exercise (e.g. 2-4 sets x 30–60 repetitions). Therefore, there may be some advantage, as per the methods in this thesis, to assigning resistance-loads and varying ratings thus repetitions for each exercise (e.g. 25 to 35 repetitions), according to the interval of time prescribed (e.g. 1 minute). Thereafter the volume of exercise can be progressively increased (e.g. 40 to 50 repetitions) by raising the work from one up to two minutes.

In terms of training integration, it was recommended that muscular–endurance exercise is performed after strength exercise, or more preferably, as a separate session if substituted for endurance rowing. However, it may be possible to train for both strength and muscular-endurance within the same session, if exercises are alternated between opposing muscle groups (e.g. pushing and pulling actions) or between the lower–(strength) and upper–body (muscular endurance).

Strength testing guidelines

In the first instance, strength testing should be used to assist periodically with the assignment of loads for weight–training. For example, after a period of accustoming to exercise (e.g. three weeks), rowers should determine appropriate training loads for prescribed repetition maximums (e.g. 6RM). To improve the reliability and precision of load assignment, assessment protocols should incorporate an adequate preparation phase (e.g. warm up sets using loads of 75%, 83%, and 92% of anticipated 6RM load). Practitioners must also remain cognizant of measurement error when assigning loads for high-repetition exercise (e.g. 30RM or 60RM), particularly for the upper-body (e.g. seated arm pulls percent typical error: 5–7%). Therefore, it may be worth repeating testing or adjusting training loads after observing diary records from multiple training sessions.

Secondly, to monitor development over the longer-term, the authors recommend that a 6RM prone bench pull and 5RM leg press (performed on the Concept2 DYNO) are prescribed as common exercises for rowers of all competitive abilities (i.e. age, ranking, or experience). As discussed, achievements in such exercises could be observed from weight training diaries or administered as specific tests. The authors recommend such data is reported in close proximity to the completion of significant phases of national training or assessment, for example, when 2000-m ergometer tests preceding trials are performed (e.g. February) or, on commencement of next season preparations following the conclusion of world championship regattas (e.g. October).

Finally, practitioners might consider using strength testing to explore differences in muscle adaptations and performance where diversity in training methods exists (e.g. low– or high–repetition). Given the high-volumes of aerobic exercise, methods that lead to greater rates of performance change and/or offer greater strength training efficacy, are highly desirable in rowing. Furthermore, methods of exercise that can promote strength differences of around ten percent (or a standardised effect size of ~0.8*SD) may be associated with successful selection outcomes for rowers during crew selection trials.

Future Research

The focus of this thesis was to establish the benefits of strength testing and (weight) training in the context of improving 2000-m rowing performance in elite rowers. In short, it was found that faster elite rowers had greater leg strength (~10%), which clearly, was more effectively gained from weight training, than rowing. A logical extension from this study would therefore be to examine whether slower or 'unselected' rowers on taking up weight training and increasing their leg strength to equal or exceed selected crews, gain selection. The author's personal observations are that this often has been the case at national selection trials however such claims remain at best conjecture.

Future research should also attempt to recruit larger study samples to establish benchmarks and guidelines for small worthwhile changes in strength that are relevant to selection or performance outcomes for different classes of rowing. For example, large differences and/or gains in leg strength appear necessary from weight training (e.g. standardised effect size > 0.8 SD of mean) for performance benefits or selection advantages to be gained for rowers contesting seats in double or quadruple sculls. However, strength differences may be greater, possibly curvilinear, for rowers in faster and larger crew-boats (e.g. eights), involving different disciplines (e.g. sweep-oar) and/or rowing styles (e.g. sequential).

Endurance rowing volumes appear to be constrained by the upper-body (chapter 6). Future researchers may wish to explore whether weight training can be used to increase upper-body strength and muscular-endurance, which in turn may facilitate greater volumes of rowing (hours or km). On occasion, rowing may need to be ceased because of pain or injury to the ribs (e.g. bone stress reaction). Research has suggested the ratio of a rower's upper-body strength (i.e. greater arm flexion) relative to their lower-body strength (i.e. weaker leg extensors) may prove useful as a screen to identify individuals at greater risk of rib–injury associated with rowing. However, our data suggest it may be better to assess a rower against a desirable benchmark(s), rather than to increase lower–body strength to rectify an 'at-risk' ratio, as (endurance) rowing appears to overload the upper–body. That is, tolerance to specific endurance training volumes (e.g. 220-250km a week) might be more readily screened using desirable benchmarks of upper-body strength or muscular-endurance strength, shown to be associated with lower rates of injury.

Finally, on review of the literature, strength and muscle mass (or cross sectional area) were highly interrelated. It is highly likely therefore that strength testing provides some insight as to the distribution of muscle mass of a rower. While changes in strength, skinfolds and body-mass have been examined in some studies including this thesis, such measures do not explicitly examine whether muscle cross-sectional area or the distribution of mass differed after weight–training. This may be particularly important to gain a better understanding of the differences observed in muscular-endurance and strength of the upper-body between weight-trained and rowing only controls. For example, (lightweight) rowers may manipulate their diet in order to minimise body fat in preparation for competition; it appears likely that greater lean tissue mass can be sustained by rowers who perform weight-training. Therefore, differences in performance outcomes explained by strength could simply reflect differences in lean body mass in those muscles important to the generation of rowing stroke-power.

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Appendices

Appendix 1: Ethics approval

MEMORANDUM

Auckland University of Technology Ethics Committee (AUTEC)

To: John Cronin
From: **Madeline Banda** Executive Secretary, AUTEC
Date: 5 October 2009
Subject: Ethics Application Number 09/215 **The reliability and validity of a continuum strength assessment to rowing performance.**

Dear John

Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 14 September 2009 and that I have approved your ethics application. This delegated approval is made in accordance with section 5.3.2.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 9 November 2009.

Your ethics application is approved for a period of three years until 2 October 2012.

I advise that as part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through *http://www.aut.ac.nz/research/research-ethics*. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 2 October 2012;
- A brief report on the status of the project using form EA3, which is available online through *http://www.aut.ac.nz/research/research-ethics*. This report is to be submitted either when the approval expires on 2 October 2012 or on completion of the project, whichever comes sooner;

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are reminded that, as applicant, you are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

Please note that AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this.

When communicating with us about this application, we ask that you use the application number and study title to enable us to provide you with prompt service. Should you have any further enquiries regarding this matter, you are welcome to contact Charles Grinter, Ethics Coordinator, by email at ethics@aut.ac.nz or by telephone on 921 9999 at extension 8860.

On behalf of the AUTEC and myself, I wish you success with your research and look forward to reading about it in your reports.

Yours sincerely

Madeline Banda
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Trent Lawton trentl@nzasni.org.nz

Appendix 2: Ethics approval

M E M O R A N D U M

Auckland University of Technology Ethics Committee (AUTEC)

To: John Cronin
From: **Dr Rosemary Godbold** Executive Secretary, AUTEC
Date: 31 August 2011
Subject: Ethics Application Number 09/215 **The reliability and validity of a continuum strength assessment to rowing performance.**

Dear John

I am pleased to advise that I have approved the minor amendments to your ethics application allowing the upgrading of the qualification from a Masters of Philosophy to Doctor of Philosophy and changes to the methodological approach and data analysis.. This delegated approval is made in accordance with section 5.3.2 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 12 September 2011.

I advise that as part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/research/research-ethics/ethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 2 October 2012;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/research/research-ethics/ethics. This report is to be submitted either when the approval expires on 2 October 2012 or on completion of the project, whichever comes sooner;

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are reminded that, as applicant, you are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

Please note that AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this. Also, if your research is undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply within that jurisdiction.

When communicating with us about this application, we ask that you use the application number and study title to enable us to provide you with prompt service. Should you have any further enquiries regarding this matter, you are welcome to contact Charles Grinter, Ethics Coordinator, by email at ethics@aut.ac.nz or by telephone on 921 9999 at extension 8860.

On behalf of AUTEC and myself, I wish you success with your research and look forward to reading about it in your reports.

Yours sincerely

Dr Rosemary Godbold
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Trent Lawton trentl@nzasni.org.nz

Appendix 3: Participant information sheet

Participant Information Sheet

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Date Information Sheet Produced:

24 September 2009

Project Title

Strength testing and training of elite rowers.

An Invitation

I, Trent Lawton, am a Doctor of Philosophy (Sport and Exercise) candidate with the AUT University in Auckland, in addition to my paid work as a strength and conditioning coach for Rowing New Zealand (RNZ) on behalf of the High Performance Sport New Zealand (HPSNZ).

As a current carded rower in RNZs High Performance Programme, you are being asked to participate in the development of new tests to assess the muscle strength of rowers in order to establish any benefit(s) associated with incorporating strength training as part of your physical preparation plans.

Your participation is entirely voluntary and whether or not you choose to participate will neither advantage nor disadvantage you in relation to your training. Please understand that you may withdraw at any time without any adverse consequences.

What is the purpose of this research?

The purpose of this project is to examine the reliability and validity of a series of muscle strength tests using the leg pressing and seated arm pulling actions on the Concept 2 Dynamometer. *Reliability* means that each time you attempt the test you record a similar result (that is, once you feel recovered and/or insufficient time has past for you are to have become stronger). *Validity* means that the test measures what it is meant to quantify, which in this project is your ability to generate force (or how strong you are).

Tests which are found to be valid and reliable will be used to examine relationships between strength and rowing performance, and to profile rowers of varying performance ability.

How was I chosen for this invitation?

You are currently a carded rower with RNZ.

What will happen in this research?

Project Outline.

There are two stages involved to this research project. The initial stage of this project is to establish the reliability and validity of testing strength using different repetition zones on a Concept 2 Dynamometer. During this phase (commencing late October 2009), the same strength tests will be repeated on three separate occasions. The second stage of this project is to test strength within ten days of other scheduled rowing performance measures (between February and June 2010) such as the 2000 m ergometer time trials, national small boats race or ergometer step tests. As differences exist within crew preparation philosophies and prescriptions with regard to the utility of strength training modalities in build up to competition, you may perform training methods that differ from other squads, crews or rowers. Strength testing will be used to assist with understanding differences in training adaptations between endurance rowing only in comparison to rowing with the addition of strength (or weight) training, with negligible disruption to your existing training regimes. Please note that all strength testing will be scheduled and those dates indicated to you via email, the Weekly Catch newsletter and on the RNZ event calendar prior to commencement of your training plans.

The tests.

A Concept 2 DYNO "Dynamic Strength Training" device will be used to measure the magnitude of average work, force and power produced during a leg pressing and seated arm pulling. The DYNO provides an accommodation resistance by action of flywheel inertia and air brake fans (drag factor). The drag factor will be set so that two dampeners are opened for the Leg Press and no dampeners opened for the Seated Arm Pulling.

The magnitude of resistance is proportional the exertion of your legs against the foot stretcher or your arms in pulling against a pair of handles. Three magnetic sensors capture flywheel angular velocity combined with sensor readings of drag forces (load) to determine average force, work and power each repetition. A consol displays this information to you on completion of each repetition as feedback. Ten seconds after the end of each trial, the DYNO will produce a summary of the average *drag factor, work, force, maximum force* and *power* achieved for the designated repetitions. This data will be recorded as your test result.

Your goal is to maximise the average amount of *work* you achieve for each test. *Work* is a product of both the displacement (i.e. range of motion) and level of effort (i.e. force or strength) achieved each repetition. You should think "length" and "strength" each repetition you perform (or "long" and "strong"), as this will maximise the amount of *work* you produce. You will be reminded of this throughout the test.

Your strength will be assessed by four tests that differ by the number of required repetitions:

- **Test one** involves 120 maximal effort repetitions **(120 Max)** within a target completion time of four minutes.
- **Test two** requires five maximal effort repetitions **(5 Max)** and lasts approximately 10 seconds. Three trials will be provided, with at least three minutes between attempts.
- **Test three** involves one trial of thirty maximal effort repetitions **(30 Max)** and lasts approximately 60 seconds, and
- **Test four** involves one trial of 60 repetitions (**60 Max)** and lasts approximately 2 minutes.

For each test you should commence a repetition every two seconds – this is equivalent to a rowing rating of about *30 strokes per minute*. There is a counter and timer on the DYNO consul that you can use to assess your repetition rate and you will be provided with feedback if your rating should be adjusted.

In total, you will perform eight tests. To reduce the potential impact of fatigue or pressure to meet time constraints, testing will be scheduled over two sessions. You will be assigned to a group of three – this will allow an appropriate work to rest ratio to enable recovery prior to progressing to the next test. Each member of the group will perform test one, prior to progressing to the next test identified on the test order. If a group has less than three, the equivalent recovery time will be achieved by using a running sheet.

The *order of testing* and approximate rest interval between tests to achieve the running time is:

Test	**How much rest before I test again?**	**Running time**
Day 1:		
• Leg Press (LP) – 120 Max	about 10 mins	Start time (T)
• Seated Arm Pulling (SR) – 120 Max	tests completed.	T+15 mins
Total number of tests: 2		**End: T+30 mins.**
Day 2:		
• LP – 5 Max, three trials.	about 3 mins	Start time (T)
• SR – 5 Max, three trials.	about 3 mins	T+15 mins
• LP – 30 Max	about 5 mins	T+30 mins
• SR – 30 Max	about 5 mins	T+35 mins
• LP – 60 Max	about 5 mins	T+40 mins
• SR – 60 Max	tests completed.	T+45 mins

What are the discomforts and risks?

For each test, you are being asked to perform a designated number of repetitions. The harder you work against the Dyno each repetition, the more challenging the test becomes. However, the anticipated discomforts and risks from participating in this testing differ very little to regular training.

The main discomfort you may experience during some of the tests is a mild burning sensation in the active muscles along with some heavy or laboured breathing. Both of these responses are normal and triggered by the build up of lactic acid as your muscles rapidly create energy for movement from sugar. As with training, the degree to which this occurs varies depending on your level of exertion, current fitness and personal tolerance to lactic acid. These symptoms should dissipate quite quickly during the recovery period assigned after each test.

The other possible discomfort is a delayed onset of muscle soreness (DOMS) the following or subsequent two days after testing. However, you are less likely to get DOMS after using the Dyno as there are no actual weights to lower – one of the main triggers of muscular soreness. Any muscle soreness should dissipate within 3 to 5 days.

There is a risk of injuring yourself should your technique during the testing become unsafe; however the probability of this occurring is no more likely than during normal strength training.

How will these discomforts and risks be alleviated?

You will have the opportunity to familiarise yourself with the equipment and the testing process, to ask questions and to receive feedback about your technique during an orientation session.

To reduce discomforts and risks from testing, you will be asked to physically prepare yourself prior to the first test by undertaking a warm up on the rowing ergometer for at least 5 minutes. If you wish to perform dynamic or static stretches, please keep them to less than 30 seconds duration as longer stretches may have the potential to reduce your strength or endurance test results. You should also keep warm and drink fluids throughout the testing session.

Immediately after each test, move about to keep blood circulating and to assist with the breakdown of lactic acid – light rowing or walking is better than standing still or lying down. Please notify the researcher if you feel that you need more time to prepare or recover between tests, as we are interested in measuring your best performance.

The following techniques points may help reduce the risk of acute injury, however, if at any time, you do not feel that you are able to complete the movements requested, please notify the researcher immediately.

Leg Press

- Sit tall, keeping your back comfortably against the back rest.
- Grasp the handles on the side of the seat to eliminate upper body swing.
- Drive from the heel to the toe as you press your legs away.
- Use your heels to pull the foot stretcher back, bending your knees until your shins are perpendicular to the floor (the same as when rowing).

Seated Arm Pulling

- Place your toes on the support brace below the seat
- Your chest should gently touch the chest pad – place one foot forward if this helps to reduce the amount of pressure experienced against the chest.
- Lead the pulling action with your shoulders then arms, finishing when your hands touch your ribs.

Finally, please notify the researcher at if you have a current injury or have had an injury within the last four months that might affect your performance, or that might be worsened or aggravated by the required tasks. For example, a current knee injury would exclude you from the leg pressing test, but not necessarily the seated arm pulling test on that occasion. A recent rib, shoulder or arm injury may exclude you from the seated arm pulling test – if discomfort occurs during a trial of the leg pressing action, you will be recommended to withdraw from testing on that occasion.

What are the benefits?

The purpose of this project is to examine whether a continuum strength assessment is a reliable and valid measure to rowing performance. The assessment of rowing strength and the utility of various strength training protocols remain relatively unexplored in the literature. Additionally, valid and reliable measures of strength are not currently utilised as part of RNZs athlete monitoring.

By participating in this study, you are providing us with data to help develop suitable tests that provide information about the strength and strength endurance capabilities and training requirements of national and international calibre rowers. You will be able to compare your results to these groups of interest and gain some insight into the relevance of your test results to rowing performance. A summary of your results and the study will be available to you on completion of the project.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

The identity and results of each participant will be kept confidential. Only the student researcher (Trent Lawton), the primary and secondary supervisor (Professor John Cronin and Dr Mike McGuigan) will analyse your results.

Only group results will be presented to RNZ or the broader rowing community in presentation, as the results of the groups of rowers examined in this project can be useful for comparison purposes, particularly for the identification and development of other potentially talented rowers. However, your coach may be given a copy of your individual results to assist with the design of any training programmes or interventions.

What are the costs of participating in this research?

There are no costs to participation, apart from scheduling your time to be available for testing. Note – all testing will occur during your normally scheduled testing or strength and conditioning sessions.

What opportunity do I have to consider this invitation?

After you have read through this form, you will have plenty of opportunity to ask any questions you would like about the study up to the test occasion. The initial reliability phase of testing sessions is scheduled to commence late October 2009. The second project stage is scheduled to occur between February and June 2012 (you will be advised of your actual testing dates with at least four weeks advance notice).

One week prior to testing, there will be an orientation session for you to familiarise yourself with the practical step by step processes of the tests, to ask any further questions and to receive feedback about your technique. After your concerns have been satisfied, you will need to decide whether or not you would like to participate in the research.

How do I agree to participate in this research?

If would like to participate in this research, please fill in and sign the attached *Consent Form* and return it to the private box kept by the Administration Officer (Julie Dillon) prior to participating in any of the tests for each project stage. Please note you are not able to participate in this research if you are not a carded rower with RNZ.

If you do not wish to participate in this research, alternative arrangements will be made for you during the regular training session in which testing is scheduled. Please also understand that you may withdraw from testing at any time without any adverse consequences.

Will I receive feedback on the results of this research?

Yes, after the initial reliability phase of the project is completed you can receive a summary of your individual results once the information is ready for distribution (around one week after testing). Please check the appropriate box on the *Consent Form* if you would like this information.

A group information session (around August 2010) will be used to present findings should the reliability of the strength tests warrant the second phase of the research project. You will be invited to attend this session if you check the appropriate box on the *Consent Form*.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr John Cronin, john.cronin@aut.ac.nz, telephone: 09 921 9999, extension 7523.

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, madeline.banda@aut.ac.nz, telephone: 09 921 9999, extension 8044.

Whom do I contact for further information about this research?

Please contact the student researcher, Trent Lawton, trentl@nzasni.org.nz, mobile 021 606 831.

Student Researcher Contact Details:

Trent Lawton, trentl@nzasni.org.nz, mobile 021 606 831.

Project Supervisor Contact Details:

Dr John Cronin, john.cronin@aut.ac.nz, telephone: 09 921 9999, extension 7523.

Dr Mike McGuigan, mikem@nzasni.org.nz, telephone: 09 477 5437 (work).

Rowing NZ Supervisor Contact Details:

Alan Cotter, alan@rowingnz.com, telephone 07 823 4587, extension 806.

Approved by the Auckland University of Technology Ethics Committee on 14 September 2009, AUTEC Reference number 09/215.

Appendix 4: Consent form

Consent Form	AUT UNIVERSITY TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project title: *The reliability and validity of a continuum strength assessment to rowing performance.*

Project Supervisor: ***Dr John Cronin***

Researcher: ***Trent Lawton***

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 24 September 2009.
- ○ I have had an opportunity to ask questions and to have them answered.
- ○ I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- ○ I understand that my results and any possible application of my results to training or affect on rowing performance will be provided to and reviewed with my coach(es).
- ○ I am not suffering from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs my physical performance (or that might be aggravated by the tasks requested), or any infection
- ○ I agree to take part in this research.
- ○ I wish to receive a copy of my individual results from this research project (please tick one): Yes○ No○
- ○ I would like to be invited to group information session to hear about the main findings from this research project (please tick one): Yes○ No○

Participant's signature: ....

Participant's name: ....

Participant's Contact Details (if appropriate):

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Date:

Approved by the Auckland University of Technology Ethics Committee on 24 September 2009 AUTEC Reference number 09/215

Note: The Participant should retain a copy of this form.

Appendix 5: Abstracts

(Chapter 2)

In the quest to maximize average propulsive stroke impulses over 2000-m racing, testing and training of various strength parameters have been incorporated into the physical conditioning plans of rowers. Thus, the purpose of this review was 2-fold: to identify strength tests that were reliable and valid correlates (predictors) of rowing performance; and, to establish the benefits gained when strength training was integrated into the physical preparation plans of rowers. The reliability of maximal strength and power tests involving leg extension (e.g. leg pressing) and arm pulling (e.g. prone bench pull) was high (intra-class correlations 0.82–0.99), revealing that elite rowers were significantly stronger than their less competitive peers. The greater strength of elite rowers was in part attributed to the correlation between strength and greater lean body mass ($r = 0.57$–0.63). Dynamic lower body strength tests that determined the maximal external load for a one-repetition maximum (1RM) leg press (kg), isokinetic leg extension peak force (N) or leg press peak power (W) proved to be moderately to strongly associated with 2000-m ergometer times ($r = -0.54$ to -0.68; $p < 0.05$). Repetition tests that assess muscular or strength endurance by quantifying the number of repetitions accrued at a fixed percentage of the strength maximum (e.g. 50–70% 1RM leg press) or set absolute load (e.g. 40 kg prone bench pulls) were less reliable and more time consuming when compared with briefer maximal strength tests. Only leg press repetition tests were correlated with 2000-m ergometer times (e.g. $r = -0.67$; $p < 0.05$). However, these tests differentiate training experience and muscle morphology, in that those individuals with greater training experience and/or proportions of slow twitch fibres performed more repetitions. Muscle balance ratios derived from strength data (e.g. hamstring-quadriceps ratio <45% or knee extensor-elbow flexor ratio around 4.2 ± 0.22 to 1) appeared useful in the pathological assessment of low back pain or rib injury history associated with rowing. While strength partially explained variances in 2000-m ergometer performance, concurrent endurance training may be counterproductive to strength development over the shorter term (i.e. <12 weeks). Therefore, prioritization of strength training within the sequence of training units should be considered, particularly over the non-competition phase (e.g. 2–6 sets × 4–12 repetitions, three sessions a week). Maximal strength was sustained when infrequent (e.g. one or two sessions a week) but intense (e.g. 73–79% of maximum) strength training units were scheduled; however, it was unclear whether training adaptations should emphasize maximal strength, endurance or power in order to enhance performance during the competition phase. Additionally, specific on-water strength training practices such as towing ropes had not been reported. Further research should examine the on-water benefits associated with various strength training protocols, in the context of the training phase, weight division, experience and level of rower, if limitations to the reliability and precision of performance data (e.g. 2000-m time or rank) can be controlled. In conclusion, while positive ergometer time-trial benefits of clinical and practical significance were reported with strength training, a lack of statistical significance was noted, primarily due to an absence of quality long-term controlled experimental research designs.

(Chapter 3)

The purpose of this project was to evaluate the utility of low– and high–repetition maximum (RM) strength tests used to assess rowers. Twenty elite heavyweight males (age 23.7 ± 4.0 years) performed four tests (5RM, 30RM, 60RM and 120RM) using leg press and seated arm pulling exercise on a dynamometer. Each test was repeated on two further occasions; 3 and 7 days from the initial trial. Percent typical error (within–subject variation) and intraclass correlation coefficients (ICC) were calculated using log–transformed repeated–measures data. High–repetition tests (30RM, 60RM and 120RM) involving seated arm pulling exercise are not recommended to be included in an assessment battery, as they had unsatisfactory measurement precision (percent typical error > 5% or ICC < 0.9). Conversely, low–repetition tests (5RM) involving leg press and seated arm pulling exercises could be used to assess elite rowers (percent typical error ≤ 5% and ICC ≥ 0.9); however only 5RM leg pressing met criteria (percent typical error = 2.7%, ICC = 0.98) for research involving small samples (n = 20). In summary, low–repetition 5RM strength testing offers greater utility as assessments of rowers, as they can be used to measure upper– and lower–body strength, however only the leg press exercise is recommended for research involving small squads of elite rowers.

(Chapter 4)

The aims of this study were to establish whether anthropometry, muscle strength and endurance accounted for differences between junior and senior elite rowing ergometer performance, and to determine annual development rates for juniors associated with training. Twenty six junior (8 females, age 18.0 ± 0.3 years and 18 males, age 17.9 ± 0.2 years) and 30 senior (12 females, 23.7 ± 3.0 years and 18 males, 24.0 ± 3.9 years) heavyweight rowers, were assessed anthropometrically, performed a 2000-m ergometer time-trial, and completed various muscular strength and endurance tests. There were no anthropometrical differences between males; however after controlling for body-fat and standing-height, senior females were of greater body-mass (70.5 ± 4.6 kg and 77.2 ± 5.9 kg, P = 0.01) and sitting-height (89.8 ± 2.2 cm and 92.2 ± 6.1 cm, P = 0.04) than juniors. Moderate to very large standardised differences in all strength and endurance tests were observed between juniors and seniors (effect size (ES) range 0.9 – 1.9). Greater development rates (5.0% to 6.0%) and adjusted 2000-m performance was associated with upper-body strength (males) and endurance (females). In conclusion, after identification of desirable anthropometry, the 2000-m ergometer potential of juniors may be accounted for by upper-body strength and endurance.

(Chapter 5)

Knowledge of the relationship between weight-room exercises and various rowing performance measures is limited; this information would prove useful for sport-specific assessment of individual needs and exercise prescription. The purpose of this study was to establish strength, power and muscular-endurance exercises for weight-room training, which are strong determinants of success in specific performance measures used to assess elite rowers. Nineteen heavyweight elite males determined their repetition maximum (RM) loads for exercises utilizing a Concept 2 DYNO [5, 30, 60 and 120RM leg pressing and seated arm pulling, (J)] and free weights [1RM power clean (kg) and 6RM bench pull (kg and W)]. Rowing performance measures included a seven-stage blood-lactate response ergometer test (aerobic condition), time-trials (500-m, 2000-m and 5000-m), a peak stroke-power test, and a 60-minute distance trial. Pearson correlation moments ($r \geq 0.7$) and stepwise multiple linear regression calculations ($R^2 \geq 50\%$) were used to establish strong common variances between weight-room exercises and rowing ergometer performance ($P \leq 0.05$). Weight-room exercises were strong predictors of 2000-m, 500-m time (s) and peak stroke-power performance measures only. Bench pull power (W) and 1RM power clean (kg) were the best two-factor predictors of peak stroke-power (R^2 = 73%; standard error of the estimates (SEE) = 59.6 W) and 500-m (R^2 = 70%; SEE = 1.75 s); while 5RM leg pressing (J) and either 6RM bench pull (kg) or 60RM seated arm pulling (J) the best predictors of 2000-m (R^2 = 59%; SEE = 6.3 s and R^2 = 57%; SEE = 6.4 s, respectively). Recommended exercises for weight-room training include a 1RM power clean, 6RM bench pull, 5RM leg press and 60RM seated arm pulling.

(Chapter 6)

The purpose of this study was to compare changes in aerobic condition, strength and muscular-endurance following 8-weeks endurance rowing alone or in combination with weight-training. Twenty two elite rowers were assigned to either rowing (n=10, 250-270 km/week) or rowing (n=12, 190-210 km/week) plus four weight-training sessions each week. Pre and post mean and standardised effect-size (ES) differences in aerobic condition (Watts at 4 mmol/L) and strength (isometric pull (N), prone bench-pull (6 Repetition-Maximum (RM)), 5 and 30 repetition leg-press and 60 repetition seated-arm-pull (J) performed on a dynamometer) normalized by body-mass and log-transformed were analysed, after adjusting for gender. The standardized differences between groups were trivial for aerobic condition (ES [; ±90%CI] = 0.15; ±0.28, P=0.37) and prone bench-pull (ES = 0.27; ±0.33, P=0.18), although a moderate positive benefit in favour of rowing only was observed for the seated-arm-pull (ES = 0.42; ±0.4, P=0.08). Only the weight-training group improved isometric pull (12.4 ± 8.9%, P<0.01), 5 repetition (4.0 ± 5.7%, P<0.01) and the 30 repetition leg-press (2.4 ± 5.4%, P<0.01). In conclusion, while gains in aerobic condition and upper-body strength were comparable to extensive endurance rowing, weight-training lead to moderately greater lower-body muscular-endurance and strength gains.

(Chapter 7)

Over the past 30 years, endurance volumes have increased by more than 20% among the rowing elite, therefore informed decisions about the value of weight training over other possible activities in periodised training plans for rowing, need to be made. The purpose of this study was to quantify the changes in lower body strength development following two 14-week phases of intensive resisted on-water rowing, either incorporating weight training or rowing alone. Ten elite females performed two resisted rowing ('towing ropes' e.g. 8 x 3 mins) plus six endurance (e.g. 16 – 28 km at 70-80% maximum heart rate) and two rate regulated races (e.g. 8000 m at 24 spm) on-water each week. After a four week washout phase, the 14-week phase was repeated with the addition of two weight training sessions (e.g. 3-4 sets x 6-15 reps). Percent (±SD) and standardized differences in effects (ES ± 90% Confidence Interval) for five repetition leg pressing and isometric pulling strength were calculated from data ratio scaled for body mass, log transformed and adjusted for pre-test scores. Resisted rowing alone did not increase leg pressing (-1.0% ± 5.3%, P = 0.51) or isometric pulling (+5.3% ± 13.4%, P = 0.28) strength. In contrast, after weight training, a moderately greater increases in leg pressing strength was observed (ES = 0.72; ±0.49, P = 0.03), although differences in isometric pulling strength were unclear (ES = 0.56; ±1.69, P = 0.52). In conclusion, intensive on-water training including resisted rowing maintained but did not increase lower body strength. Elite rowers or coaches might consider the incorporation of high intensity non-fatiguing weight training concurrent to endurance exercise if increases in lower body strength without changes in body mass are desired.

(Chapter 8)

PURPOSE: No common theory exists on criteria to appropriately select crew-rowers in pursuit of small performance gains. The purpose of this study was to establish whether anthropometry, rowing ergometry or lower-body strength were suitable criteria to identify differences between 'selected' and 'non-selected' sculling-crews.

METHOD: Twelve elite females performed a 2000-m ergometer time-trial, a five repetition leg-pressing dynamometer test (LP5), were anthropometrically profiled, and participated in on-water national crew 'seat-racing' trials. Log transformed data were analyzed to compare percent (± SD) and standardized differences in group means [ES; ±90% Confidence Interval (CI)] between selected and non-selected oarswomen, with adjustments for body mass where appropriate.

RESULTS: Selected crew-boats were 4.60 ± 0.02% faster and won by an average margin of 13.5 ± 0.7 s over 1500-m. There were no differences between crews on average in height, arm-span, sitting-height, body-mass or 8-site skinfold sum (body fat). Difference in 2000-m ergometer times were also trivial (ES = 0.2, 90%CL = -0.6 to 1.1, P = 0.63) however, selected crews had moderately greater leg-pressing strength (ES = 1.1; 90%CL = 0.3 to 1.9, P = 0.03).

CONCLUSION: Selected oarswomen with comparable anthropometry and 2000-m ergometer ability had greater lower-body strength. Coaches of elite oarswomen might consider the strength of the leg-drive as part of crew selection criteria and preparations given acceptable on-water boatmanship and attainment of 2000-m ergometer benchmarks.