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Comparison of rowing on a stationary and dynamic ergometer

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COMPARISON OF ROWING
ON A STATIONARY AND DYNAMIC ERGOMETER

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CERTIFICATE OF APPROVAL

MASTER OF SCIENCE THESIS

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ABSTRACT

The purpose of this study was to examine the differences between rowing on a stationary (SE) and dynamic (DE) ergometer. Volunteers from Ithaca College Crew (26 women, 20 men) rowed 1000 meters at race pace for each ergometer condition (counterbalanced). A 2×2 repeated measures ANOVA (α=0.05) compared stroke rate (SR), stroke ratio, impulse, peak force (PF), time to peak force, heart rate (HR), rating of perceived exertion (total body and lower extremity), respiratory exchange ratio (RER), absolute and relative oxygen consumption (VO_2), and economy ($Power \cdot VO_2^{-1}$) by condition and sex. HR was significantly higher on the DE by 1.1%. PF, stroke ratio, and RER were significantly lower on the DE by 10.8%, 16.2%, and 1.6%, respectively. Interactions occurred for SR, impulse, VO_2, and economy; separate dependent *t*-tests (α=0.05) for each sex were conducted for these variables. SR was significantly higher on the DE by 10.1% for women and 16.4% for men. Impulse was significantly lower on the DE by 7.5% for women and 11.9% for men. Absolute and relative VO_2 were both significantly higher on the DE by 5.1% for men. Economy was significantly lower on the DE by 4.9% for men. Neither VO_2 nor economy was significantly different between conditions for women. It was concluded that the DE presents decreased musculoskeletal stress but increased cardiovascular stress relative to the SE, and that these effects are more pronounced in male rowers. Future research should separate ergometer design and stroke rate effects.

ACKNOWLEDGEMENTS

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Chapter 1

INTRODUCTION

Competitive rowing is a year-round sport that typically includes the use of ergometers. These machines allow indoor simulation of rowing as well as objective assessment for comparisons within and between rowers. Whereas it is generally agreed that stationary ergometers closely approximate water rowing (Dawson, Lockwood, Wilson, & Freeman, 1998; Lamb, 1989; Urhausen, Weiler, & Kindermann, 1993), the high stroke rates used in races can be difficult to maintain on them (Martindale & Robertson, 1984). To create a better simulation of water rowing, many different dynamic designs have originated as an alternative to the traditional stationary ergometer. These designs involve entirely new machines or modifications of the old, such that part or all of the ergometer may move in response to the motion of the athlete upon it (Figure 1).

The concept behind dynamic ergometers is that they react in relation to the rower the same way that a boat does. On the water, the boat and rower transfer energy and momentum to each other throughout the stroke (Martindale & Robertson, 1984; Sanderson & Martindale, 1986; Zatsiorsky & Yakunin, 1991). On a stationary ergometer the upper body must be decelerated and accelerated to reverse direction at the catch, which requires the rower to exert force on the foot stretcher before it can be applied directly to the handle (Kleshnev & Kleshneva, 1995; Martindale & Robertson, 1984). This is potentially the source of lower stroke rates during stationary ergonometric rowing. On a dynamic ergometer the machine and athlete move away from each other during the drive and back toward each other during the recovery, allowing energy to be "saved" as it is on the water (Bernstein, Webber, & Woledge, 2002; Martindale & Robertson, 1984).

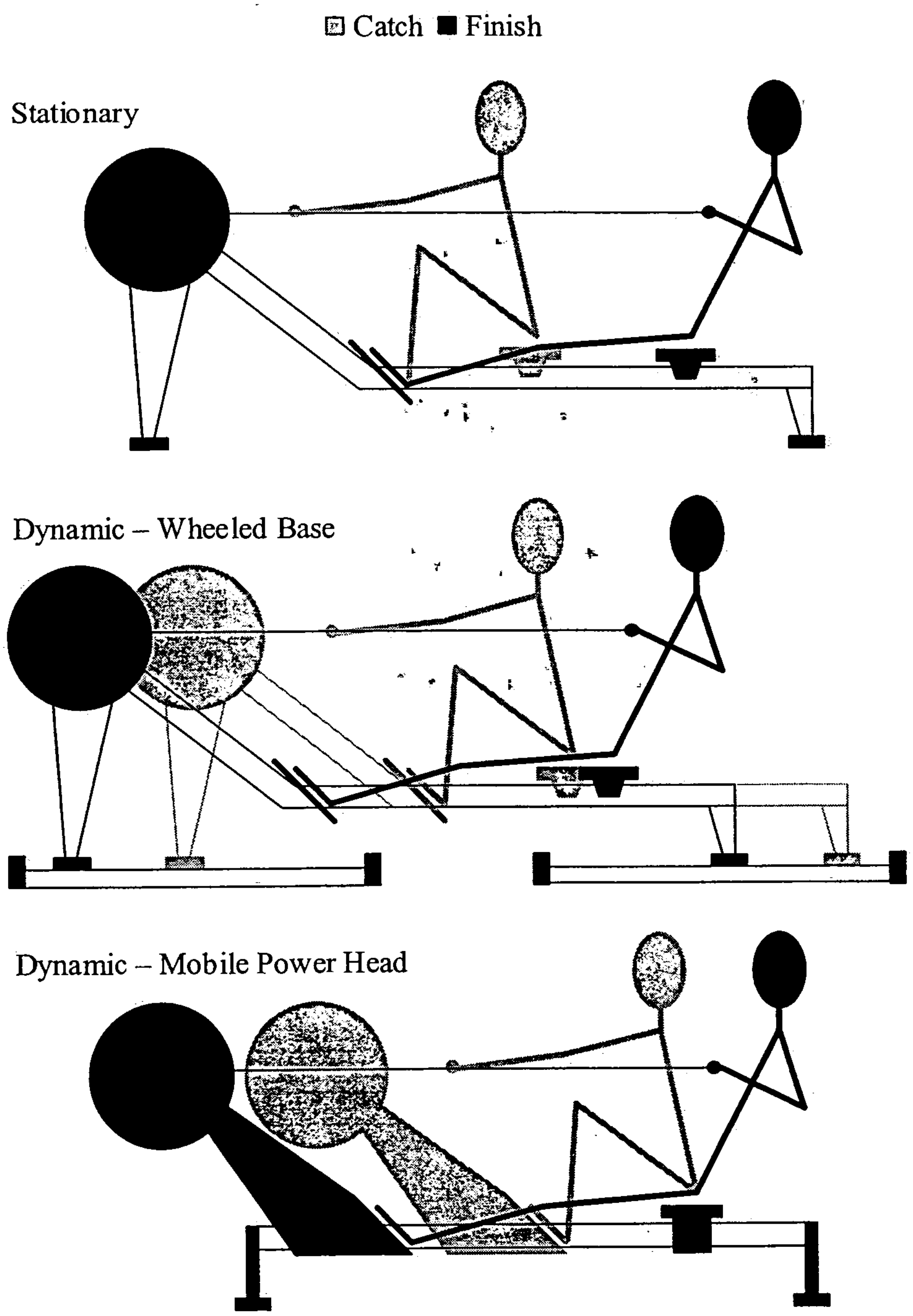

Figure 1. Diagrams of the catch and finish positions on the most common stationary and dynamic ergometer designs, being (from top to bottom) the stationary Concept 2, the Concept 2 on Slides, and the RowPerfect with a "floating" power head.

Given the mechanical advantages of dynamic ergometers, the question arises whether the use of such a machine is "easier" than the use of a stationary one. A case study designed to market the RowPerfect dynamic boat simulator would imply this is so, indicating potentially lower heart rate and lactate levels on a dynamic ergometer (Rekers, 1993). Much of the research comparing the two ergometer types has indeed focused on validating the RowPerfect machine (Bernstein et al., 2002; Elliot, Lyttle, & Birkett, 2001; Rekers, 1993, 1999). Yet, the most widely used ergometer in the United States (and likely the world) is the stationary Concept 2. "Slides" have recently been developed for use with this machine, but their effects have not been satisfactorily examined. The opportunity therefore exists to study the differences in stationary and dynamic ergometry with the Concept 2 equipment that most rowers have available.

Statement of Purpose

This study compared the physiology and biomechanics of female and male collegiate rowers at a high power output on a stationary and dynamic ergometer.

Hypothesis

It was hypothesized that rowing at a given power output would demonstrate a greater stroke rate and economy but lower impulse, peak force, heart rate, oxygen consumption, and perceived exertion on a dynamic ergometer than on a stationary ergometer, for both women and men.

Assumptions of Study

The following assumptions were made:

1. The subjects were representative of typical collegiate rowers.

2. The computer of the Concept 2 Indoor Rower reliably measured stroke rate, pace, and power output.

3. Pace (500-meter split time) was a valid measure of workload during ergonometric rowing in that it directly related to power output in watts.

Definition of Terms

Operational definitions for the terms used in this research are as follows:

1. Ergometer – a device used for indoor rowing that measures several variables; this study utilized the Concept 2 Model C, which is the most widely used ergometer in the United States, and is popular throughout the world.

2. Slides – wheeled bases designed by Concept 2 that are placed under the ergometer and allow it to roll back and forth.

3. Stroke – one rowing cycle, consisting of catch, drive, finish, and recovery.

4. Catch – the forward-most position of the rower in the stroke representing the point at which the oar would enter the water.

5. Drive – the phase of the stroke during which the rower pulls the ergometer handle by extending the legs and back, and flexing the arms.

6. Finish – the point at which the ergometer handle ceases to move toward the rower, which corresponds to the removal of the oar from the water.

7. Recovery – the portion of the stroke where the rower moves from the finish position to the catch position, essentially the opposite motion of the drive.

8. Pace – the time it takes to row 500 meters – the main display of the ergometer.

9. Stroke Rate – the cadence of the rower measured in strokes per minute.

10. Stroke Ratio – a ratio of time spent on the recovery to that spent on the drive.

11. Impulse – the integrated force applied during the drive (in Newton seconds).

12. Peak Force – the highest force measured during the stroke (in Newtons).

13. Time to Peak – the time between the catch and when peak force occurs.

14. Heart Rate – beats per minute of the athlete's heart.

15. RPE – rating of perceived exertion, on a scale of ten.

16. RER – respiratory exchange ratio (CO_2 produced divided by O_2 consumed).

17. VO_2 – oxygen uptake in liters per minute (absolute) and milliliters per kilogram per minute (relative).

18. Economy – ratio of power to oxygen uptake, as watts over absolute VO_2.

<u>Delimitations of Study</u>

This study was delimited in the following ways:

1. Only healthy collegiate rowers from Ithaca College participated as subjects.
2. The distance rowed during a trial was 1000 meters, half that of a normal race.
3. Subjects rowed at their race pace, resulting in high intensity exercise.
4. The Concept 2 Model C ergometer and Slides were used.

<u>Limitations of Study</u>

The following are limitations of this investigation:

1. The results can only be applied to collegiate rowers.
2. Observations may relate only to short duration and/or high intensity rowing.
3. Any differences are between the stationary and dynamic setups for the Concept 2 Model C and do not necessarily apply to other ergometers.

Chapter 2

REVIEW OF LITERATURE

Introduction

The rowing ergometer is one of the most important tools for crew training. It simulates the rowing motion indoors where conditions such as weather and other rowers are not factors, and where the coach can examine, assess, and advise in close proximity. Research regarding ergonometric rowing has focused on the accuracy of its simulation of water rowing, what type of ergometer design is superior, and whether a measure of rowing economy or efficiency is possible.

Stationary Simulation

The Concept 2 ergometer (Concept 2, Inc.; Morrisville, VT) was once a crude machine with a resistance fan fashioned from an old bicycle wheel. The athlete would sit on a rolling seat and pull a handle connected to a chain that in turn rotated a bicycle wheel with plastic cards on the spokes. Updated models have retained essentially the same design, though customized fans now provide resistance. Concept 2 ergometers have emerged as the standard for indoor rowing competitions and measurement of world records. The Gjessing ergometer (Gjessing & Wiik; Oslo, Norway) has been an alternative to the early Concept 2 models. It provides mechanically-braked resistance, much the way a typical cycle ergometer does. Comparisons of Gjessing and Concept 2 machines found that energy was lost in the complex braking mechanism of the Gjessing, resulting in an error of measured work; stroke rate was also higher on it than on the Concept 2 (Hahn, Tumilty, Shakespear, Rowe, & Telford, 1988; Lormes, Buckwitz, Rehbein, & Steinacker, 1993). Another mechanically-braked ergometer was the Stanford

(Gamut Engineering; Redwood City, CA), on which the handle was attached to a saw-like mechanism. This machine was used at one time for performance testing and research, but has not been compared to other models. The variant Lyons ergometer (Gamut Engineering; Redwood City, CA) involves a pivoting oar handle and numerous springs, and has been used to imitate the feel and rotational motion of sweep rowing, but not to measure work and power.

While it was undisputed that stationary rowing ergometers had provided the closest approximation of water rowing available, there had been some debate as to how accurately they simulated the activity. Lamb (1989) kinematically compared rowing on the water and on a Stanford ergometer by observing 30 oarsmen from the United States National Heavyweight Rowing Team selection camp at approximately 30 strokes per minute, presumably at full pressure. He concluded that they rowed similarly in both conditions, except for variations in the arm contribution, a small component of the total motion.

A physiological comparison of rowing on the water and on a stationary ergometer was undertaken by Urhausen et al. (1993). Regional and national level rowers exercised at various intensities on the Gjessing and in single sculls. Heart rate, lactate, and epinepherine levels were not significantly different between conditions during steady state rowing, whereas norepinepherine was higher on the ergometer. Comparison of a multi-stage ergometer test to high- and low-intensity rowing revealed that stroke rates were comparable at similar lactate levels, but heart rate was higher on the water – this was likely due to differing duration of effort. The lack of a difference in stroke rate is contrary to the findings of other studies, and can possibly be explained because endurance training for 20 minutes was examined, rather than racing sprints.

Dawson et al. (1998) investigated on-water and ergometer rowing from a motor control perspective. They observed five elite male scullers rowing in single shells and on an unidentified stationary ergometer. The subjects rowed approximately 1000 meters maximally in each condition four different times, at stroke rates of 18, 23, 28, and 33 strokes per minute. Attention was focused on the relative timing of the rowing cycle during each trial to identify sources of variance and invariance in performance. They found that the relative variability of the recovery phase accounts for almost all of the absolute variability of the stroke, and that both decrease as stroke rate increases. Furthermore, the results indicated that changes in relative timing of rowing at different stroke rates follow a simple mathematical rule. Essentially, stroke rate is increased by decreasing recovery time so that the proportion of the drive to the total stroke increases linearly with the rate. Perhaps most importantly, it was concluded that the relative timing of ergonometric rowing is similar to that of water rowing, and that stationary rowing ergometers are therefore accurate rowing simulators.

Despite the scientific evidence of similarity, prominent coaches claim an inherent difference between rowing on the water and on a stationary Concept 2 ergometer. According to Todd Jesdale of the Cincinnati Junior Rowing Club, technical flaws observed on the Concept 2 are not necessarily seen on the water; however, those with problems in one setting will often have different problems in the other (Milliman & Grogan, 2001). As stated by many other coaches, rowers must think about their technique while on an ergometer and try to imitate their on-water stroke, because in their opinion the machine invites several bad habits (Milliman & Grogan, 2001).

Torres-Moreno, Tanaka, and Penny (1999) attempted to identify these "bad habits" of ergonometric rowing by observing three rowers out of a group of 44 volunteers. These three were chosen for their poor technique. A stationary Concept 2 ergometer was used to compare them to an Olympic champion rower from the 1996 Atlanta games. The analysis was done by both digitizing video of all four rowers and obtaining data from a miniature load cell attached to the ergometer handle. Four common technical flaws were found in the three chosen subjects: failure to "lock" the lower trunk, slight knee flexion at the end of the drive, vertical fluctuation of the handle during the drive, and a decrease in recovery time to increase stroke rate. The purpose of the study was to identify errors of ergometer rowing that could adversely affect water rowing, but the design did not facilitate this. Since the researchers selected subjects "to exemplify components of poor on-water technique," their bias clearly affected the results. Additionally, it could easily be argued that at least one of the identified "flaws" of ergonometric rowing is in fact a normal part of rowing – elite single scullers achieve higher stroke rates by decreasing the time spent in the recovery phase, both on and off the water (Dawson et al., 1998).

In sum, research indicates that stationary rowing ergometers closely approximate water rowing. Since the simulation is not quite perfect, the door remains open for improved ergometer designs. Researchers, noting differences in stroke rate and kinematics between ergometer and water rowing, have designed experiments to modify the machine to give rowers more of the "floating" feel that they experience in a boat. As a result, manufacturers have incorporated these ideas.

Dynamic Development

The original criticism of stationary ergometers was the difficulty of maintaining racing stroke rates longer than a few minutes. Martindale and Robertson (1984) examined this phenomenon by studying mechanical energy differences between on-water single sculling and rowing on a stationary Gjessing. Specifically, they sought to quantify the instantaneous total body and segmental energy patterns of rowing, and to contrast these between the conditions of single sculling and ergonometric rowing. Two male and two female scullers participated by rowing in each condition three times: below, at, and above their normal racing stroke rate. Several stroke cycles were filmed in each case. The researchers also constructed a wheeled cart for the ergometer and compared data using it to the two other conditions. Thus, data were collected on the water, on a stationary ergometer, and on an improvised dynamic ergometer. While reliable instantaneous flywheel data could not be collected, it appeared that work on the stationary ergometer was greater than that on the wheeled ergometer at a given stroke rate. "Savings of energy" through exchanges and interconversions were greater on the water and on the wheeled ergometer than on the stationary ergometer. In addition, the subjects stated that the wheeled ergometer "felt" more like water rowing than the stationary setup. It was concluded that mounting the ergometer on a moving base better simulates water rowing.

The authors argued that the main differences between normal ergometer rowing and single sculling could be explained by the need for rowers on a stationary machine to accelerate and decelerate their body mass at both ends of the stroke. In contrast, the boat and rower move freely on the water, transferring mechanical energy between each other. Research reviewed by Zatsiorsky and Yakunin (1991) supports this idea. It has been shown that the rower and the boat transfer momentum to each other on the water due to mutual displacement of their centers of mass. Because of this, the velocity of the boat decreases at the beginning of the drive phase (when the rower pushes on the foot stretchers and rolls toward bow) and increases at the commencement of the recovery phase (when no oar force is present and the athlete begins rolling toward stern).

Based upon the conclusions of Martindale and Robertson (1984) and Lamb (1989), Kleshnev and Kleshneva (1995) designed a special device called "IGL-1" to be a mobile workplace for the ergometer. Rowers of varying skill performed 10-stroke, 90-second, and 6-minute tests on an ergometer, both stationary and dynamic (mounted on IGL-1). It was found that in the dynamic condition leg contribution increased and arm contribution decreased. Moreover, forces exerted on the handle and foot stretcher were synchronous on the dynamic ergometer (as they are in a boat), but foot forces preceded hand forces when stationary. This was explained as being necessary to overcome the inertia of the rower's body before force could be applied to the handle, which is similar to the finding of Martindale and Robertson (1984) that more mechanical energy is "wasted" in a reversal of momentum on a stationary ergometer. The conclusion was that a mobile base makes an ergometer a better simulator of on-water rowing (even though that condition was not observed), and that such designs should therefore be used for training and research.

After these findings, various ergometer manufacturers developed dynamic designs for their machines, or invented entirely new models. Concept 2 created Slides, which function as the wheeled carts that Martindale and Robertson (1984) and Kleshnev and Kleshneva (1995) fashioned – the entire machine moves in the opposite direction than that of the rower at any given time. The RowPerfect ergometer (Care RowPerfect; Hardenberg, Netherlands), in contrast, is designed such that the foot stretchers and flywheel roll along a bar just as the seat does. On this machine the "power head" and the seat move apart during the drive, and draw nearer during the recovery. In this way only part of the ergometer is in motion, and weights can be added to represent the relative mass of different boats that athletes might row. Since a Concept 2 ergometer on Slides presents a greater rolling mass (the entire machine) than does the RowPerfect, it cannot be used to simulate smaller boats (such as single sculls). However, it should approximate rowing in an eight, which is the class of boat favored for competition at almost every level, especially collegiate.

Responding to rowers' complaints regarding the "feel" of stationary rowing ergometers like the Concept 2, Rekers (1993) examined the dynamic RowPerfect model to determine if it is an accurate simulator of conditions in a boat. By analyzing the force-time profiles of elite rowers in a boat and on a RowPerfect ergometer, as well as with that ergometer converted to a stationary design (by clamping the power head so it could not move), he found that the dynamic design was a better simulation of on-water rowing conditions than was the stationary.

Building upon his earlier research, Rekers (1999) provided more evidence to support the use of the RowPerfect ergometer. He collected anecdotal evidence from the Holland men's eight to confirm that the simulation was indeed accurate. Rekers also noted that the use of a RowPerfect ergometer limits the peak loads on the body in comparison to traditional stationary ergometers. He argued that peak loads are the foremost cause of injury, especially to cartilage and tendons, and decreasing them makes the RowPerfect a safer and more effective ergometer.

It should be noted that Rekers developed arguments for the specific purpose of promoting and selling RowPerfect ergometers. Though the data appear genuine, the research is not peer-reviewed, and there is generally a lack of statistical analysis to establish the significance of any findings. That being said, the most useful results of Rekers involve a case study of Frans Goebel (an elite Dutch sculler) in August 1993. Goebel rowed on the RowPerfect ergometer dynamically and with it clamped to produce a stationary design. A cursory review of the data reveals that heart rate and blood lactate levels were lower in the dynamic condition, relative to power output. The implications of this are that at any given power output (or workload), rowing on a dynamic ergometer may be less physiologically intense than rowing on a stationary ergometer.

Truly scientific support for the RowPerfect ergometer came from Elliott et al. (2001). They studied eight national level scullers in their single shells and on the RowPerfect, performing 500-meter trials at rates of 24, 26, and 28 strokes per minute.

The force-angle and force-time profiles of the two conditions were highly correlated according to their data, and the positions of trunk, thigh, and shank segments were statistically similar. Conclusions of this study included that the RowPerfect ergometer is similar to single sculling, and that it can be considered validated for off-water training. Other ergometers and higher stroke rates were not examined.

Bernstein et al. (2002) studied six elite male rowers on a RowPerfect ergometer with the head both mobile and fixed, in the same way that Rekers (1993) did. The purpose of the study was to identify differences in rowing technique between the two situations, and the possible effects these might have on risk of back injury. Using three-dimensional motion analysis, the researchers found that in the stationary condition the rowers would extend further at the catch position, elongating the stroke. They would also exert higher mean forces than in the dynamic condition when performing the same total work at the same metabolic load. These differences were partially associated with higher stroke rates in the dynamic condition. The researchers hypothesized that rowing on stationary ergometers could pose a greater risk for musculotendinous injury. Their results agree with those of Martindale and Robertson (1984), Rekers (1993), and Elliott et al. (2001), showing that dynamic ergometers closely approximate water rowing.

<u>Rate and Rhythm</u>

Given that the impetus for creating dynamic ergometers was to allow practicing at a higher stroke rate (Martindale & Robertson, 1984), an understanding of this variable is important. It can generally be stated that a higher stroke rate brings greater speed on the water, though in a race this is not necessarily true. Coaches will remark that a crew with a low rate, rowing the same speed as another with a high rate, is “stronger” and, without doubt, the superior crew.

The exact effect of stroke rate during on-water rowing was examined with the U.S. men’s eight that entered the 1976 Olympics (Martin & Bernfield, 1980). The crew was filmed prior to competition, rowing six trials at each of three stroke rates: 37, 39, and 41 strokes per minute. A positive correlation was found between stroke rate and the velocity of the rowing shell. The researchers stated that since a narrow (and high) stroke rate range was chosen, less technically proficient crews (or those rowing with a different style) would likely be unable to produce the same results. Hence, the conclusions may only be applicable to elite crews. There was no discussion of economy or efficiency differences with changing stroke rate.

Kyröläinen and Smith (1999) varied stroke rate for subjects rowing maximally on an unidentified stationary ergometer. Eight male club level rowers participated by rowing four minutes maximally at 28, 30, and 32 strokes per minute. Body position, foot stretcher reaction force, handle force, and electromyography were recorded at four intervals. Calculated external work decreased and knee extensor activity increased during maximal effort. Overall it was determined that rowers had decreased control over technique and altered motor unit recruitment throughout the duration of each trial, but that these changes were consistent across stroke rates. No significant differences were noted between stroke rates. It is possible that the limited range observed may not have presented the opportunity to identify differences between high and low rates.

In a study by Sparrow, Hughes, Russell, and Le Rossignol (1999), six healthy males without any rowing experience learned to use a stationary Concept 2 ergometer in six days. Heart rate and perceived exertion decreased over the six days, indicating that the subjects grew more accustomed to the motion. They then rowed at their own preferred rate and at rates 20% above and below that, with power output kept constant at 100 watts. Interestingly, heart rate, oxygen consumption, and perceived exertion were all significantly lower at the preferred rate than at the other two, and rowing economy was significantly greater. The differences were more pronounced above the preferred rate than below. How these results may apply to the difficulty rowers have achieving racing stroke rates on stationary ergometers was not addressed.

Likewise, Nesi, Bosquet, Berthoin, Dekerle, and Pelayo (2004) had cyclists perform constant work at preferred pedal rate and a cadence 15% higher. They found that at the higher pedal rate, exercise tolerance decreased and VO_2 increased, indicating increased negative muscular and internal work, and a possible shift in motor unit recruitment.

It would appear that a high stroke rate is desirable in a race, as it is directly related to boat velocity. In studies which compared various stroke rates on the water and on stationary ergometers, only narrow stroke rate ranges were examined (Kyröläinen & Smith, 1999, Martin & Bernfield, 1980). Given that preferred rate is physiologically less taxing than a higher or lower one (Nesi et al., 2004; Sparrow et al., 1999), it would stand to reason that training at a higher stroke rate should make racing more comfortable. Dynamic ergometers may therefore better prepare rowers for successful racing, since they enable higher stroke rate than do stationary machines. Though untested, these are logical conclusions from the literature.

Economy and Efficiency

The word "efficiency" appears in numerous contexts, and is largely overused. Many researchers have sought to evaluate the mechanical efficiency (for lack of a better term) of water and ergometer rowing. Such research has made use of several tools: kinematics (Martindale & Robertson, 1984; Nelson & Widule, 1983), electromyography (Rodriguez, Rodriguez, Cook, & Sandborn, 1987), force profile analysis (Spinks, 1996), and hydrodynamics (Affeld, Schichl, & Ziemann, 1993; Zatsiorsky & Yakunin, 1991). Attempts to improve rowing performance by optimizing mechanical efficiency have included development of equations for estimation (Affeld et al., 1993; Nelson & Widule, 1983; Sanderson & Martindale, 1986), observation of coordination within a crew (Hill, 2002; Wing & Woodburn, 1995), and biomechanical feedback on land (Hawkins, 2000; Smith & Loschner, 2002; Spinks & Smith, 1994) and water (Smith & Spinks, 1998). The heavy emphasis on mechanical measurements is not surprising, given that a measurement of work or power output is often necessary for such calculations. Additonally, boats and rigging are an integral part of the sport, so mechanical knowledge among coaches and athletes is likely more common than in other sports.

Three components of boat velocity were at the core of equations developed by Sanderson and Martindale (1986): maximal power generation from the rower, maximal use of this power to move the boat, and maximal efficiency of this propulsive power. After formulating a series of equations for each factor, the researchers concluded that: it is most efficient to move the boat at a constant speed (i.e., velocity fluctuations around the mean should be minimized) because of the energy dissipation from drag; the mass of the boat should be positively scaled to that of the rower because small athletes are slightly disadvantaged by the effect of the scale of the boat on the drag coefficient; and stroke rate should be negatively scaled to the mass of the rower because stroke rate, stroke length, and applied force affect the ratio of internal power to propulsive power. The authors also suggested that some of the equations should be verified and used to evaluate rowing technique.

Nelson and Widule (1983) kinematically analyzed 18 members of the Purdue women's team in an attempt to formulate an equation with which to estimate efficiency. The subjects were filmed and digitized, and data from one full stroke for each subject was used. From this, the researchers calculated efficiency as the actual sum of trunk and knee angular velocity when the oar is perpendicular to the boat divided by the possible sum of these if both maxima occurred with the oar perpendicular. Using this equation, it was found that the subjects in the "skilled" group were 11% more efficient than the "novice" group. It should be noted, however, that the subjects were split into the two groups based upon ergometer score rather than rowing experience, and the skilled rowers were significantly taller than the novice rowers. While most of the varsity and novice team members fell into the skilled and novice groups, respectively, perhaps the difference in athletic ability confounded the estimation of technical efficiency.

Estimation of rowing economy or efficiency on the water is difficult. Affeld et al. (1993) attempted to resolve the issue of hydrodynamic efficiency by revising an earlier equation: (velocity of the center of gravity)·(propulsive force)·(mechanical power of the rower)$^{-1}$. Applying airfoil theory to the oar blade, they generated a new equation to estimate efficiency: [(mechanical power of the rower)-(power lost in the wake)]·(mechanical power of the rower)$^{-1}$, where loss of power equals blade drag times blade velocity, and the mechanical power of the rower equals the moment of the oar times the angular velocity of the oar. Using this efficiency estimate, they were able to demonstrate that newer style "Big Blade" (hatchet-shaped) oars allow rowers to achieve 3% greater efficiency than with older "Macon" (tulip-shaped) blades.

Aside from digressions regarding the presence or absence of lift forces on an oar and the origin of observed vortices, Affeld et al. (1993) supplied little underlying support for their estimation of hydrodynamic efficiency. Furthermore, it is unclear how to practically measure the variables in the equation. While the method may be useful for development and analysis of oar designs, it does not directly benefit the improvement of rowing technique, and cannot be utilized to examine ergonometric rowing.

The underlying problem with equations of rowing efficiency is that they seek to define an ideal stroke. As can clearly be seen from all levels of competition, rowers using widely disparate styles can win just as many races. The key to mechanical efficiency appears to be coordination within and between rowers. Rodriguez et al. (1990) used electromyography to observe five male rowers on a stationary Concept 2 ergometer. They concluded that the strength of individual muscles was far less important than the coordination of muscle groups acting together.

Similarly, achieving boat velocity does not require the strength of individual rowers, but rather the effectiveness of all the athletes moving together. Hill (2002) examined the force graphs of six elite coxless fours (boats with four sweep rowers and no coxswain). While it had been known that rowers possess individual force profiles (Spinks, 1996), this study revealed that form differences decreased as force output increased. This is similar to the observation of Dawson et al. (1998) that variability in relative timing decreases as stroke rate increases. Hill (2002) also found that kinesthetic perception of force profile differences between rowers is easier for form (i.e., technique) than area (i.e., power output). It was concluded that because of this, rowers should be able to more easily adapt their technique to that of others in the boat by training more often at high force output.

Several researchers have used the idea of coordinating force application within a boat to develop methods for training with biomechanical feedback. The idea is that rather than attempt to develop a hypothetical optimal technique, it makes more sense to help rowers match their style to that of others in the same boat. Real-time biomechanical feedback helps rowers to "see" their stroke and modify it accordingly (Hawkins, 2000; Smith & Loschner, 2002; Spinks & Smith, 1994). Similar methods are available on the water, with data being sent to the coach via telemetry (Smith & Spinks, 1998).

Essentially, notions of rowing efficiency have shifted from optimizing individual technique to coordinating team technique. Biomechanical evaluation is useful for making such assessments, and certainly kinematic, force profile, and hydrodynamic methods all have merit. However, when comparing ergometer designs physiological analysis cannot be overlooked. Unfortunately, evaluation of physiological economy while rowing in different ergometer and on-water conditions has been somewhat lacking.

Summary

The differences between stationary and dynamic ergometers have been investigated to a certain degree. Most of the data collected have involved single scullers on the RowPerfect ergometer, even though most rowers use larger sweep boats and Concept 2 ergometers. Also, it appears that preferred stroke rate is an important determinant of rowing economy and relative intensity. Dynamic ergometers allow stroke rates closer to what is experienced in a race, but how this and other differences from stationary ergometers affect off-water training is not clear. Finally, though mechanical efficiency estimates are available, physiological measurement of economy is simple and allows for straightforward comparison of different conditions that rowers experience.

Chapter 3

METHODS

Subjects

Volunteers from Ithaca College Crew were recruited for this study. All members of the team fit to compete (according to the judgment of the coaches and athletic trainers) were welcome to participate, inclusive of novice and varsity, lightweight and openweight, and women and men. Involvement in the study in no way helped or hindered any subject's position on the team. Rowers were notified of the opportunity via coach announcements (recruitment statement in Appendix A). A total of 48 rowers volunteered (Table 1), but two subjects were excluded from data analysis, as detailed in the Statistical Analysis section.

At the time of this study, Ithaca College had a highly competitive Division III crew, and the subjects were assumed to be representative of American collegiate rowers. All subjects gave written informed consent (Appendix B) and had the right to withdraw without consequence. The study was approved by the All-College Review Board for Human Subjects Research of Ithaca College.

Design

Participants rowed on a Concept 2 Model C ergometer once while stationary and once while mounted on Slides, with the order of conditions counterbalanced. Each trial consisted of rowing 1000 meters at race pace. This is half the distance of a sprint, and allows achievement of a high-intensity steady state without preventing a repeat bout. Race pace was self-determined by the rowers, as they were in the midst of extensive

Table 1.

Descriptive Data for the Subjects

	Number	Age (y)	Height (cm)	Mass (kg)	Experience (y)
Women	26	20.1 ± 1.2	169.5 ± 8.2	65.2 ± 8.3	2.7 ± 1.8
Men	20	19.5 ± 1.1	182.5 ± 7.0	80.5 ± 10.2	2.7 ± 2.4
Combined	46	19.8 ± 1.2	175.1 ± 10.0	71.8 ± 11.9	2.7 ± 2.1

training and knew their capabilities. The display of the ergometer was visible at all times to the subjects, and they were asked only to maintain their goal pace (as they would for a 2000-meter test), ignoring all other variables. Warm-up (on a dynamic ergometer) and stretching were allowed as desired, and subjects could rest between trials until they felt fit to continue.

Data Collection and Analysis

All testing occurred during a two-week period which concluded one week before the final competition of the racing season (the ECAC regatta). An exception was made for the women in the first- and second-varsity boats. These 12 subjects participated in the week following the ECAC races, as they began a three-week preparation for the NCAA Division III championships, which they won. Data were recorded over the final minute of each trial, during which time steady state should have been attained.

A custom-made 2200 N tension load cell (Bertec Corporation; Columbus, OH) mounted between the handle and chain of the ergometer collected force data (1000 Hz), allowing calculation of stroke rate, impulse, peak force, time to peak force, and stroke ratio from the raw data using DATAPAC 2K2 (RUN Technologies; Mission Viejo, CA) and Excel (Microsoft; Redmond, WA) software. The catch of each stroke was identified as the point at which force increased from the baseline, and the finish was the point at which it returned to baseline; both of these events were clearly evident on the force profile. Stroke rate was computed as $60 \cdot (\text{mean stroke duration})^{-1}$, with stroke duration measured in seconds. Stroke ratio was computed as $(\text{mean recovery time}) \cdot (\text{mean drive time})^{-1}$. Using all the strokes in the final minute, impulse was the mean integrated force, and peak force was the mean of the highest measured force. Likewise, time to peak force was the mean of the time between the catch and attainment of peak force for the strokes.

Heart rate was gathered with the use of a Polar F1 heart rate monitor (Polar Electro Inc.; Lake Success, NY) strapped to the subjects' chest, with the display watch held by the test administrator. The highest heart rate observed during the final minute was recorded. Perceived exertion was rated by the subjects immediately upon completion of each trial. They verbally rated (1-10) their perception of total body and lower extremity exertion, with 10 representing maximal effort.

Expired gases were measured with a ParvoMedics TrueMax 2400 (Consentius Technologies; Sandy, UT) gas analyzer. Subjects wore a mouthpiece with Rudolph valves connected by a hose to the metabolic cart, which was recalibrated between subjects. VO_2 and RER were averaged every five seconds, and the twelve samples preceding trial termination were averaged to obtain data for the final minute. Rowing economy was calculated as $Power \cdot VO_2^{-1}$ ($W \cdot L^{-1} \cdot min^{-1}$), using the average power output from the ergometer computer and absolute VO_2 measurement for the final minute.

The ergometer computer recorded power output over the entire bout, as well as average stroke rate. An independent *t*-test ($\alpha=0.05$) revealed no significant difference between the stroke rate obtained from the load cell and that averaged by the ergometer for subjects with data from both. The stroke rates from both sources were also highly correlated ($r=0.96$). Because of these similarities, measurements of stroke rate from the ergometer were used in the absence of force data.

Statistical Analysis

Subjects were excluded from data analysis if they demonstrated at least a five percent difference in average power output between trials (which was the case for one woman and one man). For the nine subjects without load cell data, stroke rate was recorded as the average calculated by the ergometer computer. Five trials had less than a full minute of data from the load cell, but all of these had at least the final 40 seconds of force data recorded, and these measurements were incorporated into the results.

A 2×2 (condition by sex) ANOVA with repeated measures compared results within subjects (stationary versus dynamic) and between subjects (female versus male). Variables which demonstrated an interaction of condition and sex were analyzed separately for women and men using dependent *t*-tests. The level of significance for all statistical tests was set at $\alpha=0.05$, and these analyses were performed using SPSS (SPSS Inc.; Chicago, IL) software.

Summary

Volunteers from Ithaca College Crew (26 women, 20 men) rowed 1000 meters at race pace on a Concept 2 ergometer once while stationary and once while dynamic (counterbalanced). A 2200 N tension load cell gathered stroke rate, stroke ratio, impulse, peak force, and time to peak force. Heart rate was collected with a chest monitor. Perceived exertion was rated (1-10) at the end of each trial. RER and VO_2 were measured by a gas analyzer. Economy was calculated as power output (from the ergometer) divided by absolute oxygen uptake.

A 2×2 ANOVA with repeated measures located significant differences by condition and sex. Variables with condition by sex interaction were tested separately for women and men with dependent *t*-tests. The level of significance was set at $\alpha=0.05$ for all statistical tests.

Chapter 4

RESULTS

A dependent *t*-test comparing mean power output between conditions revealed that the subjects did have slight variation between trials. This measure was 1.7 W lower in the dynamic condition than the stationary ($p=0.00$). Even so, power output in both conditions was very highly correlated ($r=0.999$), and expressing the difference in terms of percentage (0.67%) and effect size (0.02) shows very little change. This inability to perfectly control power output cannot be ignored in the consideration of differences between conditions for the dependent variables, however. Finally, it should be noted that the two subjects excluded for varying power between trials by more than five percent were also the only two more than two standard deviations from the mean difference in power between trials.

Significant differences between conditions were found for stroke rate, stroke ratio, impulse, peak force, heart rate, RER, VO_2 (absolute and relative), and economy. Furthermore, condition by sex interaction was found for stroke rate, impulse, VO_2 (absolute and relative), and economy. All data are displayed in Figure 2, and Appendix C contains ANOVA source tables. Separate results by sex for variables with interaction are in Table 2. Normalized and averaged force profiles are presented in Figure 3 for visual comparison – the differences in impulse (area under the curve) and peak force are readily apparent. Following the figures is a summary of the findings with differences in the means reported separately for women and men for variables with condition by sex interaction, and collapsed across sex for those without.

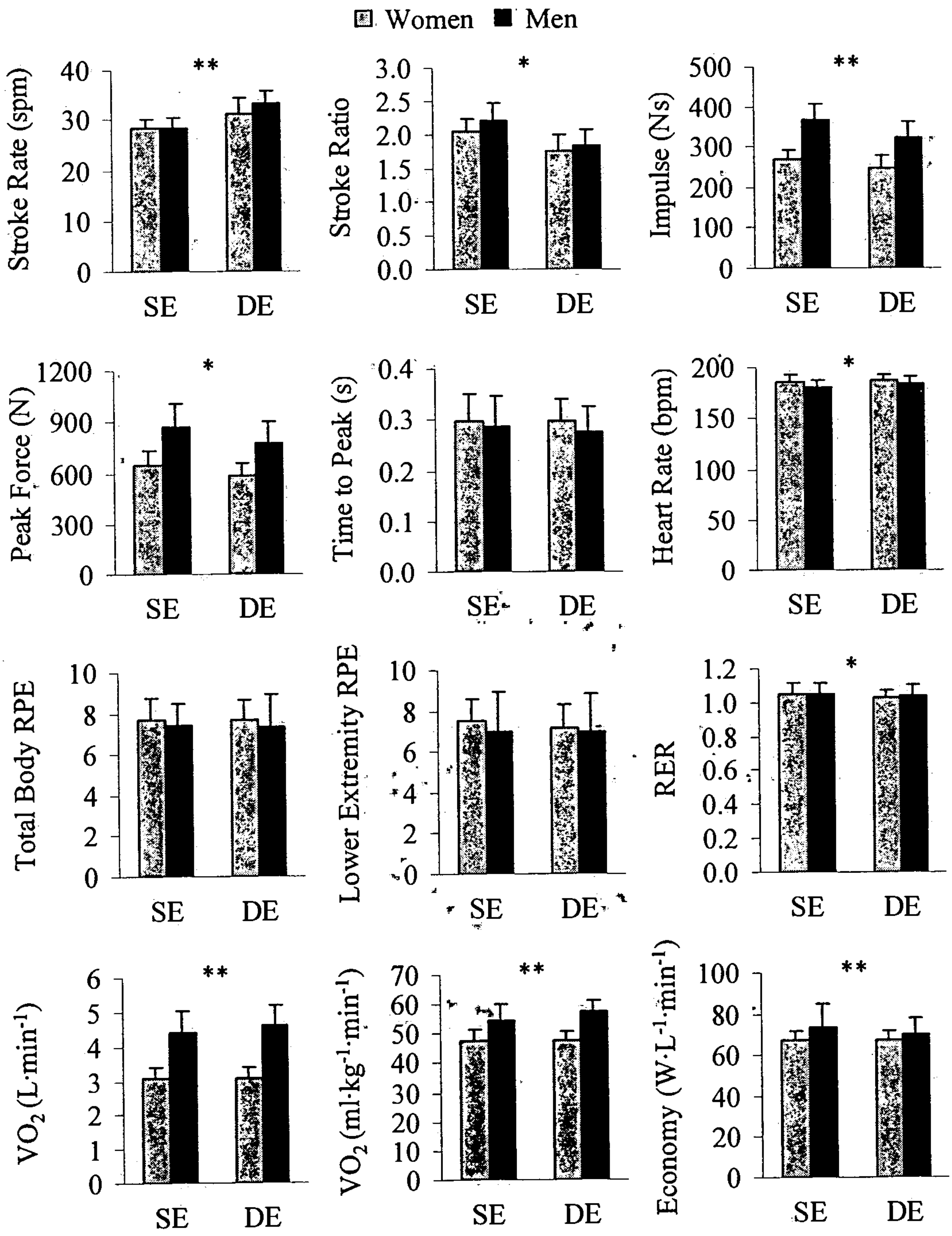

Figure 2. Mean (+SD) values for women and men on the stationary (SE) and dynamic (DE) ergometer. An asterisk denotes a statistically significant difference ($p<0.05$) between conditions, and a second asterisk indicates interaction of condition and sex.

Table 2.

Means (±SD) of Variables with Condition by Sex Interaction for Women and Men on the Stationary (SE) and Dynamic (DE) Ergometer

		Stroke Rate (spm)	Impulse (Ns)	VO_2 ($L \cdot min^{-1}$)	VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	Economy ($W \cdot VO_2^{-1}$)
Women	SE	28.4 ± 1.7*	269.0 ± 24.7*	3.07 ± 0.35	47.5 ± 4.0	67.2 ± 4.1
	DE	31.3 ± 2.9*	248.7 ± 28.2*	3.08 ± 0.33	47.7 ± 3.2	67.4 ± 4.7
Men	SE	28.5 ± 2.0*	366.1 ± 43.1*	4.39 ± 0.66*	54.6 ± 5.6*	73.6 ±11.3*
	DE	33.1 ± 2.6*	322.6 ± 39.7*	4.61 ± 0.62*	57.3 ± 4.2*	70.0 ± 8.0*

*Statistically significant difference ($p<0.05$) between conditions for that sex.

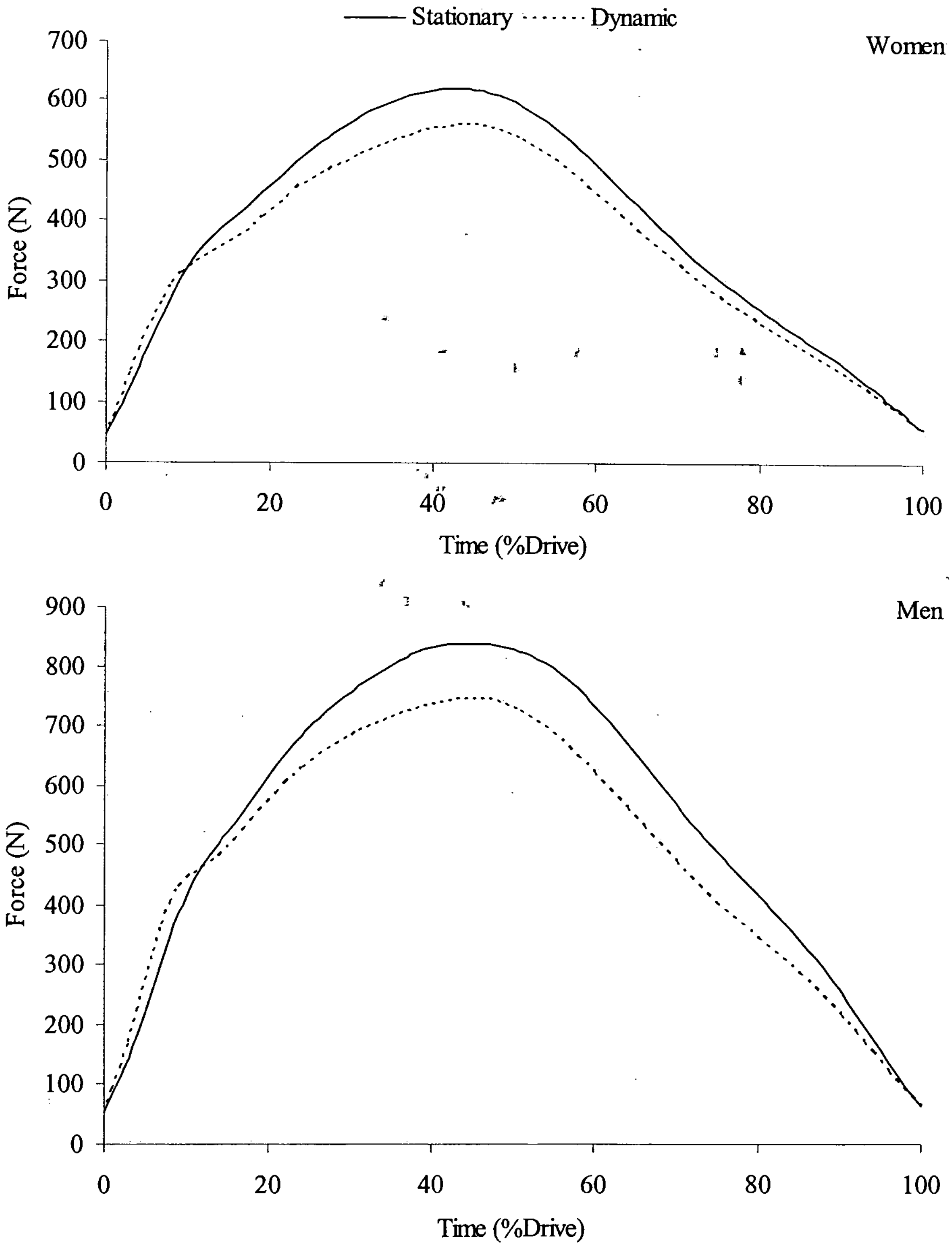

Figure 3. Normalized and averaged force-time profiles for women and men during the drive phase of the stroke on the stationary and dynamic ergometer.

Biomechanical Variables

The biomechanical data generally indicate that relative to the stationary, in the dynamic condition subjects rowed more strokes per minute with less force per stroke, and that these differences were greater for men than women. Stroke rate was higher ($p=0.00$) on the dynamic ergometer, and demonstrated interaction such that the increase was 2.9 spm for women ($t_{25}=-7.68$, $p=0.00$) and 4.7 spm for men ($t_{19}=-11.18$, $p=0.00$). Stroke ratio was 0.34 lower in the dynamic condition across subjects ($p=0.00$). Impulse was lower when dynamic ($p=0.00$), with a difference of 20.3 Ns for women ($t_{20}=6.43$, $p=0.00$) and 43.5 Ns for men ($t_{15}=7.92$, $p=0.00$). Finally, peak force was 81.0 N lower overall in the dynamic condition ($p=0.00$), and time to peak force did not differ significantly.

Physiological Variables

According to the physiological results, measures of cardiovascular intensity were higher on the dynamic ergometer than the stationary, especially for men, but measures of muscular effort demonstrated less obvious effects. Heart rate was 2.1 bpm higher across sex in the dynamic condition ($p=0.01$). No significant differences were found for the RPE of either total body or lower extremity. RER was 0.02 lower overall on the dynamic ergometer ($p=0.02$). Absolute and relative VO_2 were higher ($p=0.00$) in the dynamic condition, and both interacted with sex. Men had VO_2 changes of 0.22 $L \cdot min^{-1}$ ($t_{19}=-3.07$, $p=0.01$) and 2.75 $ml \cdot kg^{-1} \cdot min^{-1}$ ($t_{19}=-3.05$, $p=0.01$), but examination of women alone did not reveal significant differences. Correspondingly, economy was lower on the dynamic ergometer ($p=0.03$), and separate tests for sex indicated a significant difference of 3.6 $W \cdot L^{-1} \cdot min^{-1}$ for men ($t_{19}=2.35$, $p=0.03$) but no difference for women.

Chapter 5

DISCUSSION

The aforementioned hypothesis of this study was based upon the fact that mechanical energy is saved with a dynamic ergometer design, relative to a stationary one (Martindale & Robertson, 1984). If the dynamic design is biomechanically more efficient, it would stand to reason that rowers should exhibit decreased physiological stress on such an ergometer, as with the apparently lower heart rate and lactate levels of Frans Goebel (Rekers, 1993). Results of the current study do not support this notion.

Rate and Ratio

The decision not to control stroke rate between conditions was made because one of the best-established differences between rowing on the two types of machines is the higher (more race-like) stroke rate on dynamic ergometers (Bernstein et al., 2002; Martindale & Robertson, 1984). However, it may be the case that the 13% stroke rate increase from stationary to dynamic confounds the comparison between the two. That is, the observed differences in other variables may be due to the ergometer change or stroke rate variation, or both. It should be noted that every single subject rowed at a higher rate on the dynamic ergometer. Many of the observed differences are likely due to a combination of ergometer design and stroke rate factors. The fact that men generally exhibited more pronounced differences than women might be partially attributed to the fact that men varied stroke rate more than women did (16.4% versus 11.9%).

The observed 16% difference in stroke ratio between conditions is one of the results most easily attributed to the change in stroke rate. The ratio shift is due almost exclusively to a change in recovery time. Time spent on the drive was identical for women in both conditions (0.69 seconds), and very similar for men (0.67 seconds stationary versus 0.66 seconds dynamic). These data agree with findings that increases in stroke rate are accomplished by decreases in recovery time (Dawson et al., 1998; Torres-Moreno et al., 2000).

Forces

Impulse was lower on the dynamic ergometer than on the stationary by 8% for women and 12% for men, and peak force was 11% lower overall. Probably because of the higher stroke rate, rowers produced the same power by rowing more strokes per minute with less force per stroke on the dynamic ergometer. The force difference between conditions agrees with the results of Bernstein et al. (2002). In contrast to a previous study in which collegiate rowers pulled 20 maximal strokes on a dynamic Concept 2 ergometer (but not on a stationary one), impulse and peak force values in the current study (for the dynamic condition) were 20-25% lower, but time to peak, stroke ratio and stroke rate were comparable (Benson & Abendroth-Smith, 2004). The disparity in impulse and peak force between the studies is reasonable, given that Benson and Abendroth-Smith (2004) utilized very brief maximal effort. Additional comparison to a review of rowing mechanics indicates that peak and mean forces were within the ranges of handle forces measured in previous studies (Zatsiorsky & Yakunin, 1991).

The lack of a difference in the time taken to achieve peak force suggests that the average rate of force development was the same in both conditions. This in turn indicates that the shape of the force-time profile did not change drastically between conditions, only the magnitude did. Visual inspection of the curves (Figure 1) supports this, though a slight irregularity at the beginning of the drive on the dynamic ergometer hints that the initial rate of force development was greater in the dynamic condition; this variable was not analyzed, however. Force profiles from other studies often have a similar "bulge" between the catch and peak force, and such a conformation appears to occur more often on the water and with dynamic ergometers than with stationary ones, and may be absent on the stationary ergometer because of the disparity between foot stretcher and handle forces in that condition (Bernstein et al., 2002; Elliot et al., 2001; Kleshnev & Kleshneva, 1995; Martindale & Robertson, 1984). Despite this phenomenon, the stationary and dynamic force profiles suggest that rowers implemented a similar motor program in both conditions. That the time spent on the drive was comparable between conditions further supports this notion.

Physiology

The likely cause of observed differences in heart rate, VO_2, and economy is stroke rate – increased exercise cadence might reduce muscular stress while increasing cardiovascular demands (Nesi et al., 2004; Sparrow et al., 1998). The 1.1% increase in heart rate from stationary to dynamic ergometer seems like a small change, but is probably closer to 1.5% relative to heart rate reserve, and the effect size (0.30) suggests that the difference is not negligible. This change in heart rate is contrary to Rekers (1993), but the disagreement is not worrisome because his observation of lower heart rate and lactate on a dynamic ergometer did not utilize any statistical tests and was intended to present the RowPerfect in a favorable light. Furthermore, control of or changes in stroke rate were not mentioned in that report. Other comparisons of stationary and dynamic ergometers either did not measure heart rate or controlled it between conditions as a measure of exercise intensity (Bernstein et al., 2002; Kleshnev & Kleshneva, 1995; Martindale & Robertson, 1984).

There are several possible explanations for the lack of a difference in perceived exertion. Many of the subjects expressed preference for one ergometer condition over the other, but their opinions seemed almost evenly divided. Since these views were not recorded, they cannot be factored into the analysis. Subjects were fairly evenly split between those who reported RPE greater in one condition, greater in the other, and equal in both. The literature indicates that dynamic ergometers "feel" more like on-water rowing (Martindale & Robertson, 1984; Rekers, 1999), but whether or how this feeling might transfer to perceived exertion has not been investigated. Dawson et al. (1998) found that perceived exertion is lowest when rowing at a preferred stroke rate, and it is entirely possible that some subjects simply preferred a lower rate and others favored a higher one. If this were the case, however, the other observed physiological differences would likely not have occurred. The most probable explanation is simply that the subjects performed the same mechanical work, and knew this from the ergometer display. They were accustomed to similar workouts, and were apt to have notions of how they should feel after such an exercise bout. This is of course speculation, but the dearth of perceived exertion data in previous studies hinders a more concrete conclusion.

The difference in respiratory exchange ratio between ergometer conditions was 1.6%, and once again an effect size of 0.30 shows a meaningful change. Values above 1.00 (as seen in both conditions) indicate buffering of lactate, which increases expired carbon dioxide (Roitman, 2001). Lower RER in the dynamic condition suggests less muscular fatigue – it would seem that less lactate buffering occurred, due to less force production (i.e., less muscle activity) per stroke. Direct measurement of blood lactate and electromyography would help to clarify this, but such data were not collected for the current study. If local fatigue were in fact lower on the dynamic ergometer, this would cause less local perceived exertion, so the absence of a difference in lower extremity RPE seems very odd. Possible preferred rate differences between subjects might once again be considered a confounder.

Increased oxygen uptake on the dynamic ergometer indicates greater physiological intensity in that condition. The 5.1% increase in both absolute and relative VO_2 for men implies greater internal work on the dynamic ergometer to achieve the same external work. This conclusion is even clearer with consideration of the 4.9% drop in economy for men from the stationary to the dynamic ergometer. These differences were observed as main effects in the ANOVA, but were not visible in the *t*-tests conducted for women alone. It can be said that collegiate rowers in general exhibit increased VO_2 and decreased economy on a dynamic ergometer, but the female response should be further investigated.

Conclusions

Overall it appears that rowing at a high intensity presents increased cardiovascular stress and decreased musculoskeletal stress on a dynamic ergometer relative to a stationary one. These effects appear to be more pronounced in men than women. The decision to use one machine or the other should be made based upon training goals. If muscular and connective tissue strength is desired, the higher forces experienced on the stationary ergometer may be advantageous. Training the body to withstand the intense cardiovascular demands of sprint racing would likely be more effective with a dynamic machine. Future research should attempt to tease apart the effects of ergometer design and those of stroke rate.

Chapter 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

This study compared rowing on an ergometer while stationary and while dynamically mounted on a wheeled base. Members of Ithaca College Crew (26 women, 20 men) volunteered to row two 1000-meter bouts at race pace. The counterbalanced trials were on a Concept 2 Model C ergometer that was alternately stationary and dynamic (mounted on Slides). A Bertec tension load cell (2200 N) mounted between the handle and chain collected stroke rate, stroke ratio, impulse, peak force, and time to peak force. A Polar heart rate monitor measured heart rate. Perceived exertion (total body and lower extremity) was rated on a scale of ten at the end of each trial. A ParvoMedics TrueMax 2400 gas analyzer measured expired gases, recording RER and VO_2 (absolute and relative). Economy was calculated as the ratio of power output (measured by the ergometer) to absolute VO_2. All measurements related to the final minute of the trial, except for perceived exertion.

Comparisons were made using a 2×2 repeated measures ANOVA, with separate dependent *t*-tests for women and men for variables with condition by sex interaction ($\alpha=0.05$). Relative to stationary, in the dynamic condition stroke rate was higher by 10.1% for women and 16.4% for men, stroke ratio was 16.2% lower, impulse was lower by 7.5% for women and 11.9% for men, peak force was 10.8% lower, and time to peak force did not differ significantly.

Also compared to the stationary condition, on the dynamic ergometer heart rate was 1.1% higher, neither RPE differed significantly, RER was1.6% lower, absolute and relative VO_2 were higher by 5.1% for men, and economy was lower by 4.9% for men. Despite demonstrating significant main effects, VO_2 and economy showed no significant differences for women alone.

Conclusions

It appears that rowing on a dynamic ergometer decreases musculoskeletal stress but increases cardiovascular stress, and more so for men than for women. It is not entirely clear which differences were due to the ergometer, and which were due to stroke rate. It is clear, however, that the stroke rate changed between conditions because of the ergometer design.

Recommendations

The stationary ergometer should be used to strengthen muscle and connective tissue, and the dynamic ergometer should be used to train the cardiovascular system and prepare for sprint racing. Future research should investigate different stroke rates on both machines, as well as examine different workloads.

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APPENDIX A

Recruitment Statement

"Aaron Benson is conducting rowing research and needs volunteers from the team. Anyone who wants to should sign up for a time to participate. It will take about half an hour during the day, on campus. You'll just need to row two 1000-meter pieces at race pace, and do a couple of power twenties. You can get more information about it from Aaron."

APPENDIX B

Informed Consent

Purpose of the Study

Aaron Benson, a graduate student in the Department of Exercise and Sport Sciences at Ithaca College is conducting a research study to examine physiological and biomechanical variables while rowing on stationary and dynamic ergometers. You have volunteered to take part in the study because you are a rower who wants to better understand the ergometer.

Benefits of the Study

It is hoped that by participating you will gain a better understanding of the science behind the sport of rowing. The results will be used as part of a Master's thesis, and may be presented at scientific conferences. There are possible implications on the effectiveness of ergometer training, as well as assessment of good rowing technique.

What You Will Be Asked to Do

You will sign up for a convenient time during the day to go to the Center for Health Sciences. You will likely spend about half an hour there, and you will not need to return a second time. For this study you will wear the mouthpiece of a metabolic analyzer, as well as a heart rate monitor. You will be asked to row a thousand meters at your own race pace on both a stationary ergometer and one mounted on wheeled carts. There will be adequate time for warm-up and recovery allowed. After each trial a drop of blood will be obtained from your earlobe with a sterile lancet, the site will be cleaned with alcohol. When you first mount the ergometer on slides you will row two sets of twenty strokes at race pace, once while catching with fully extended arms and once while flexing them slightly at the catch. You will not be allowed to participate if you are not medically cleared to compete or practice with the rowing team.

Risks

Participation in this study will not include any physical risks beyond normal ergometer rowing (i.e. strains, sprains, spasms, lightheadedness, exercise-induced asthma, etc.). Appropriate stretching will be allowed before any data collection begins. As this is an experimental treatment, there may be some unknown risks that are currently unforeseeable.

Compensation for Injury

If you suffer an injury that requires any treatment or hospitalization as a direct result of this study, the cost for such care will be charged to you. If you have insurance, you may bill your insurance company. You will be responsible to pay all costs not covered by insurance. Ithaca College will not pay for any care, lost wages, or provide other financial compensation.

If You Would Like More Information About the Study

You may ask questions at any time of Aaron Benson, the principal investigator. He may be reached at 607-351-3454 or abenson1@ithaca.edu. If you wish to obtain your individual results he will be happy to provide them. The overall anonymous results will be made available to the entire team.

Withdrawal from the Study

Participation in this research is entirely voluntary. You may refuse to participate or withdraw at any time without consequence or loss of benefits.

Initial: ____________

APPENDIX B (continued)

How the Data Will be Maintained in Confidence

Research records will be kept confidential to be consistent with federal and state regulations. Only the investigators will have access to the data. Your individual results will remain anonymous. The results of the study may be presented at professional meetings and published in professional journals. Video data will only be recorded upon consent (below), and will not be shown in any presentation without appropriate consent (below).

I have read the above and I understand its contents. I agree to participate in the study. I acknowledge that I am 18 years of age or older.

____

Print or Type Name

____ ____________________

Signature Date

I give my permission to be videotaped.

____ ____________________

Signature Date

I give my permission to be videotaped and to allow that tape or image to be used in conference and classroom presentation.

____ ____________________

Signature Date

I give my permission for my data to be shared with the Ithaca College rowing coaches, with the understanding that they will not affect team standing.

____ ____________________

Signature Date

APPENDIX C

ANOVA Source Tables

Comparison of Ergometer Condition

Variable	F	Hypothesis df	Error df	p
Stroke Rate	179.58	1	44	0.00
Stroke Ratio	107.45	1	35	0.00
Impulse	113.29	1	35	0.00
Peak Force	59.76	1	35	0.00
Time to Peak	0.88	1	35	0.35
Heart Rate	6.76	1	37	0.01
Total Body RPE	0.10	1	44	0.76
Lower Extremity RPE	0.43	1	44	0.51
RER	6.17	1	43	0.02
Absolute VO_2	11.54	1	43	0.00
Relative VO_2	10.78	1	43	0.00
Economy	4.89	1	43	0.03

Comparison of Sex

Variable	F	Hypothesis df	Error df	p
Stroke Rate	2.17	1	44	0.15
Stroke Ratio	3.08	1	35	0.09
Impulse	62.87	1	35	0.00
Peak Force	41.52	1	35	0.00
Time to Peak	1.01	1	35	0.32
Heart Rate	5.29	1	37	0.03
Total Body RPE	0.89	1	44	0.35
Lower Extremity RPE	0.65	1	44	0.42
RER	0.29	1	43	0.59
Absolute VO_2	97.49	1	43	0.00
Relative VO_2	48.64	1	43	0.00
Economy	4.75	1	43	0.03

Interaction of Ergometer and Sex

	F	Hypothesis df	Error df	p
Stroke Rate	10.06	1	44	0.00
Stroke Ratio	1.60	1	35	0.21
Impulse	15.01	1	35	0.00
Peak Force	2.04	1	35	0.16
Time to Peak	1.59	1	35	0.22
Heart Rate	2.27	1	37	0.14
Total Body RPE	0.10	1	44	0.76
Lower Extremity RPE	0.43	1	44	0.51
RER	0.90	1	43	0.35
Absolute VO_2	8.83	1	43	0.00
Relative VO_2	8.12	1	43	0.01
Economy	6.60	1	43	0.01