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Changes in Simulated 2,000 Meter Rowing Performance During 4 Years of Intercollegiate Women's Rowing

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**Changes in Simulated 2,000 Meter Rowing Performance During 4 Years of
Intercollegiate Women's Rowing**

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B.S. University of Connecticut, 2009

A Thesis

Submitted in Partial Fulfillment of the

Requirements for the Degree of Master of Arts

at the

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2011

APPROVAL PAGE
Master of Arts Thesis

Changes in Simulated 2,000 Meter Rowing Performance During 4 Years of
Intercollegiate Women's Rowing

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ABSTRACT

This study examined the performance gains in annual simulated 2,000 meter (2K) rowing tests of female collegiate rowers over their four years of collegiate-level training and competition. Data compiled over 14 years on 47 well-trained, collegiate female rowers were used. Subjects' PR (personal record) 2K scores for each of their four years with the University team were analyzed. Results showed significant differences between both Year 1 to Year 2 and Year 2 to Year 3 2K PR scores. The greatest change in 2K scores occurred between Year 1 and Year 2. No significant differences were seen between Year 3 and Year 4 2K scores. From the data collected, a range for expected annual improvement in collegiate female 2K testing was created. Observed changes in simulated rowing will be useful for coaches, trainers and competitors alike.

Chapter 1

INTRODUCTION

The progression of and rate of improvement in the performance of elite athletes, particularly collegiate athletes, is a topic of great importance to trainers and competitors alike. Among coaches, there is a widespread appreciation for the potentially valuable information gained via knowledge of how sport-specific performance can be improved through various types of training methodologies. Currently, there is a noticeable lack of published research addressing the effectiveness of sport-specific strength and conditioning practices, especially in the sport of rowing (5, 19). Recent growth in the number of collegiate-level women's rowing teams provides incentive for research in this area of sport-specific science. The abnormally large roster size of rowing teams makes monitoring individual progress difficult for coaches due to a low coach to rower ratio. Tracking longitudinal progress in rowing performance provides useful information in the evaluation of a training program's effectiveness as well as advancement in optimizing training programs for these athletes. Studies concentrating on longitudinal performance changes in sports other than rowing have shown general annual improvement, yet the uniqueness of specificity in rowing performance testing makes tracking the progression of this sport advantageous to coaches. For this reason, our research will focus on quantifying the changes in rowing performance over a collegiate female athlete's four year career.

Due to a lack of pre-collegiate rowing programs across the nation, the majority of rowers at the collegiate level begin their rowing career with no previous experience (1,

10). Consequently, it is of great importance for coaches to appropriately (and safely) introduce these novice athletes to rowing-specific training programs (10) while determining an inexperienced athlete's potential for success in the sport. Players and coaches alike have become increasingly interested in the scientific methods for predicting the potential and skill of these athletes. Although specific individual physical and physiological parameters are important factors in the progression and improvement of rowing performance, the focus of this research is to characterize the progression of female rowing performance over a four year collegiate career based on incremental simulated indoor rower (ergometer) testing.

Incentive for a better understanding of ergometer performance may be partly related to the establishment of indoor rowing as a world competition (13). The most well-known indoor rowing competition is the World Indoor Rowing Championship in Boston, also known as "C.R.A.S.H.-B.", which began in 1982 (2). Many collegiate programs encourage their team members to participate in this highly-competitive annual contest, which consists of completing a timed 2,000 meter test (2K) on an ergometer. Some coaches even promote this event as the most important testing opportunity of the year where rowers should achieve their best performance. Consequently, the results of such a competition may be an important factor affecting a rower's standing on the team as determined by their coach. Continued annual improvement in 2K performance is expected from these rowers in order to keep their good standing.

One of the most obvious incentives for coaches and scientists to pursue a better understanding of the world of rowing performance is the recent growth in women's rowing participants at the collegiate level. In 1997, only 291 youth and high school rowing programs were in existence nationwide (20). Despite the low incidence of high schools, which offer rowing as a conventional sport opportunity (1, 10, 19) recent increases in the number of Division I women's rowing programs in the U.S. indicate a need for greater concentration in the area of training for this sport (19). According to the National Collegiate Athletic Association (NCAA), women's rowing is one of the fastest growing varsity sports in the NCAA (19). The number of varsity women's rowing programs in the United States has increased steadily since the sport's induction as an NCAA Championship sport in 1996-97 (20). There were 96 initial varsity level women's rowing teams at this induction which grew to 136 NCAA teams in 2000-01 (20). Considering the sport's continuing gains in collegiate popularity, this number arguably has grown even more over the past 10 years (from 2001-2011).

Large recent growth in the number of women's collegiate rowing teams in the United States points to Title IX which went into effect on July 21, 1975. This law prohibits discrimination based on sex in education programs and activities receiving or benefiting from federal funding, including athletics (20). As an attempt to comply with Title IX, many institutions have added women's rowing to their list of varsity athletic team offerings due in part to the sport's potential for generating an extremely large roster size. Teams with larger roster sizes make it easier for schools to comply with Title IX since equality between men's and women's varsity teams is based on the total number of

athletes from all sports combined. Of any NCAA women's sport offered at the collegiate level, rowing has, by far, the largest average roster size (20).

Because the number of NCAA women's rowing teams is predicted to increase, further research developments are necessary, which focus specifically on training and performance for these athletes. Due to the sport's consistently large roster sizes, monitoring of individual team members' performance becomes increasingly difficult as the ratio of rowers to coaches increases. A simple way to monitor these athletes' progress is possible through comparisons of their progressive 2K performances.

The major objective of this study is to facilitate the development of this burgeoning program by quantifying the typical female collegiate rower's ergometer performance during her initial years. Such information should help coaches determine whether or not a novice athlete without rowing experience has the potential to succeed later on in her career. Yet, few studies have been undertaken which focus on how certain physical characteristics may affect collegiate rowing performance, especially studies including data collected using female subjects (1, 19). Determining the effects of physical variables on athletic performance in elite and/or collegiate athletes has been a topic of research interest for many years. Although this subject area is in need of additional, more advanced research, there are recent studies addressing this topic in various sports. Miller et al. (18) examined the relationships among several physical variables in collegiate football players and found correlations of these relationships with performance in various physical tests which are recognized as indicators of a player's

progress in football (18). A number of investigations have attempted to determine which physical and/or physiological variables are the most important indicators of excellence in rowing performance (6, 7, 9, 11, 14, 15, 19, 21, 23, 26, 28). Conflicting results, complexity of various rowing training programs, low female subject representation, and a lack of long-term performance monitoring have made it difficult for researchers to determine which variables reliably predict of rowing performance. Instead of attempting to quantify the relationships between several controversial variables and rowing performance, the current study predicts female rowing performance based on the actual rate of improvement in ergometer testing as determined by longitudinal monitoring.

Tracking longitudinal changes in the performance of athletes is a useful tool for coaches when looking to develop sport-specific training programs and for evaluation of athletes' progress in such training (8, 15, 17, 18, 24). Since an intercollegiate athlete typically has only four years to reach their maximum potential in performance for their sport, tracking the rate of progress for these athletes during their collegiate careers is vital. However, published research that monitors the development of collegiate athletic performance is limited. Studies investigating such a progression in collegiate football players have indicated that the greatest rate of change in performance testing occurs during an athlete's initial year of collegiate training (18, 24). Similarly, Hunter et al. found that the greatest changes in strength (bench press and squat 1RM), VO_{2max} , and vertical jump occurred between the players' first and second years of training over their four year collegiate basketball career (8). Overall, data from these longitudinal studies

have indicated consistent annual improvement across the majority of their respective performance evaluations (8, 18, 24).

To our knowledge, no studies yet exist which interpret ergometer testing data to monitor changes in performance for rowers during their collegiate careers. In the sport of rowing, performance testing parameters are unique in how specific they are to an athlete's actual performance during a competition. Other team sports, such as soccer, basketball and football, are limited in the competition performance-specific testing they are able to carry out. Due to environmental variables (such as temperature, wind and precipitation) conducting controlled evaluations of an athlete's outdoor rowing performance is particularly difficult (3). By testing rowers individually through competition-length time trials on ergometers, coaches are able to evaluate each athlete's ranking on the team in a controlled environment (13, 16, 25). When comparing on-water to simulated rowing methodologies only slight disparities in physiological responses exist (25).

The rowing ergometer performance assessment most often utilized by rowing coaches is a timed 2,000 meter test which is the length of a typical collegiate sprint race (13, 26). This commonly used testing method has been shown to provide highly reliable results due to the rowing machine's fixed resistance (no required calibration) and subject familiarity with such tests (22). Ranking of the team's rowers often is based on the results of such a test although intangibles, such as each individual's on-water rowing technique (which involves more balance and efficiency when compared to the movement

dynamics of an ergometer) and synchronization with boatmates, also are taken into consideration by coaches trying to ‘boat’ their top crew (3, 19).

When attempting to determine the factors responsible for changes in a rower’s overall performance, it is useful to evaluate relevant information compiled for athletes participating in sports other than rowing. Athletes’ performance gains resulting from strength training programs, the rate of performance improvement in elite athletes and relationships between an athlete’s physical and physiological characteristics and sport performance all are informative topics to consider.

Based on information cited by other athletic programs, we hypothesize that the largest change in a female rower’s 2K time should occur between the athlete’s first and second years of training with the team. This hypothesis is based principally on research conducted previously (albeit mainly with respect to male athletes), which has indicated consistently that the largest gains in performance testing for other sports occur during these initial years (8, 18, 24). Therefore, the purpose of this study was to determine whether a selected group of collegiate female rowers achieved performance gains over their four years of training and competition with the team and also if their prior high school experience had any major impact on their pattern of performance. Another factor considered was whether these athletes continued to make advances in their performance throughout their collegiate careers or ended up reaching their personal record (PR) performances prematurely. Based on our results, we hope to provide information that would be useful to coaches in the development of realistic training objectives, evaluation

of individual rowers' ergometer testing progress, what to expect from rowers during their initial stages of training with the team, and what kind of changes in ergometer testing results a coach might expect to occur over an athlete's four years of training with a collegiate women's rowing team.

Chapter 2

REVIEW OF LITERATURE

Introduction

The exercise physiology associated with competitive rowing performance is unique in comparison to that of other higher profile sports and demands a specialized training program for these athletes. Studies have investigated the effects of classic linear periodization, differing training environments and modes of resistance training programs on the rowing performance of elite male and female athletes. The physical and physiological characteristics of these athletes also have been investigated in an attempt to determine their relationships, if any, with performance advantages. From these relationships, prediction methods for on- and off-water rowing performance (although quite controversial) have been established with the hope of predicting an athlete's success in the sport. Due to rowing's complex physiological requirements, an athlete's success can be predicted by comparison of longitudinal performance measures, such as indoor rowing ergometer testing. Studies focused on the longitudinal improvement of performance in elite athletes of other sports have found annual changes in performance parameters, indicating the possibility of establishing such changes in rowing athletes as well. Our research focuses on quantifying the annual changes in collegiate level female rowing performance in an attempt to provide information useful to coaches who seek to monitor their athletes' yearly progression and improvement throughout their careers.

Physiology of Rowing

Designing a strength training program for rowing relies heavily on a thorough understanding of the sport's physiological requirements. Rowing has been classified as an "intense exercise event" due to its demands from both the body's aerobic and anaerobic energy systems for exercise bouts, which generally last between 1 and 8 minutes (20). During a typical race, the body's aerobic energy system provides approximately 70% of a rower's required energy while the anaerobic energy system supplies the remaining 30% of energy required (14, 9, 21, 13, 8, 6, 30, 23, 26, 10). Table 2.1 (below) shows the results of selected studies measuring the aerobic and anaerobic contributions of energy expenditure during ergometer exercise in elite male rowers (30).

Study	Number of subjects	Duration	Aerobic contribution (%)
Present study	19	6 min 43 s	84
Droghetti <i>et al.</i> (1991)	19	6 min	80
Hagerman <i>et al.</i> (1978)	310	6 min	70
Hartmann (1987)	17	6 min	82
Mickleston and Hagerman (1982)	25	15–18 min	72
Roth <i>et al.</i> (1983)	10	6 min	70
Secher <i>et al.</i> (1982)	7	6 min	70–86

Table 2.1 Mean aerobic energy contribution during simulated rowing exercise. Compiled studies used elite heavyweight male rowers (Russell *et al.* 1998).

The amount of energy contributed by each of the body's aerobic and anaerobic systems has been found to vary slightly by investigation method used as well differing based on the rower's gender. Documentation of elite male rower physiology has shown

an anaerobic system contribution of approximately 14% during 6 minutes of maximal effort rowing, while the anaerobic system contribution of elite female rowers during similar 4 minute testing was 23% (31). Based on the results of a 6.5 minute ergometer test performed by national level oarswomen, investigators found that aerobic and anaerobic energy contributions during the piece were 80% and 20%, respectively (31). Using similar methods, Pripstein et al. (29) monitored college-age female rowers during a simulated 2,000 meter rowing test and found the anaerobic energy contributions to be 12% of the rowers' total energy production. With varying results considered, the majority of a rower's training appears to revolve around improvement of their aerobic capacity.

Laursen et al. (20) reviewed intense exercise performance and discussed the importance of combining different modes of training to form a successful program. Intense exercise events, such as rowing, rely on near maximal energy delivery, both aerobic and anaerobic, over a sustained period of time. Programs lacking an appropriate combination of high-intensity and high-volume training may result in performance progression standstills without further improvement. Therefore, optimal training sessions for improvement in intense exercise performance are designed to include long duration low-intensity periods with phases of very high-intensity work (20).

Steinacker et al. (32) evaluated the available literature related to training in rowing based on physiological characteristics of trained rowers. In that review, many studies supported the notion that rowing athletes are capable of providing some of the

Group or sport	Age	Males	Females
Nonathletes	10-19	47-56	38-46
	20-29	43-52	33-42
	30-39	39-48	30-38
	40-49	36-44	26-35
	50-59	34-41	24-33
	60-69	31-38	22-30
	70-79	28-35	20-27
Baseball/Softball	18-32	48-56	52-57
Basketball	18-30	40-60	43-60
Bicycling	18-26	62-74	47-57
Canoeing	22-28	55-67	48-52
Football	20-36	42-60	—
Gymnastics	18-22	52-58	36-50
Ice hockey	10-30	50-63	—
Jockey	20-40	50-60	—
Orienteering	20-60	47-53	46-60
Racquetball	20-35	55-62	50-60
Rowing	20-35	60-72	58-65
Skiing, alpine	18-30	57-68	50-55
Skiing, Nordic	20-28	65-94	60-75
Ski jumping	18-24	58-63	—
Soccer	22-28	54-64	50-60
Speed skating	18-24	56-73	44-55
Swimming	10-25	50-70	40-60
Track and field, discus	22-30	42-55	—
Track and field, running	18-39	60-85	50-75
	40-75	40-60	35-60
Track and field, shot put	22-30	40-46	—
Volleyball	18-22	—	40-56
Weightlifting	20-30	38-52	—
Wrestling	20-30	52-65	—

highest recorded VO_{2max} values of any athletes in the world. College-age female non-athletes have been shown to produce VO_{2max} values of approximately 33-42 ($ml \times kg^{-1} \times min^{-1}$); whereas, college-age female rowers are capable of a VO_{2max} range from 58-65. When comparing VO_{2max} values to college-age female athletes in other high-profile sports, rowers are second only to Nordic skiers who possess a VO_{2max} of 60-75 (36).

Table 2.2 Maximal oxygen uptake values ($ml \cdot kg^{-1} \cdot min^{-1}$) for athletes and nonathletes (Wilmore et al. 2008).

Research by Secher et al. (31) provided VO_{2max} values for internationally competing male rowers approximately 25 years of age. The winning competitors of these international championships had a mean VO_{2max} of 63 ($ml \times kg^{-1} \times min^{-1}$), while the other (losing) competitors had a mean VO_{2max} of 67 (31).

This sizeable value for maximum oxygen uptake is related to a rower's required utilization of all extremities and the trunk when working to propel the boat he or she is racing in (34, 32, 38, 11). These total-body movements amount to usage of approximately 70% of the body's total musculature (32). To engage this large muscle mass, approximately 75-80% of a rower's power during their stroke comes from the lower body (legs) leaving about 20-25% of their power produced by the upper body (arms) (17).

At the beginning of each rowing competition, a great amount of muscular strength is required by each individual in the boat to successfully accelerate from a standstill and propel the shell forward. Once the shell has been accelerated to "race pace" maintenance of the shell's speed during an entire race requires rowers to utilize large amounts of oxygen. Consequently, increasing one's endurance is a primary focus of a successful training program in the sport of rowing (32). Musculature utilized by athletes during rowing competition should be comprised of both high strength and endurance characteristics. Generation and maintenance of high force output throughout an entire race depends on the presence of both these characteristics (17).

Optimal performance in either 2K or 6K rowing competitions is limited by a rower's maximum strength, starting power, and muscular endurance (32). The type of training program design for competitive rowing athletes is highly determinate of their gains in these areas of trainable performance indicators. As a rule, rowers must generate huge amounts of force in the beginning of a competition when the velocity of a stationary shell is quickly propelled to race pace in as short of a period of time as possible. Strength, for rowers, is more important in relative (to body weight) terms than absolute (maximum) terms due to the drag associated with the total weight of a boat (26). Four basic physical forces (gravitational, buoyant, drag, and propulsive) act on a shell while transporting rowers with their individual oars through an aquatic environment. This system is depicted in Figure 2.1 below (2).

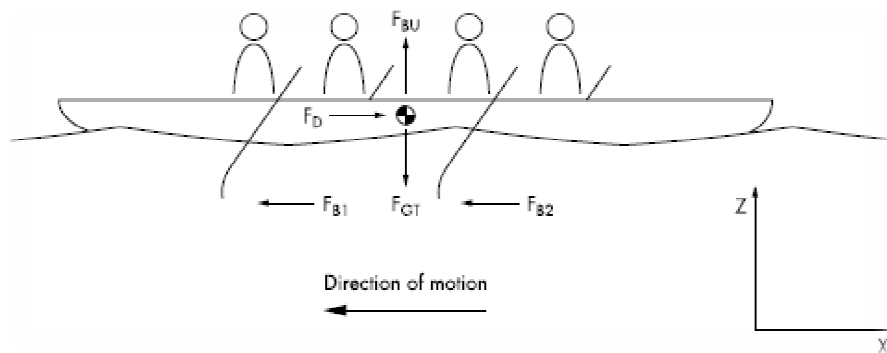


Figure 2.1 Free body diagram of forces acting on a shell while transporting rowers (Baudouin et al. 2002).

Increased weight in the boat results in an increased surface area of the shell that makes contact with the water, thus increasing friction due to water and decreasing the boat's relative speed (2). Once a rower's strength is developed, maintenance and conversion of this strength to rowing power is necessary. Conversion may be achieved

by increasing on-water resistance in the boat with dragging bungees or other means of increasing the boat's drag factor (26).

Strength and Conditioning: Classis Linear Periodization

Published research focused on the optimal prescription of strength and conditioning practices in the sport of rowing is very limited. Specific training programs for elite athletes (including rowers) have been addressed rarely in scientific literature, possibly due in part to a ban on publishing such materials in many Eastern countries (30). According to Gee et al. (9), only two research articles have been published as of 2010 with the purpose of providing such instructional information for rowers. In these two studies Ivey et al. (14) and McNeely et al. (26) investigated the needs of a preparatory training phase for novice rowers (14) and performance goals for rowing athletes, including strength and power tests (26), respectively. Ivey et al. (14) proposed methods for the achievement of anatomical adaptation, maximum strength and power gains, fitness assessment, injury prevention, and development of rowing-specific flexibility.

Throughout the season, a rowing-specific periodized training program should include a preparatory period and specific training advancements consisting of strength first, followed by power and concluding with muscular endurance (14). McNeely et al. (26) advocated for the use of 1RM tests in determining maximum strength and a 30-second test performed on a rowing ergometer, similar to a Wingate test, for an estimation

of a rower's anaerobic power. Standard scores based on various classes of rowers in these testing parameters also are provided (26).

According to evaluation of strength training for collegiate women's rowing from Ivey et al. (14), periodization training methods require a "preparatory phase" due to the high rate of incoming collegiate rowers who lack any specific rowing experience prior to college. Anatomical adaptation is a major feature of the preparatory phase. During this period, inexperienced rowers begin developing a physiological acquaintance with rowing-specific movements and exercises which allows them to advance while avoiding injury (14). This physiological acquaintance with rowing movements also makes it easier for novice rowers to comprehend and reproduce any demonstrations of rowing technique portrayed by their coaches.

Maximum strength development is initiated following the adaptation phase. This period consists of a 4-week phase which includes 2 lifting sessions per week. These sessions consist of upper and lower body exercises in 3 sets with most repetitions ranging from 6-8 (14). Following the strength phase, power is developed over a 3-week period during which time the rowers strength train 3 times per week. Upper and lower body exercises are performed in sets of 2-5 with a range of 3-8 repetitions per set. In order to determine a rower's progress during these training phases, testing occurs during week 5 (following the adaptation phase) and week 12 (following the power phase). Upper and lower-body strength is tested by a 5RM bench press and barbell squat, respectively. Power is tested using a 5RM hang clean and vertical jump protocol (14).

The effects of high-load periodized resistance training (RT) and high-repetition reverse step loading periodized resistance training on the 2K ergometer performance of varsity and novice female collegiate rowers was investigated by Ebben et al. (7). Findings of the study indicated that both forms of training were effective in lowering the rowers' 2K times, shown by Figure 2.2, below (7).

Improvement in Rowing Performance Time
After Resistance Training

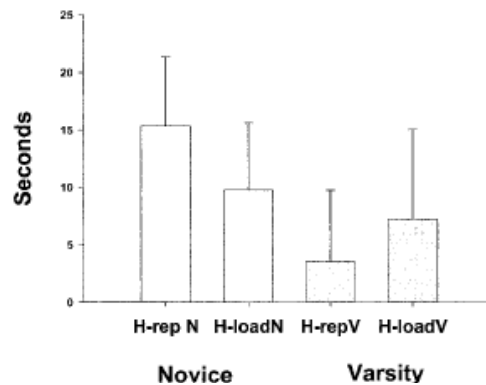


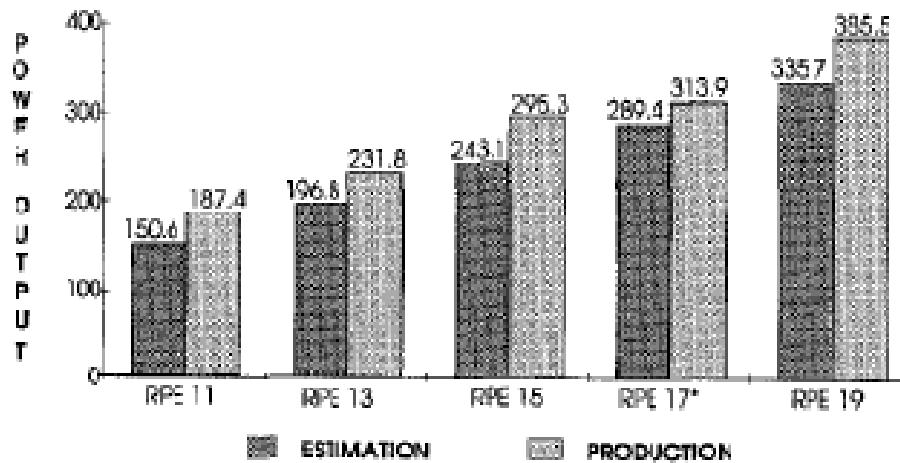
Figure 2.2 Improvement in ergometer performance time (seconds) after high-rep and high-load training in novice and varsity rowers (Ebben et al. 2004).

In addition, high-load RT was more effective for the varsity rowers while high-repetition RT was more effective for the novice rowers. Consideration of the differences in these training protocols with respect to varsity and novice 2K performance is important when determining a rower's training program. Seemingly, the optimal training program for each athlete will not be identical across an entire team.

Effects of Testing Environment on Rowing Ergometer Performance

Although strength training has been shown to improve 2K performance, Cohen et al. (4) demonstrated the differences in collegiate rowing performance based on the factors of synchronized training versus solitary training. Results indicate that rowers training in a synchronized atmosphere show an increased pain threshold, possibly due to heightened endorphin concentrations and opioidergic activity. This increased pain threshold is an important factor in 2K performance gains due to the high degree of pain and discomfort experienced by those rowers performing “all-out” ergometer testing.

In a study conducted by Mahler et al. (22) elite oarsmen rated their perceived exertion (RPE) after completion of a 6 minute “all-out” ergometer time trial. This 6 minute test was administered with the intention of reproducing a typical sprint-race scenario (ex. 2K). Using a Borg Scale (3) representing effort values from 6-20, with 19 indicating “100% effort; very, very hard” and 20 indicating “exhaustion”, the mean response given by subjects was a score of 18, which indicates “95% effort” (22). These responses coincide with a very high measure of physical effort and heart rate, as the RPE scale values increase linearly with the subject’s work load and also correlate highly with heart rate (3). Support for the validity of Borg’s RPE Scale utilization in the monitoring of intensity during rowing ergometer exercise is found in a study by Marriott and Lamb (24). Competitive male rowers accurately rated their perception of effort during an ergometer trial with varying levels of intensity, shown below in Figure 2.3 (24).



* indicates a non-significant difference between estimation and production trials

Figure 2.3 Mean power outputs (watts) at varying RPE levels during estimation and production ergometer trials (Marriot and Lamb 1996).

The baseline (estimation) levels of intensity comparison for each subject were determined in a previously established range of individual work outputs during a protocol of incremental intensities.

A study by Connolly (5) explored the effectiveness of different attentional strategies in female and male collegiate rowers based on differences in their ergometer performance, heart rate and perceived exertion during testing. The two strategies included “association” during which athletes were asked to focus on their own breathing, technique and how fast the other rowers are racing, and “dissociation” during which rowers focused on tasks irrelevant to their testing performance. Results indicated better ergometer performances in those rowers utilizing an associative strategy versus dissociative strategy. Overall, heart rate and perceived exertion during testing were

higher during the associative sessions which indicate a higher exercise capacity in these athletes.

Strength Training Benefits in Rowing

The effects of resistance training on rowing performance have been demonstrated by a few studies involving various types of training interventions which range from modifications in repetition ranges, load and volume variations, types of periodization schemes, and duration of training. To our knowledge, no studies exist which show a decline in rowing ergometer performance after the addition of resistance exercise into the athletes' training routine. An overwhelming majority of these published studies have focused on the use of male rowers as subjects. Literature addressing the effects of strength training in female rowers is extremely limited.

Izquierdo-Gabarren et al. (15) examined the differences in performance gains resulting from resistance training protocols including repetitions to failure versus not to failure. Using highly trained rowers, results indicated greater improvements in strength, muscle power, and rowing performance for the group following a program with moderate repetitions not to failure when compared with a group following a program with higher volumes of repetitions to failure. These results indicate the advantages of moderate-volume high-intensity stimuli when attempting to develop both strength and endurance concurrently, as is commonplace in the sport of rowing (15).

Research investigating physiological and performance responses in rowing based on the impacts of low-intensity versus low- and high-intensity training programs was conducted by Ingham et al. (12). Results of this study indicated that subjects in both training programs showed improved ergometer performance, VO_{2peak} , and WVO_{2peak} (12).

A recent study by Gallagher et al. (8) investigated the effects of concurrent endurance and resistance training in improving 2,000 meter ergometer times based on groups of collegiate male rowers performing high repetition/low-load, low repetition/high-load, or no weight training in addition to their team ergometer workouts. Results indicated that rowers in both resistance training groups made strength gains yet did not show statistically significant improvements in their ergometer testing times when compared to those rowers in the group who did not weight train. These improvements are shown below in Figure 2.4 (8).

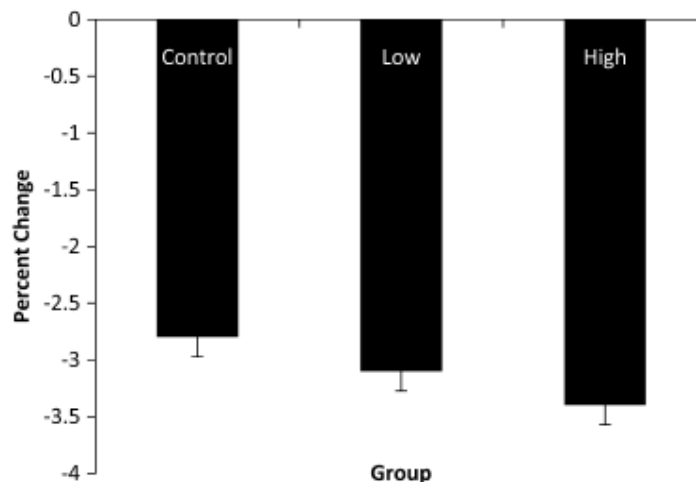


Figure 2.4 Percent change in 2,000 meter simulated rowing times after an 8-week training intervention (Gallagher et al. 2010).

Overall, the low-repetition high load group showed the greatest improvements in ergometer times despite lack of significant findings, considering the study's low n size and short duration of strength training intervention (8 weeks).

Findings from research conducted by Webster et al. (35) using male and female rowers indicated improvement in the subjects' 2K ergometer performance after 8 weeks of aerobic and resistance training. RT consisted of 2 lifting sessions per week during the 8 week training period. These sessions included 6 upper body and 4 lower body exercises with sets ranging from 2-6 and repetitions ranging from 4-12. During the post-training 2K tests, investigators found that at the "catch" (forward compression) of their stroke, subjects' hip angle decreased and elbow angle increased when compared to their pre-training 2K tests. The effect of training on hip angle is shown by Figure 2.5 (below) through comparison of pre- and post- training 2K analysis (35).

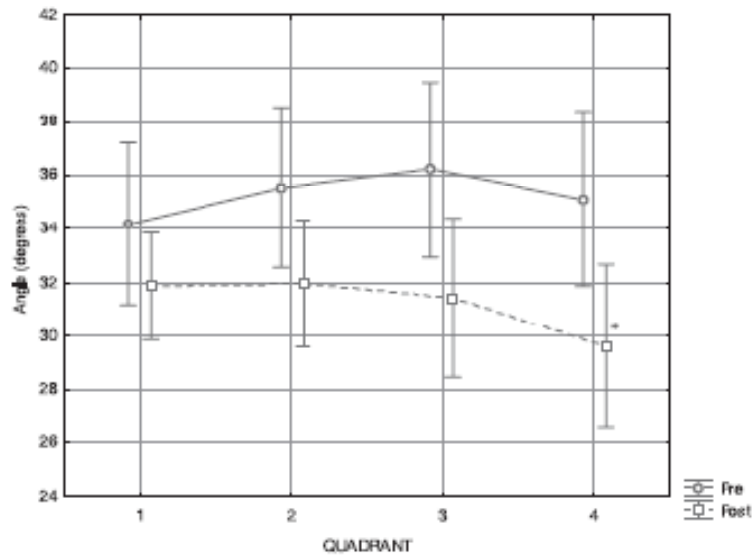


Figure 2.5 Hip angles at the catch during each 500 meter quadrant of a 2,000 meter ergometer trial before and after training intervention. *P<0.05, significant difference from before intervention (Webster et al. 2006).

These changes in joint angle, accompanied by reductions in 2K test times, provide evidence in support of the positive association between a rower's range of motion and an increase in stroke length with greater force and power production during ergometer performance (35). Therefore, changes in the rowers' joint angles indicate a positive influence of resistance training on both female and male indoor rowing performance.

With a resistance training protocol similar to that of the one used in Webster et al. (35), Kennedy et al. (18) implemented a 10 week program in which male and female rowers at both the university and club level lifted twice each week in comparable types of sessions to those performed by Webster et al. Based on the rowers' pre- and post-exercise intervention 2K times, it appears that the 10 weeks of periodized resistance training yielded faster times in both male and female subjects (18). The authors recognize the possibility that these improved 2K scores were partially attributed to an improvement in the rowers' pacing strategy as a result of concurrent constant-pace training on the ergometer. Thus strength training, when combined with ergometer training, is part of an exercise program beneficial to rowers.

Relationships in Athlete Physical and Physiological Characteristics and Sport Performance

Determining the relationships among athletes' morphologies and physiological capabilities and performances in their respective events is a valuable process for coaches and competitors alike. In the sport of rowing, a lack of athlete experience prior to

collegiate competition makes the application of such relationships useful when evaluating incoming and/or novice rowers.

Womack et al. (37) studied the relationships between 2,000 meter ergometer performance VO_{2peak} and peak rowing velocity in elite male rowers. Results indicated a significant correlation between changes in 2K performance and changes in peak velocity, specifically noting the greatest 2K performance improvements were found for those subjects that increased peak velocity during the training season. Therefore, monitoring changes in peak velocity may be a better predictor of progress in 2K performance than changes in VO_{2peak} .

Performance data from collegiate female rowers has been used to determine the relationships between ergometer test times, competitive experience, and the coach's ranking of the rowers (19). Competitive experience was categorized by international, national, first varsity, second varsity, and non-varsity. Results of this study by Kramer et al. (19) indicate that one measure of rowing performance may be predictive of other others, as shown by a high interrelationship among the subjects' 2,500 meter ergometer time, competitive experience, and coach's ranking.

Performance and physical characteristics of collegiate female rowers established by their level of experience (varsity, novice) and years of collegiate rowing participation (1, 2, 3, or 4) were examined by Battista et al. (1). Results indicated that few of the investigated variables showed significant differences based on experience levels of

collegiate rowers, either varsity vs. novice or total years of collegiate experience. Overall, novice versus varsity rowers showed significant differences in vertical jump performance, and 2K test results. The only significant differences among rowers based on years of experience (1, 2, 3, or 4) were height and 2K erg results (1).

Prediction Methods for On and Off-Water Rowing Performance

A study by Perkins et al. (28) provided information on the physiological profiles of collegiate female rowers and evaluated whether or not these measures could be used to predict the rowers’ boat assignments as determined by the program’s head coach. Results, shown in Table 2.3, indicate that there were no significant differences in VO_{2max} , submaximal lactate or 2K ergometer times when comparing varsity (1V) and junior varsity (2V) rowers (28).

	1V (n = 8)	2V (n = 8)	Total (N = 16)
Height (cm)	177.0 ± 3.1	177.9 ± 3.0	177.5 ± 3.1
Weight (kg)	75.9 ± 6.5	81.4 ± 11.5	78.6 ± 9.5
$\dot{V}O_2$ max (L·min ⁻¹)	3.93 ± 0.30	3.78 ± 0.50	3.85 ± 0.40
HR _{max} (b·min ⁻¹)	189 ± 9	190 ± 11	189 ± 10
Submaximal lactate (mmol·L ⁻¹)	3.0 ± 0.9	3.6 ± 1.0	3.3 ± 1.0
2K time (second)	450.0 ± 8.5	455.7 ± 12.1	453.0 ± 10.5
2K $\dot{V}O_2$ (ml·min ⁻¹)	3.76 ± 0.23	3.63 ± 0.40	3.70 ± 0.32
2K HR (b·min ⁻¹)	184 ± 10	185 ± 11	184 ± 10

* Values are mean ± SD. There were no significant differences between groups for any variable listed in the table.
 † HR = heart rate.

Table 2.3 Physical and physiological profiles of 1st Varsity (V1) and 2nd Varsity (V2) crew members (Perkins et al. 2003).

This lack of physiological differences between varsity statuses indicated placement into the 1V and 2V boats depended on variables independent of the previously indicated

performance measures. The authors indicated a need for further research on prediction of rowing performance based on factors including anaerobic power and muscular strength.

In 2010, Izquierdo-Gabarren et al. (16) focused on determining the most influential prediction factors on rowing performance in elite and amateur rowers. Between these two groups, there were no significant differences in body height or body fat percentages. Results of strength and power assessments indicated that these variables may be highly predictive of traditional rowing performance (16). A significant correlation between collegiate male 2K ergometer performance and 7 minute leg press at 50% RM (1 repetition maximum) was found by Jurimae et al. (17). That correlation provided a basis for using leg press as a possible measure of strength endurance in male rowers.

Variation in male and female 2K ergometer performance based on various strength and power determinants (vertical jump, inverted row, leg press, and back extension) was investigated by Huang et al. (11). Correlations between 2K performance and these variables were significant for vertical jump, inverted row and leg press. Leg press was documented as the strongest predictor of 2K performance. These results support the importance of developing strength and power in potentially successful male and female rowing competitors.

Metabolic, anthropometric and strength variables in elite male rowers were used by Russell et al. (30) to formulate prediction equations for their 2,000 meter rowing

ergometer performance. However, the formation of a predictive equation using a combination of all three types of variables did not predict 2K performance any better than methods using variables from only one physiological category. Instead, results indicated that use of strictly anthropometric variables or a combination of physiological variables better projected 2K ergometer times than did any single variable alone (30).

Rate of Performance Improvement in Elite Athletes

To our knowledge, there are no previously published studies that document the annual progress of collegiate athletes using 2K ergometer testing. When analyzing 2K performances in female collegiate rowers, Battista et al. (1) documented improvements corresponding with increasing years of collegiate rowing experience, for example, freshman rowers versus senior rowers. Though the only significant differences were seen between the least and most experienced rowers, that particular study design did not include variables necessary for the assessment of influence due to sport-specific training and experience in the varsity (more experienced) rowers (1).

Although not specifically addressing women's rowing, a recent study by Stodden et al. (33) examined the longitudinal effects on a football team's body composition and performance based on the athletes' participation in a collegiate strength and conditioning program. Overall, the first year of training showed the greatest rate of improvement among all test parameters. Diminishing improvements in all performance tests towards the end of each athlete's collegiate career suggested the importance of monitoring

progress in strength and conditioning areas for all athletes in order to implement specific training interventions that will continue performance gains.

Similarly, a study by Miller et al. (27) showed the effects of training time, player position, and body composition in relation to exercise performance in collegiate football players. Selected performance variables included power clean, bench press, squat, vertical jump, 40-yd dash, and 20-yd shuttle. These athletes were all participants in a multiple-set, periodized strength and conditioning program prior to testing for this study. Results of analysis, shown in Table 2.4, indicate the greatest rate of change in performance of the selected parameters to be between the athletes' first and second semesters of training (27).

Time interval (semester)	Magnitude of change (%)		
	Power clean	Bench press	Squat
1-2	+53	+4	
1-3			+31
2-3	+12	-2	
3-4	+9	+31	
3-5			+11
4-5	+2	-22	
5-6	+4	+40	
5-7			4*
6-7	-28*	-34	
7-8	+44*		
1-7		+36	+39*
1-8	+109*		

* Time intervals with at least 1 semester containing only 2 data points. These amount of data may be insufficient to show a population trend.

Table 2.4 Magnitude of change in collegiate football performance by semester interval (Miller et al. 2002).

Long-term changes in power performance of elite Australian Rules football players were investigated by McGuigan et al. (25). Their results indicated a statistically significant improvement in peak power output and velocity over the duration of the study, which lasted 3 years. Those athletes took part in a periodized resistance training program of three sessions per week in addition to the competition season, which included only two sessions per week. Undulating periodization was utilized during the competitive season. Peak velocity was found to be a strong indicator of monitoring the training needs and progress of the athletes. Periodized programs allowed these elite athletes to continue improving their power and velocity performance (25).

In conclusion, tracking an athlete's progression in performance over an extended period of time can be beneficial not only for determining an athlete's training needs but also to evaluate how effectively they respond to a given training program. To explore this factor specifically for women's rowing, my study evaluates whether or not the performance of collegiate-level female rowers continues to improve throughout their collegiate career based on analysis of progression in their ergometer testing results. Based on results of studies that explored performance progression in other sports, I hypothesize that the greatest improvement in rowing ergometer scores will occur between the rowers' first and second years of training with the team. Based on my results, I hope to provide coaches with a source of information, which will be useful in the development of realistic training objectives and allow them to better evaluate an individual rowers' ergometer testing progress. My study also should indicate to coaches what to expect

from rowers during their initial stages of training with the team, and what kind of changes in ergometer testing results a coach can expect to observe over an athlete's four years of training with a collegiate women's rowing team.

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Chapter 3

METHODS

Experimental Approach to the Problem

This study was designed to examine the relationships existing between and among several performance variables collected through an analysis of longitudinal athletic data involving collegiate level female rowers. Currently, there exists very limited research involving the monitoring of performance changes in collegiate rowers over extended periods of time. The intention of this current study was to compile a longitudinal description of testing results and potential variables affecting the performance of NCAA Division I collegiate female rowers based on their gains over four years of successive 2,000 meter ergometer tests. Variables of particular interest in testing data included the change in 2K time between incremental years based on individual subject scores and subjects with and without high school experience. Potential variables of consideration included each rower's 2K personal record (PR) from every year on the team and whether or not the athlete began their collegiate career with previous rowing experience. When computing my results, each subject's annual 2K PR score was used as opposed to their average annual 2K score due to a typical rowing coach's interest in their athletes' overall best score improving each year. Thus, if the year's training program helped each athlete peak once per year, then it was considered a success.

Subjects

The records analyzed in this study included retrospective performance data from the years 1997-2011 beginning with which the rowing team became recognized as a Division I varsity athletic team at the University. Performance data from 47 selected NCAA Division I collegiate female subjects were investigated. These subjects included both lightweight and heavyweight rowers ranging in age, height, weight, previous rowing experience, and sweep rowing preferences (starboard or port). A qualifying variable for the 47 selected subjects was that all rowers had completed four consecutive years of rowing eligibility at the University. This selection process did not include coxswain members of the rowing team. The data used in this study were part of a previously established database that had been collected from 1997 to 2011. Permission for retrospective analysis of strength and conditioning data was approved by the University of Connecticut's Institutional Review Board for use of human subjects in research.

Procedures

Entire team 2K test results were collected and sorted into each "training season" period from 1997-2011. The "training season" for each period included the months of September-May during which team members were expected to participate in team practices/workouts as a whole. The remaining months, June-August, were considered the "off-season" as there were no team practices/workouts held during this time. Following this method of seasonal classification, the years from 1997-2011 were separated into 14

distinct training seasons (ex. September-May of 1997-1998 is the first training season). Each athlete, over their four years on the team, was present for four consecutive training seasons (Year 1 = freshman, Year 2 = sophomore, Year 3 = junior, and Year 4 = senior status). After all retrospective 2K test results were sorted into their corresponding training seasons, data for each rower were organized and presented as the subject's 2K PR within each training season (4 scores each).

Because yearly data sets for each subject throughout their career are not complete, three separate "sequential" data sets were created for subjects with 2K results recorded during sequential years (Years 1 and 2, Years 2 and 3, and Years 3 and 4). Accordingly, only values for those subjects with 2K scores for both their first and second years were used in the sequential comparison of Year 1 to Year 2 2K PR scores (n=30). Similarly, only values for those subjects with 2K results recorded during both their second and third years were used in the sequential comparison of Year 2 to Year 3 2K PR scores (n=45) and only values for those subjects with 2K results recorded during both their third and fourth years were used in the sequential comparison of Year 3 to Year 4 2K PR scores (n=37). An "inclusive" data set was created for 2K PR results using subjects with at least one 2K score each for Year 1, Year 2, Year 3, and Year 4 (n=26).

Over the 14 years of data considered for the current study a total of 34 2K test results were recovered. The number of documented 2K tests for each training season ranged from 1-5. Due to the historical nature of this study, it is reasonable to consider the possibility that not every 2K test result had been recorded and that an undetermined

number of results might not be retrievable from the team's performance data archives. Although acknowledging this possible source of error, the effects of incomplete data were standardized by using the lowest recorded 2K time available for each rower to represent their training season 2K PR.

In order to categorize each subject's rowing experience prior to college, information reported in yearly university issued media guides were reviewed to determine whether each of the 47 subjects had rowed previously in high school. Subjects were then sorted into two groups (high school experience: yes or no) based on information obtained from the corresponding annual media guides.

Statistical Analysis

All values are presented as mean \pm standard deviation (SD). The data sets met the assumptions for linear statistics or where sphericity was violated, a Greenhouse-Geisser correction was used as noted. A one-way analysis of variance (ANOVA) with repeated measures was used to compare 2K performance over time. Where appropriate, a Fishers LSD post-hoc test was used to determine pairwise differences between the means. Significance in this study was set at $P \leq 0.05$.

Chapter 4

RESULTS

The primary findings of this investigation indicated that with the exception of Year 3 to Year 4, there were significant differences in 2K performance between chronological years of training seasons in analyses of athletes with an inclusive (Year 1, 2, 3, and 4) data set as well as in analysis of those subjects with sequential (Year 3 and Year 4) scores.

Mean Yearly 2K PR Scores

When comparing the annual mean 2K PR scores of those subjects with high school experience (n=11) versus those without (n=30), there was a significant difference between Year 2, Year 3, and Year 4 2K PR scores.

Figure 4.1

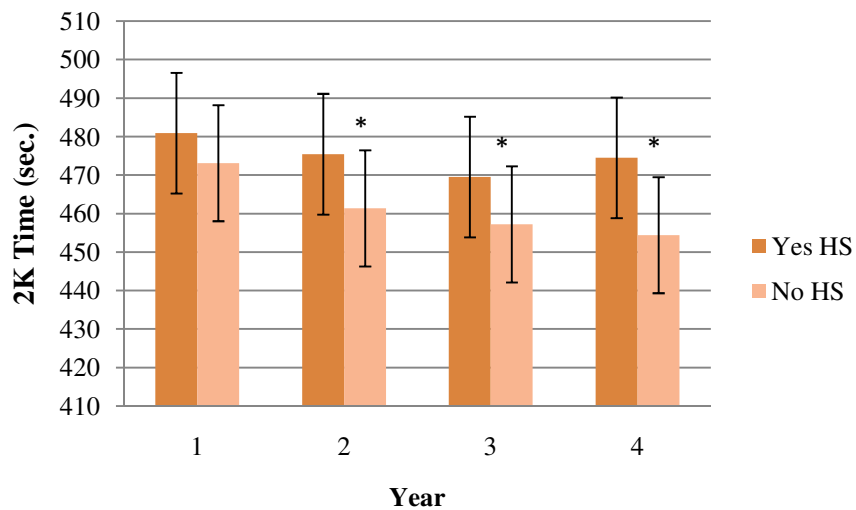


Figure 4.1: Mean 2K PR score (seconds) each year (1-4) for those subjects with high school experience (n=11) and those subjects without high school experience (n=30). *P<0.05, significant difference in 2K time between Yes HS and No HS at Year 2, Year 3 and Year 4.

No significant differences were seen between the annual mean 2K PR scores of the inclusive (n=26) and sequential (1-2 n=30, 2-3 n=45, 3-4 n=37) data sets.

Figure 4.2

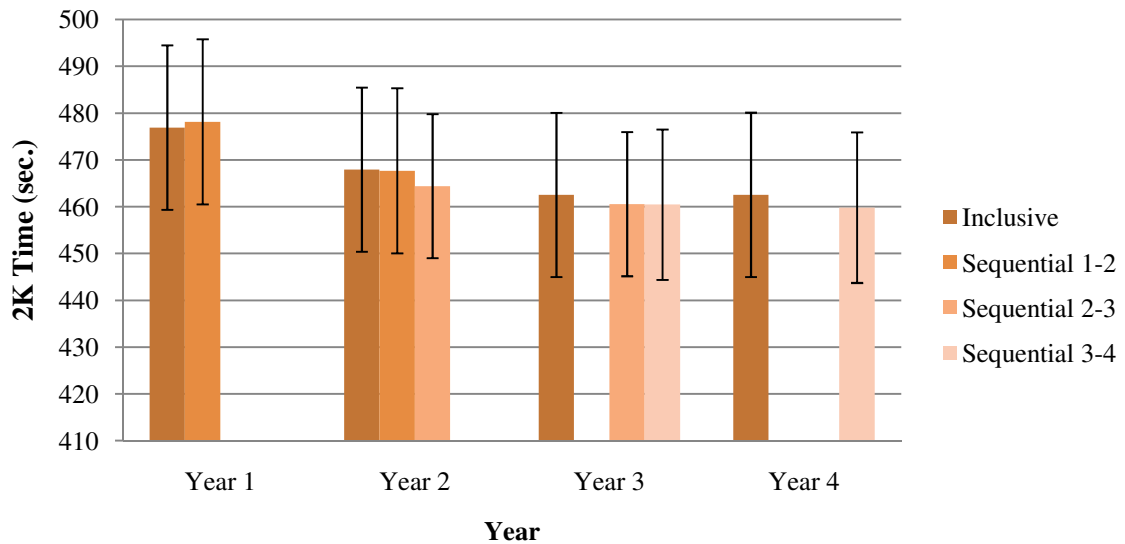


Figure 4.2: Mean 2K PR score (seconds) each year (1-4) for inclusive (n=26) and sequential (1-2 n=30, 2-3 n=45, 3-4 n=37) data sets.

Yearly Improvement in 2K PR

Subjects with high school experience showed no significant differences in their annual change in 2K PR between Year 1 and Year 2, Year 2 and Year 3, and Year 3 and Year 4. Those without high school experience showed significant differences only between Year 1 and Year 2 2K PR scores.

Figure 4.3

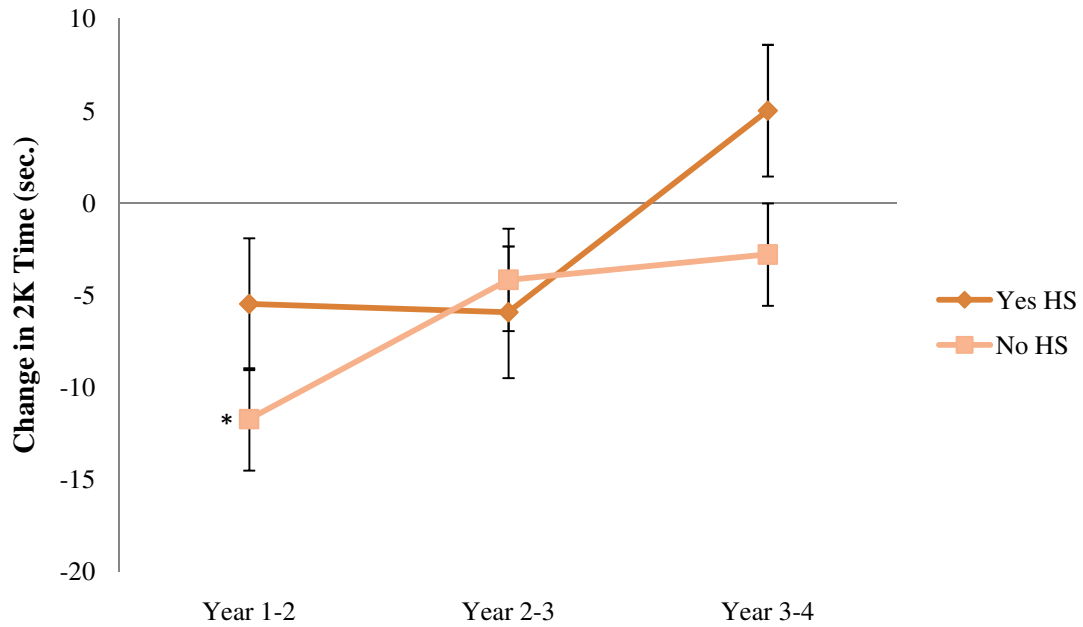


Figure 4.3: Mean change in 2K PR time (seconds) between years 1-4 for subjects with high school experience (n=11) and subjects without high school experience (n=30). *P<0.05, significant difference between Year 1 and Year 2 2K PR scores for No HS.

Significant differences in 2K PR values were observed between Year 1 and Year 2 when comparing values from both the inclusive four year data set and sequential (two year) data sets. The mean difference between Year 1 and Year 2 2K PR scores was the highest between any two consecutive years in both data sets. Significant differences in 2K PR scores were seen between Year 2 and Year 3 for both data sets as well but no differences were seen between Year 3 and Year 4 for either set.

Figure 4.4

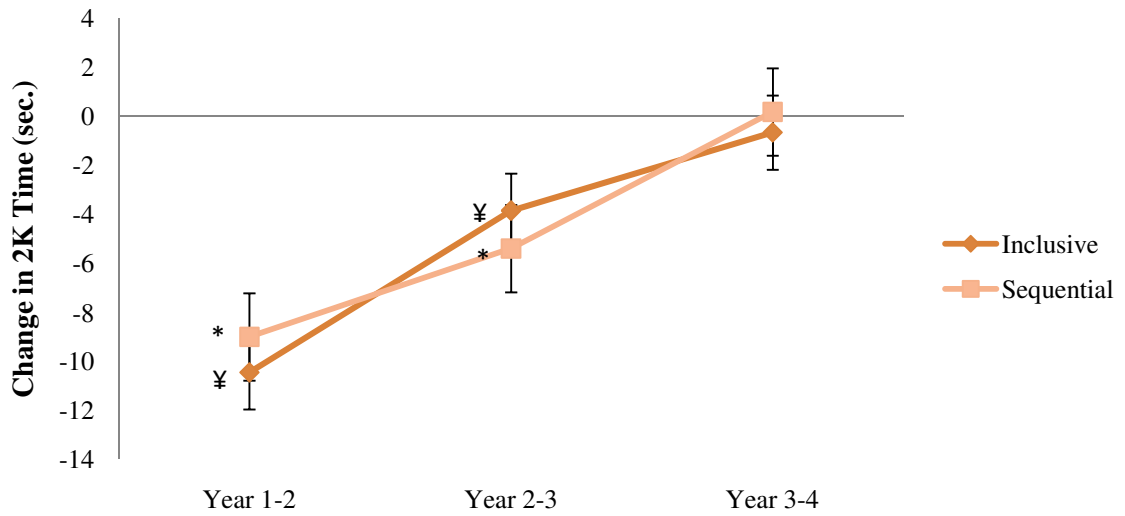


Figure 4.4: Mean change in 2K PR time (seconds) between years 1-4 for inclusive (n=26) and sequential (1-2 n=30, 2-3 n=45, 3-4 n=37) data sets. *P<0.05, significant difference between Year 1 and Year 2, Year 2 and Year 3 scores for sequential data set. ¥P<0.05, significant difference between Year 1 and Year 2, Year 2 and Year 3 scores for inclusive data set.

Chapter 5

DISCUSSION

Overall, my results demonstrate a main effect of time on the female collegiate rowers' 2K PR scores from each year they competed with the team. Findings from analysis of yearly improvements in 2K PR scores agreed with my hypothesis that the greatest amount of improvement would occur between the rowers' first and second years on the team. Subsequently, results indicate that these athletes continued to make advances in their performance until Year 4 in which no significant improvements were seen from Year 3 scores. Large initial gains in 2K performance followed by subsequently lesser annual improvements may be explained by these athletes reaching their genetic potential by the end of their collegiate careers or that their training programs did not optimize the rowers' potential for continued annual improvement.

A range of expected yearly improvements in 2K testing can be created based on findings from our analysis of annual performance changes. Coaches should consider monitoring their athletes' annual performance improvements based on these ranges in order to evaluate each athlete's ergometer testing progress. Athletes with performance progression falling outside of these ranges may be considered for supplemental coaching and individualization of their training programs. Expectations for improvements in a rower's 2K testing over their college career may be predicted based on a range of yearly improvements created from analysis of these data sets. It is important to note that when creating a data set for rowers with scores from both Year 1 and Year 4, the same subjects were used as in the complete 4 year data set (both n=26) since these subjects ended up

being the same for both sets. With a larger n-size, overall improvement in 2K performance (Year 4-Year1) would be more accurate.

Based on these results, the following ranges of 2K improvement were created by combining results from analysis of both the inclusive data set and sequential data sets. Since both analyses provided consistently similar results and ranges, combining these values gave a more comprehensive range of expected annual 2K improvement.

1. *Year 1 to Year 2*: From a rower's first to second year, a coach should expect to see improvements in their 2K PR score falling into the range of 5.322-14.188 seconds with an average improvement of 8.996-10.443 seconds.
2. *Year 2 to Year 3*: From a rower's second to third years on the team, a coach should expect to see improvements falling into the range of 0.790-9.893 seconds with an average improvement of 3.844-5.392 seconds.
3. *Year 3 to Year 4*: From a rower's third to fourth years on the team, a coach should expect to see changes falling into the range of -3.819-3.780 seconds with an average change of -0.019-0.654 seconds.
4. *Year 1 to Year 4*: Over a four year collegiate rowing career, coaches should expect to see overall improvements within the range of 8.236-20.503 seconds and an average total improvement of 14.369 seconds.

Stodden et al. (24) reported the greatest rate of improvement for all testing parameters in collegiate football players occurred during their first year of training. Similarly, my results indicated that the greatest improvements in 2K scores were seen between the rowers' first and second years on the team. Additionally, as gains across all football performance tests diminished towards the end of the athletes' collegiate careers, so did those indicated by the changes in our 2K performance tests as well.

Results similar to those from Stodden et al. (24) were presented in a study by Miller et al. (18), which quantified changes in performance variables based on semester standing (1-8) in collegiate football players. The greatest change in performance for these athletes occurred between their first and second semesters of training. My analyses of 2K performance showed similar results in that performance gains were greatest between the athletes' first year and second years of training on the team.

Based on my analyses, significant differences in 2K test results were not seen between Year 3 and Year 4 of collegiate rowing. In contrast, McGuigan et al. (17) showed that some professional (not collegiate) male Australian Rules football (ARF) players continued to exhibit significant yearly improvements in muscular power and velocity over a 3 year period. However, these elite athletes had, on average, more than seven years of training when participating in the study which separates them (experience-wise) from our collegiate level subjects. Yet the yearly improvements in these ARF subjects does contradict the common assumption that athletes of this caliber perform close to their peak genetic potential, and thus are expected to show limited additional

performance gains. The continually increasing power and performance observed in these athletes contrasted with my results, which depicted limited performance improvements after three years of rowing training. McGuigan et al. (17) suggested the adoption of individualized training programs to compensate for individual athlete responses to a given training program. If not entirely explained by limitations due to reaching their genetic potential, the lack of significant improvement between my subjects' third and fourth years of training indicates a possible need for creation of more individualized training programs.

Overall, whether or not a rower had rowing experience prior to joining the selected collegiate team was not significant in relation to yearly 2K improvement. Significant differences in annual improvement were seen only in those subjects without high school experience between Year 1 and Year 2. Interpretation of these results should consider recognition of the non-specific criteria methods used in identification of individuals with high school rowing experience. High school rowing programs vary in the types and amount of training included in their routines. Some schools do not incorporate ergometer training at all, while others place a heavy emphasis on this area of rowing-specific practice. Also, the length of a high school competition period varies between one and two seasons per year. Consideration of how these factors affect the quality of an athlete's pre-collegiate rowing experience may explain why I failed to observe any significant differences between 2K test results between experienced and non-experienced collegiate rowers.

According to Perkins et al. (19), the lack of rowing programs available at the high school level results in many collegiate rowing teams being comprised of athletes mostly having no previous rowing experience. At the college used for collection of my data, more emphasis was placed on recruiting students already attending the college (but who did not have previous rowing experience) rather than recruiting high school students who had been involved previously in rowing programs at their schools. As a result, most of the rowers with experience did not have significantly different 2K scores than those with no previous experience. A similar analysis may achieve different results if conducted at a college with more scholarships available to female rowers and a more aggressive recruiting strategy. Further research, ideally at colleges with recruitment of high-quality experienced rowers as a priority, is needed to determine the difference in 2K performance progression between those rowers with experience and those without.

A study by French et al. (4) tracked the longitudinal muscular power changes in collegiate female gymnasts over a three year period, during which a sport-specific resistance training program was introduced. Their results indicated that these athletes' whole body muscular power improved based on progression in power testing parameters (countermovement jump and squat jump protocols) over the three year period. Such a sport-specific training routine may be necessary for collegiate rowers to improve their ergometer performance consistently during a collegiate career. Power is an important factor for successful rowing performance since approximately 70% of the body's musculature is required during a stroke (29). About 75-80% of a rower's power during this stroke comes from the lower body leaving approximately 20-25% of their power to

be produced by the upper body (12). If adequate power training, with a focus on lower body, is not made a prioritized aspect of a rower's program, performance achievements may not reach the athletes' potential.

Based on the ranges for annual 2K improvement created using the results from this study, coaches can determine whether or not individual athletes are on track in terms of their yearly 2K performance progression. Any athletes falling outside of these predicted ranges should be considered for individualized training programs targeted specifically towards improving their 2K performance consistently with the team's average progression.

Collegiate rowing has a notoriously high turnover rate, especially during the athletes' initial years with the program. Due to regulations imposed by this university related to compliance with Title IX, the women's rowing is required to have at least 60 people on their roster each year by a certain date. Based on the limited number of athletes who completed all four years of training with the team (n=47) it may be inferred that a low annual return rate exists for this program.

In addition, the reported mean 2K PR scores from Year 1 (Figure 4.2) may be used to help coaches predict whether or not any given freshman athlete will continue with the team for all four years of their college careers. This prediction is possible due to the inclusion criteria for our data collection; all subjects used in this study were athletes who successfully completed 4 years on the team.

Predictions based off of initial 2K performance may be useful in helping a coach determine an athlete's potential for success and continuation with the team. Perkins et al. (19) expressed the need for methods allowing coaches to assess incoming athletes' performance and predicted success in rowing. Differences in ergometer performance capacities of these incoming athletes may reveal a need for individualized programs specific to each athlete's initial testing results.

Additional studies should consider the inclusion of changes in strength and power performance along with changes in 2K performance to help establish specific factors affecting longitudinal ergometer performance. In addition, a wider range of data collection may be useful in comparison of ergometer performance across schools with similar distinguishing factors (ex. Big East programs, programs in existence for similar periods of time, programs with comparable recruiting methods and number of rowing scholarships available). My results indicate that the most significant 2K performance improvements were seen between Year 1 and Year 2. However, this range includes two whole years of testing (730 days). If available, comparison of 2K scores between incremental semesters (1-8) would be more beneficial to studies quantifying progressive improvements in collegiate ergometer performance than our yearly (1-4) comparisons.

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