Variations of Pacing in Simulated Rowing - Effects on Physiological and Performance Variables

A thesis presented for the degree of Master of Science (Sport and Exercise Science)

Massey University, Auckland

Chris Lynch 16th July 2012

Abstract

Background: Observation of pacing strategies in competitive rowing show that a parabolic-shaped strategy of a fast-starting 500 m, a slowing over the middle 1000 m and an increase of pace in the final 500 m, is the common self-selected strategy. This typical pacing strategy is influenced by the tactical need for the rower or crew to row in water free of wake and to be in a position where competitors can be observed. Previous work has suggested however that the fast start is also physiologically beneficial in causing a faster oxygen uptake ($\dot{V}O_2$) kinetic response, thereby reducing the initial oxygen deficit and the concomitant accumulation of fatiguing by-products.

Objective: The purpose of this study was to investigate the influence of starting strategy on $\dot{V}O_2$ kinetics and performance during 2000 m simulated rowing.

Methods: Six (*n*) trained rowers ($\dot{V}O_{2peak}$ 61.9 ± 4.2 ml·kg^{-1}·min^{-1}) performed a baseline 2000 m ergometer rowing trial using a Concept II rowing ergometer. From the baseline data, starting strategies were developed for the first 500 m. A fast-start (107% ± 3.27% mean overall velocity) and an even start strategy (100% ± 1.78% mean overall velocity) were developed. Rowers then completed trials using these starting strategies. All trials were carried out in a counterbalanced order. Performance variables and heart rate were downloaded from the ergometer. Physiological measures of $\dot{V}O_2$ were measured throughout exercise. Post-trial blood lactate was also measured. A general linear model with repeated measures was used to determine the effects on the relevant physiological and performance variables elicited by the starting strategy permutations across 100 m and 500 m sectors. A one-way ANOVA was used to determine the effect on overall time and overall power as well as post-trial blood lactate values. Effect size was also determined by use of Cohens *d* values.

Results: No significant differences were found between trials for overall finishing time (mean ± SD; baseline 409.5 ± 26.5 s, fast start 406.4 ± 32.7 s, even start 406.4 ± 27.1 s), mean work across 2000 m (baseline 329.1 ± 53.0 W, fast start 343.0 ± 68.0 W, even start 340.3 ± 57.9 W) or post-trial lactate (baseline 12.4 ± 3.7 $mmol \cdot L^{-1}$, fast start 12.2 ± 3.1 $mmol \cdot L^{-1}$, even start 14.0 ± 1.1 $mmol \cdot L^{-1}$). No significant differences were found in the $\dot{V}O_2$ response in the first and last quarter of the 2000 m trials but results show $\dot{V}O_2$ response was significantly greater for a fast start when compared to baseline for the second (Wilks' Lambda =.104, $F_{(2, 3)}$ =12.923, p<.05, multivariate eta squared=.896) and third quarters (Wilks' Lambda=.063, $F_{(2, 3)}$ = 22.378, p<.05, multivariate eta squared=.937), respectively.

Conclusions: Whilst data indicate that variation on the starting strategy had relatively small effect on performance outcomes it did indicate that the rate at which $\dot{V}O_2$ increases is sensitive to the pattern of work rate imposition. The duration of rowing can vary between 5.8–7.4 min and $\dot{V}O_{2max}$ is normally attained within the event therefore any benefit from the faster $\dot{V}O_2$ kinetic response in the second and third quarters is unlikely to have significant impact on performance outcomes.

Keywords: Pacing, pacing strategy, rowing, starting strategy

Declaration

This dissertation constitutes my own work and all material that is not my own is fully acknowledged. No part of this work has been submitted for assessment elsewhere.

Signed

Date 16th July 2012

Acknowledgements/Dedications

This work has been a labour (of love at times) and I would like to acknowledge and thank all those that in some way have contributed to it. I would like to specifically thank all those participants who volunteered their time and energy allowing me to collect the data I needed. Also thanks to Dave Rodger of the Auckland Regional Performance centre for rowing. Thank you to Kathy Hamilton for enrolment advice and thanks Dr Ajmol Ali and Dr Andrew Foskett for their time, patience and feedback, without which this work would be much the worse for. Thank you.

Contents

List of tables

List of figures

List of appendices

1.0 Introduction

In many athletic endeavours a successful performance outcome is reaching the endpoint of the event before the other competitors. To achieve this, performance is often required to be completed in the fastest time possible, while ensuring that enough metabolic capacity is available during the event to avoid premature fatigue. This can be accomplished through use of an effective pacing strategy.

Olympic rowing is an extended (≥2 min) maximal event with a high metabolic cost. Success requires a pacing strategy that maximises metabolic capacity but is also tactically advantageous. Observation of both on-water and ergometer rowing has shown that a parabolic pacing strategy pattern, characterised by a fast start, is the consistent pattern of competitive rowing (Brown, Delau, & Desgorces, 2010; Garland, 2005; Muehlbauer, Schindler, & Widmer, 2010; Secher, 1983). This parabolic strategy has been further defined as a reverse J-shape strategy (Abbiss & Laursen, 2008).

It has been hypothesised that an overall even pace strategy would be an effective one for rowing (Abbiss & Laursen, 2008; Secher, 1983). Theoretical support for this hypothesis has come from mathematical modelling studies of cycling and observation of cycling performance (de Koning, Bobbert, & Foster, 1999; Hettinga, De Koning, Broersen, Van Geffen, & Foster, 2006; Hettinga, De Koning, & Foster, 2009; Hettinga et al., 2011). However, there has been no examination of the effectiveness of an overall even pace strategy in rowing.

The typical parabolic pacing strategy of rowing is characterised by a fast start. This is tactically advantageous as it ensures the boat is in clear water and able to view opponents but the high initial power output, requiring high anaerobic contribution to effort, is a possible cause of reduced power output later in the event. An even pace start would require lower levels of anaerobic contribution to the effort and so is likely to benefit the holding of an optimum even pace throughout the remainder of the event. However, an even paced start may be tactically disadvantageous as boats would be no longer able to observe opponents. Currently, there is no evidence of the effect of manipulation of starting strategies in rowing on performance outcomes.

Any variation in pacing strategies is likely to influence or mediate physiological response to effort. It has been suggested that the fast start of rowing is not only beneficial to performance outcomes, it also speeds the oxygen kinetics and therefore may signal greater aerobic energy supply earlier and preserve anaerobic energy capacity until later in the event (Bishop, Bonetti, & Dawson, 2002; Garland, 2005; Secher, Espersen, Binkhorst, Andersen, & Rube, 1982). Work by Aisbett et al. (2009a), Aisbett et al. (2009b) and Bailey et al. (2011) has demonstrated that a fast start increases oxygen kinetics in cycling but no work has examined oxygen kinetic response to starting strategies in rowing.

The pacing of an event is a crucial component of success and examination of pacing strategies in rowing show that a parabolic strategy is currently employed. Theoretical support for an even pace strategy being optimal has been presented but the hypothesis of an even pace strategy being optimal for rowing has yet to be tested. The fast start that is typical in the current pacing strategy of rowing has been suggested as being tactically advantageous and possibly physiologically advantageous. Therefore to establish if an increase from the habitual starting pace is of further benefit to both performance outcomes and physiological response is important. Consequently, the central problem addressed by this study is to examine performance outcomes and physiological response to experimental manipulation of the starting pace of 2000 m ergometer rowing.

1.1 Background

Rowing has a high metabolic cost and successful rowers have to have a large aerobic capacity, exhibit high absolute strength and a high level of muscular endurance when compared to other endurance athletes (Åstrand & Shephard, 2000). The variable nature of pacing in rowing can result in a mean metabolic cost of ~6.8 L $O_2 \cdot min^{-1}$ for open weight men (Secher & Volianitis, 2009). This value reflects the energy required to overcome inertia and maintain momentum against the drag force of the water upon the boat.

Distribution of the total energy or work across the 2000 m flat-water course is termed the pacing strategy (Abbiss & Laursen, 2008). Observation of pacing strategy in rowing consistently demonstrates a parabolic shape, defined as a reverse J-shape pacing strategy (Brown et al., 2010; Garland, 2005; Muehlbauer et al., 2010; Secher, 1983). Both on-water and ergometer rowing demonstrate similar pacing strategies (Table 1.1). However, the amplitude of the profile, specifically the first quarter, is reduced in ergometer rowing (Brown et al., 2010; Garland, 2005; Muehlbauer et al., 2010).

Table 1.1 Typical reverse J-shape strategy for on-water and ergometer performance (Garland, 2005).

Quarter	On-water pace (%)	Ergometer pace (%)
0-500 m	103.3 (1.8)	101.5 (1.5)
500-1000 m	99.0 (1.2)	99.8 (0.8)
1000-1500 m	98.3 (1.2)	99.0 (1.0)
1500-2000 m	99.7 (1.9)	99.7 (1.6)

Pace is expressed as a mean (SD) percentage velocity for race as a whole

Note. Adapted from "An analysis of the pacing strategy adopted by elite competitors in 2000 m rowing." by S. W. Garland, 2005, *British Journal of Sports Medicine, 39*(1), 39-42

Differences in the amplitude of pacing profiles have been observed in on-water rowing between sexes and between performance levels (Brown et al., 2010; Muehlbauer et al., 2010). However, Garland (2005) did not find any difference between men's and women's crews - possibly due to the use of exclusion criteria in the sampling. Despite some variation between sexes, performance levels and exercise modes, a reverse J-shape pacing strategy is observed in both on-water and ergometer rowing.

Whilst a reverse J-shape pacing strategy is consistently observed, it has been suggested that an overall even pace strategy would be more effective for rowing (Abbiss & Laursen, 2008; Secher, 1983). Maintenance of a mean velocity throughout 2000 m rowing would be the most economical strategy and therefore maximise capacity (Secher, 1983). Theoretical support for an even paced strategy comes from critical power models and the second law of motion, both of which dictate that velocity is governed by the maximal constant force that an athlete can exert against the resistive forces experienced (Billat, Koralsztein, & Morton, 1999). The hypothesis of an even pace strategy being optimal has been supported in mathematical modelling studies of cycling and observation of cycling performance (Corbett, 2009; de Koning et al., 1999; Wilberg & Pratt, 1988). However, key differences between cycling and rowing, including the physiological attributes of the populations measured and the environment in which the activity takes place preclude these findings being applicable to rowing. Presently there is no examination of the effectiveness of an overall even pace strategy in rowing.

The starting phase of the overall pacing strategy is of importance and fast starts are typical for rowing. A fast start is tactically beneficial in on-water performance and it is also beneficial to performance outcomes. A fast start has less time in the acceleration phase, would reach an optimum even pace quicker than other strategies and some time is additionally spent at a pace greater than the overall mean velocity. Therefore a fast starting strategy will result in a quicker overall time as long as the remaining portion of the event is at an optimum even pace. Whilst a fast start is advantageous the initial power output required to overcome inertia may cause inhibition of power output later in the event, possibly due to metabolite build up (Foster, 1994). An even pace start would require lower levels of anaerobic contribution to the starting effort and so may have lower metabolite build up facilitating the holding of an optimum even pace later in the event. However it may be tactically disadvantageous as competitors can not be observed.

Research that has manipulated starting strategies is equivocal on the effect on performance outcomes (Aisbett, Le Rossignol, McConell, Abbiss, & Snow, 2009a; Aisbett, Le Rossignol, & Sparrow, 2003; de Koning et al., 1999; Hettinga et al., 2006;

Schenau, De Koning, & Degroot, 1992). Examination of cycling time trial performance by Aisbett et al. (2009a), De Koning et al. (1999) and Schenau et al. (1992) found a fast start improved performance times, contrastingly Aisbett et al. (2003), and Hettinga et al. (2006) found no effect on final performance times with any manipulation of a fast, even or slow paced starting strategy. This ambiguity is likely due to the variety of protocols used, the small sample sizes and use of statistical significance rather than effect size. At present there is no evidence of the effect of manipulation of starting strategies in rowing on performance outcomes.

Variation of starting strategies has been shown to influence or mediate physiological response to effort (Aisbett et al., 2009a; Aisbett, Lerossignol, McConell, Abbiss, & Snow, 2009b; Bailey, Vanhatalo, Dimenna, Wilkerson, & Jones, 2011; Jones, Wilkerson, Vanhatalo, & Burnley, 2008). Specifically a fast start has been shown to speed the oxygen kinetic response (Bailey et al., 2011; Jones et al., 2008). Bailey et al. (2011) indicated that the rate at which oxygen uptake ($\dot{V}O_2$) increases after the onset of exercise is sensitive to the pattern of work rate imposition, even when the mean rate of work is identical. Physiological rationale for why the faster $\dot{V}O_2$ kinetic response is observed is developed from work by McCreary et al. (1996). This work found that there is direct proportionality between the products of phosphocreatine (PCr) splitting and muscle or pulmonary $\dot{V}O_2$ during transitions to and from moderate-intensity constant-load exercise (McCreary et al., 1996). It is also known that greater rates of PCr breakdown occur at higher intensity of exercise (Medbo & Tabata, 1993). These findings suggest that a fast start in rowing may not only be beneficial to performance outcomes but may also speed aerobic contribution, thereby preserving anaerobic capacity for later in the event.

The identification of optimum pacing strategy, including a starting strategy has direct application for coaches when considering pacing strategies for 2000 m rowing competition.

1.2 Aim

The aim of this study is to investigate the effect of different starting pace strategies on overall performance and the distribution of metabolic capacity in 2000 m ergometer rowing. Specifically this study will;

- compare the effects of a fast start and an even paced starting strategy in 2000 m rowing performance on performance outcomes
- compare the physiological responses of a maximal starting and an even paced starting strategy in 2000 m rowing performance

1.3 Hypothesises

H_0 There is no significant difference in overall time between a fast paced or even paced start in 2000 m ergometer rowing

H_1 There is significant difference in overall time between a fast paced or even paced start in 2000 m ergometer rowing

H_0 There is no significant difference in the pattern of $\dot{V}O_2$ between a fast paced or even paced start in 2000 m ergometer rowing

H1 There is significant difference in the pattern of $\dot{V}O_2$ between a fast paced or even paced start in 2000 m ergometer rowing

2.0 Literature review

The aim of this review is to examine variations of pacing and starting strategies that can be employed in 2000 m rowing performance and the key physiological links to those strategies. The review begins with a brief overview of rowing and discussion of the pertinent physiological characteristics of rowers. It then examines the physiological demands of rowing. Pacing strategies and how they are described are then reviewed. This is followed by discussion of the predominant pacing strategies used in rowing. The starting strategy is an important component of a pacing strategy and the different starting strategies applicable to rowing are also discussed. The final section examines how pacing strategy is possibly physiologically regulated and influenced by mechanisms and theories of fatigue with the possible effect a fast start strategy has on key physiological variables also being discussed.

2.1 Rowing

Rowing is a sport governed by the Fédération Internationale des Sociétés d'Aviron (FISA) and encompasses the diverse disciplines of coastal, adaptive, sprint and indoor rowing, as well as the Olympic discipline. Olympic rowing offers the opportunity to compete in one of thirteen male or nine female events over a 2000 m distance. Rowers are classified by body mass into lightweight and open weight categories. Lightweight men's crews have a limit of a mean mass of 70 kg, with no rower in the crew over 72.5 kg. The limits of women's crews are 57 and 59 kg, respectively. For lightweight single sculls the limits are 72.5 kg for men and 59 kg for women.

Rowing is divided into two distinct categories: sweep rowing and sculling. Sweep rowers have a single oar on one side of the boat. Sweep boats have a minimum of two rowers and a maximum of eight, excluding the coxswain. Sculls range from the single to the quadruple sculls using two oars of a shorter length, simultaneously. The techniques of sweep rowing and sculling differ significantly (Hagerman, 1986). Whilst Hagerman (1986) identified a significant difference between the techniques, work used in this literature review that examines the physiological demands of rowing does not differentiate between or state which technique the participants were most familiar with. The duration of racing can vary between 5.8–7.4 min over a 2000 m straight flat-water course, dependent on level of competition, the boat and water conditions (Secher, 1983).

2.1.1 Aerobic and ventilatory characteristics of rowers

The aerobic capacity of rowers is large relative to other endurance athletes (Åstrand & Shephard, 2000). Absolute values of $\dot{V}O_{2max}$ are relevant in assessment of maximal aerobic capacity since bodyweight is supported in the boat (Hagerman, 1986). Male national and elite open weight rowers have values of up to 6 and 6.5 $L \cdot min^{-1}$ $\dot{V}O_{2\,max}$ respectively, while national and elite open weight female rowers have values of 4 and 4.4 $L \cdot min^{-1}$ $\dot{V}O_{2max}$ respectively (Secher & Volianitis, 2009). This aerobic capacity is amongst the largest seen in female endurance athletes, with female rowers being within 10% of the best international female skiers and runners (Åstrand & Shephard, 2000).

As would be expected in such vigorous maximal exercise, minute ventilation ($\dot{V}_E$) is greatly increased during rowing. During competition $\dot{V}_E$ is typically greater than 200 $L \cdot min^{-1}$ and as high as 250-270 $L \cdot min^{-1}$ (Secher & Volianitis, 2009). During a 6 min all-out rowing test $\dot{V}_E$ is seen to rise exponentially until around the third minute when the rate of increase slows down but still continues to rise until the end of the effort (Secher & Volianitis, 2009).

2.1.2 Muscular characteristics of rowers

The muscular forces generated during competitive rowing are much higher when compared to other endurance sports (Secher & Volianitis, 2009). Successful rowers produce about 75-80% of power with their legs and 20-25% of power with their arms, the trunk acting as a link between the feet on the stretcher of the boat and the ultimate transmission of force to the oar (Secher & Volianitis, 2009). For an effective stroke the rower has to achieve both a combination of high stroke force and optimal stroke length (Secher & Volianitis, 2009).

In elite male rowers, the mean power that is applied to the boat is ~420 W, which is approximately 70% of the highest power obtained during 5 maximal strokes in elite rowers (Secher & Volianitis, 2009). Of particular importance are the strength and velocity of contraction of the quadriceps muscle group for the vigorous extension of the legs in the drive phase (Hagerman, 1986). In a comparison of force-velocity curves of endurance athletes, male rowers exhibited the highest absolute force (Hagerman, 1986). However, it is not only force, but also strength endurance, as application of force must be maintained for more than 200 strokes at stroke rates of around 34-38 strokes·min^{-1} in competition.

A relatively high muscle mass is found in rowers when compared to other endurance sports (Secher & Volianitis, 2009). It was reported by Hagerman (1986) that highly trained rowers have a large representation of slow twitch fibres in those muscles that make major contributions to the rowing action. Elite rowers are characterised by about 70% slow twitch fibres in the vastus lateralis and deltoidus muscle compared with about 50% in non-athletes, the remaining fibres being mostly fast twitch type oxidative-glycolytic (Secher, 1983).

Muscular capillary densities of rowers are nearly double that reported in the same muscle of untrained subjects (Hagerman, 1986). Rowers typically possess high oxidative metabolic capacity and also possess elevated levels of succinate dehydrogenase and citrate synthase (Secher & Volianitis, 2009). This increased capillarisation and muscle oxidative capacity is a major contributing factor in rowers being able to meet the high metabolic cost of rowing.

2.1.3 Metabolic cost of rowing

The metabolic cost of rowing reflects the energy required to overcome inertia and gain momentum against the drag force of the water upon the boat. The mean metabolic cost of rowing at racing speed has been estimated to be ~6.4 L $O_2 \cdot min^{-1}$ (Secher, 1983); however this value was calculated with the assumption that the rowing velocity is close to constant during the event. The variable nature of pacing in rowing can result in a mean metabolic cost of 2000 m rowing being ~6.8 and ~5.9 L $O_2 \cdot min^{-1}$ for open weight men and lightweight men respectively, and ~5.3 and ~4.9 L $O_2 \cdot min^{-1}$ for open weight women and lightweight women respectively (Secher & Volianitis, 2009).

Stroke rate affects the mechanical efficiency of performance and at less than 25 strokes$\cdot min^{-1}$ mechanical efficiency is ~18%; efficiency increases to 20-23% at 35 strokes$\cdot min^{-1}$ (Secher & Volianitis, 2009). Depending on the boat type, races are rowed at rates of 30-40 strokes$\cdot min^{-1}$ and therefore assumption of a constant mechanical efficiency of ~22% is acceptable in determination of the metabolic cost of rowing.

2.1.4 Anaerobic and aerobic contribution to rowing

Anaerobic contribution to energy demand is likely to be the predominant at the start as high power output is required to overcome the inertia of the boat, and again close to the end of the event when attempting to secure a finishing position. Energy for the remaining work is predominantly supplied aerobically.

There is no unusual development of glycolytic enzymes in rowers, although they do demonstrate high percentages of the lactate dehydrogenase sub types 1-3 (Secher & Volianitis, 2009). The blood lactate concentrations of rowers are typically high post-event compared to other endurance athletes (Åstrand & Shephard, 2000). Values of blood lactate concentration have been reported as 15 and 17 $mmol \cdot L^{-1}$ after a national regatta and a FISA championship respectively (Secher & Volianitis, 2009). In a case study of the physiological correlates of a world class rower, values of peak blood lactate concentration from a maximal progressive ergometer test were 12.5 $mmol \cdot L^{-1}$ compared to peer values of 11.6 $mmol \cdot L^{-1}$ (Lacour, Messonnier, & Bourdin, 2009). In an extreme example of tolerance to blood lactate after a championship rowing ergometer competition, a World Champion rower reported a blood pH value of 6.74, corresponding to a blood lactate concentration of 32 $mmol \cdot L^{-1}$ (Nielsen, 1999).These findings suggest that rowing has a substantial anaerobic component and rowers need to be able to tolerate high levels of blood lactate to be successful.

The relative contributions from aerobic and anaerobic energy sources to 2000 m on-water rowing has been estimated to be 75-80% aerobic and 20-25% anaerobic

(Secher & Volianitis, 2009). This estimation is an aggregate value from earlier studies by Hagerman (1986), Secher (1983) and Secher, et al. (1982). More recent work has examined the relative contributions from aerobic and anaerobic energy sources to both on-water and ergometer rowing and has described higher values for the aerobic component.

Examination of the metabolic cost of both on-water and ergometer rowing found that the contribution to total work was 87% aerobic, 6% anaerobic glycolysis and 7% ATP-PCr for on-water rowing performance and 84% aerobic, 7% anaerobic glycolysis and 9% ATP-PCr for ergometer rowing (de Campos Mello, de Moraes Bertuzzi, Grangeiro, & Franchini, 2009). This agreed with an earlier study examining aerobic and anaerobic energy contribution during 2000 m race simulation in female rowers. It concluded that an 87.7% contribution from the aerobic system and a combined 12.3% contribution was made from anaerobic sources (Pripstein, Rhodes, McKenzie, & Coutts, 1999).

Whilst the findings of Pripstein et al. (1999) and de Campos Mello et al. (2009) show agreement, both appear to overestimate the aerobic cost of rowing performance in comparison to the earlier work of Hagerman (1986) Secher, et al. (1982) and , Secher (1983) . However, it is likely that with the refinements of measurement technique and greater precision in measurement equipment, the work of both Pripstein et al. (1999) and de Campos Mello et al. (2009) provides a representative value of the metabolic cost to on-water rowing performance. It is therefore reasonable to revise the estimate up to ~85% contribution from the aerobic system and a 15% contribution from combined anaerobic sources.

Whilst the work of Pripstein et al. (1999) and de Campos Mello et al. (2009) have established a more representative value of the metabolic cost to on-water rowing performance, the discrepancy between values for on-water and ergometer performance in the work by de Campos Mello et al. (2009) requires explanation. This discrepancy was recognised by the author who concluded that the results seem to indicate that the ergometer braking system simulates conditions of a bigger and faster boat and not that of a single scull. It was suggested that a 2500 m test should be used to properly simulate on-water single-scull racing in respect of metabolic cost.

Whilst the distance for testing single scullers should be greater to ensure effort on the ergometer replicates performance, the overall level of agreement for values for aerobic and anaerobic contribution to on-water and ergometer rowing performance from these studies suggest that ergometer rowing does replicate the metabolic cost of on-water rowing performance (Secher & Volianitis, 2009).

2.1.5 Summary

Rowing imposes a high degree of physiological challenge to the human body by the involvement of nearly all the muscle groups during intense dynamic exercise. Rowers have large aerobic capacity, exhibit high absolute strength as well as high level of muscular endurance when compared to other endurance athletes. The large aerobic capacity and high muscular endurance reflects the metabolic cost of the event. Anaerobic contribution to overall effort is prevalent at the start and end of a race and rowers demonstrate ability to tolerate very high blood lactate concentrations.

2.2 Pacing strategies

In order to optimise performance athletes must regulate their rate of work output in order not to exceed capacity. The distribution of this total work or energy expenditure across an exercise task is termed the pacing strategy (Abbiss & Laursen, 2008). Implementing an effective pacing strategy can influence performance outcome.

Typically, the performances of the gold, silver and bronze medallists are within 1% of each other, so only small variations in pacing strategy can dictate competitive results (de Koning et al., 1999). Understanding the potential of variation in pacing strategy upon performance outcomes offers opportunity to gain competitive advantage in a close competitive arena.

Pacing strategy is influenced by a multitude of physiological, cognitive and environmental variables that all determine how a strategy is governed internally and externally by an athlete. The result of that governance, described by time or velocity at any given point in the exercise task, is the pace and this represents only the outcome from a number of factors, including the mechanical power generated, momentum, kinetic energy and the degree of resistive force encountered at that moment. The terms pace, pacing and pacing strategy are often used interchangeably, however the pacing strategy describes distribution of total work or energy across the overall effort whilst pace and pacing describe by time or velocity the observation made at a given point in the exercise task (Abbiss & Laursen, 2008).

2.2.1 Describing pacing strategy

Pacing strategy can be described by the resultant pacing profile of the total work or energy of an exercise task. Terms such as negative, positive, even, parabolic or variable are used to describe the variety of pacing profiles of different exercise tasks and under differing exercise conditions. The pacing profile should be viewed in the context of the situation in which the athletic performance occurs. The nature of a situation can determine which profile may be most favourable to athletic performance. For example, a negative pacing profile may be more favourable to an extended endurance event, as there is a rationale for a more concentrated distribution of work in the later stages of the event. Rowing is a maximal extended event and it is unlikely that negative or positive pacing strategies would be favourable to this event (Abbiss & Laursen, 2008). A negative pacing strategy is likely to place the boat so far back as to be uncompetitive and a positive pacing strategy is likely to exhaust the rower before completion of the distance. Therefore an even, parabolic or variable pacing strategy is likely to be most favourable to performance.

The exact pattern of the strategy is dependent not only on how the athlete distributes work or energy but also upon the number of sampling points in its measurement. If only two sampling points are used a profile may be described as positive in the first half and negative in the second, when 4 sampling points would cause it to show a parabolic profile. Rowing pace is generally measured at 4 sampling points, allowing the pacing strategy to be described using 4 x 500 m splits. An increase in the number of sampling points does allow better definition of the pacing profile however there is a number beyond which they become unnecessary. For example to use 100 m splits over 2000 m would not change the profile type observed.

2.2.2 Research paradigms of pacing strategy

Three research paradigms have been used to examine pacing strategy. The observation of self-selected pacing strategy, observed either during laboratory time trials of exercise tasks or actual competitive events is the most common. This paradigm has allowed the description of the observed pacing strategy of competitive rowing events (Brown et al., 2010; Garland, 2005; Muehlbauer et al., 2010; Secher, 1983).

Observation of pacing strategy in actual competition allows a large sample size to be used which adds robustness to the findings; however performance in actual competition is not always representative of physiologically preferred pacing strategies. To achieve success in many competitive events it is only necessary to have established a winning margin against fellow competitors at the end of the race. Dependent on the stage of competition it may be tactically desirable to race slower or quicker to either secure a place or conserve energy. Pacing strategies may also be determined by the actions of competitors, team mates, and variable environmental conditions (Abbiss & Laursen, 2008; Muehlbauer et al., 2010). Therefore a range of variables can affect pacing strategy in actual competition.

Observation of pacing strategy in controlled laboratory conditions offers control over variables when replicating performance. This increases the internal validity of the findings. However the ergometer must replicate both performance and those variables. In rowing, air resisted ergometers can be adjusted to replicate the degree of hydrodynamic drag of water of various water conditions and have been shown to have a high reliability that make a combination of ergometer, athlete and test protocol very suitable for monitoring rowing performance and for investigating factors that affect that performance (Schabort, Hawley, Hopkins, & Blum, 1999).

Experimental manipulation of pacing, during which the athlete is required to consciously alter the pacing or the pacing is externally controlled at a level different to that of the habitual self-selected pace is also extensively used. This paradigm has been used to examine the effect of different starting strategies on both performance outcomes and physiological variables (Aisbett et al., 2009a; Aisbett et al., 2009b; Bailey et al., 2011; Jones et al., 2008).

Experimental manipulation has tended to concentrate on short duration, high intensity events lasting 30 s to 5 min (Aisbett et al., 2009a; Aisbett et al., 2009b; Bailey et al., 2011; Bishop et al., 2002; Corbett, 2009; Foster, 1994; Hettinga et al., 2006). The likely reason for this concentration of work is the increased influence of nutritional status, thermoregulation and environmental factors on pacing in longer duration events.

The third paradigm is the mathematical modelling of pacing strategies. The models simulate exercise tasks and incorporate variables and constants for both power production and power dissipation. The predicted outcomes from the models can then be compared to the observation of actual competitive performance (de Koning et al., 1999; Hettinga et al., 2011). Mathematical modelling of power/velocity and force/time relationships enables a wider variety of pacing strategies to be examined and observed without the actual need for athletes to trial them in a competitive environment. However the theoretical findings from these studies often lack the ecological validity that trials in competition would give.

The three different paradigms offer opportunity to provide substantive evidence toward defining optimal pacing strategies for given sports, but findings have yet to be combined from various paradigms to provide a fuller examination of pacing and performance in one sport; the exception to this is cycling, where an equivalence of findings from studies using each paradigm can be found (de Koning et al., 1999). Examination of pacing strategy in rowing has concentrated upon the observation of self-selected pacing strategy in actual competitive events and there is a lack of research of mathematically modelled pacing strategies or findings from experimental manipulation of possible pacing strategies.

2.2.3 Summary

The distribution of total work or energy across an exercise task is termed the pacing strategy and description of time or velocity at any given point in the task is termed pace. Description of the pacing strategy is by its resultant profile and uses terms such as negative, positive or parabolic. The accuracy of the description of a profile is determined by the number of sampling points of pace throughout the task.

Research of pacing strategies has utilised three different paradigms, all offer advantages and disadvantages in attempting to determine the optimal pacing strategy for a given sport and set of conditions. Combination of findings from these paradigms would aid in identifying optimal strategies. The ease of obtaining data from competition has resulted in extensive observation of competitive performance, particularly in rowing. Whilst this provides understanding of what pacing strategy is prevalent it does not identify the reasons why it is undertaken or if it is the optimal strategy.

2.3 Pacing strategies of rowing

2.3.1 Parabolic pace strategies

A parabolic pace strategy is described by a progressive reduction of percentage of average velocity over the first half of the event and a progressive increase in percentage of average velocity in the latter portion of the event. This parabolic pattern has been further categorised by Abbiss and Laursen (2008) as a U-shape, J-shape or a reverse J-shape strategy (Figure 2.1). Categorisation of a parabolic pacing strategy into its defined shape is determined by the degree of reduction of pacing over the first half compared to the degree of increase in pacing in the latter portion of the event.

Parabolic strategies are commonly observed in maximal extended events such as rowing. Both on-water and ergometer rowing describe a parabolic strategy (Brown et al., 2010; Garland, 2005; Muehlbauer et al., 2010; Secher, 1983). Furthermore this strategy is typically categorised as a reverse J-shape. The measurement of pace by

500 m quarter sector times describes the extent of the decrease in pace over the first three quarters and the increase in pace over the remaining quarter (Table 2.1).

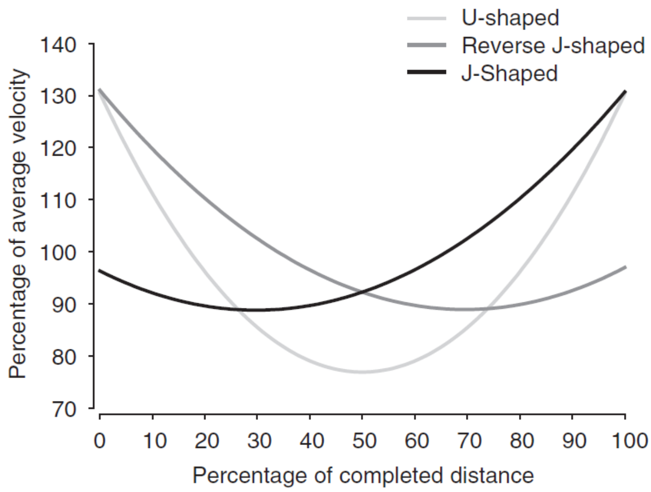

Figure 2.1 Example of U-shaped, reverse J-shaped and J-shaped pacing profiles during exercise (Abbiss & Laursen, 2008).

Note. Reprinted from "An analysis of the pacing strategy adopted by elite competitors in 2000 m rowing." by S. W. Garland, 2005, *British Journal of Sports Medicine*, *39*(1), 39-42

Table 2.1 Typical reverse J-shape strategy for on-water performance (Garland, 2005).

Quarter	On-water pace (%)
0-500 m	103.3 (1.8)
500-1000 m	99.0 (1.2)
1000-1500 m	98.3 (1.2)
1500-2000 m	99.7 (1.9)

Pace is expressed as a mean (SD) percentage velocity for race as a whole

Note. Reprinted from "An analysis of the pacing strategy adopted by elite competitors in 2000 m rowing." by S. W. Garland, 2005, *British Journal of Sports Medicine*, *39*(1), 39-42

Secher (1983) first described a reverse J-shape strategy for on-water performance in analysis of the finalists placed 1st to 6th in the men's 1974 FISA World Championships. Garland (2005) also reported a reverse J-shape strategy for on-water performance in analysis of 1612 open weight boats in the Olympic Games of 2000 and the rowing World Championships of 2001 and 2002. Whilst both Secher (1983) and Garland (2005) were congruent in their findings, the work of Garland (2005) excluded some boats and Secher (1983) limited the sample size to finalists only.

The exclusion criteria included by Garland (2005) and later adopted by Brown et al (2010) in a subsequent study, was designed to elicit only what was determined as a "representative performance". The rationale for this exclusion was that boats trailing in last place or a long way ahead of the other competitors may have deliberately slowed toward the end of the race to conserve energy, knowing a placing was not possible or knowing they would not be included in subsequent rounds of the competition. These factors would cause the boat to not demonstrate a typical pacing strategy. The use of exclusion criteria by Garland (2005) and the limited sample size of Secher (1983) prevent the definitive determination of the typical pacing strategy in rowing competition.

Muehlbauer et al. (2010) examined the pacing strategy of the 2008 Olympic regatta, and confirmed the previous observations of Garland (2005) and Secher (1983). This work did not use any exclusion criteria and it included all boats (single, double, and quadruple sculls, coxed and coxless pair, four, and eight) in every open weight heat and final race (*n*=72 boats for men, *n*=60 boats for women). Whilst a smaller sample size than previous work, it was inclusive of all boats. Analysis distinguished between race type (heats vs. finals), boat rank (winner vs. other boats), boat type (single vs. other boats) and sex. It was found that all boats exhibited a reverse J-shape pacing strategy demonstrating a significantly faster first quarter compared to the second and/or third quarter and an end-spurt in the final quarter (Muehlbauer et al., 2010).

Variation in the reverse J-shape strategy was found in the performance between men's and women's crews. The final quarter of all races was significantly quicker than the third quarter for both men's and women's crews but only significantly quicker than the second quarter for men's crews (Muehlbauer et al., 2010). This was in contrast to Garland (2005) who found no difference in performance between sexes, but the use of exclusion criteria in sampling may have obscured any possible observed difference in that study. The findings of Muehlbauer et al. (2010) would suggest men's crews both start and end quicker, relative to the middle quarters of the event or during those middle quarters' men's performance declines to a greater extent than female performance. Alternatively, women's crews' performance tends more toward an even overall pace in the first three quarters after a fast start with only an increase in the final quarter. Other work has not identified such differences in pacing between males and females (Meur et al., 2009). Further study is required to determine which hypothesis is supported but these findings suggest there is a difference in pacing strategy between males and females.

Further work has observed the pacing strategies of actual rowing competition. Brown et al. (2010) investigated the influence of performance level on the pacing strategies of single scull rowers. Data was sampled from 507 boats in on-water rowing championships and competitors were categorised into elite, national and sub-elite. Similar to Garland (2005) exclusion criteria were used to remove boats whose performance may not be representative of best effort. It found a parabolic pacing strategy described all races and also that performance level altered effort regulation.

Elite level rowers tended to demonstrate a more even pace profile of ~5% normalised mean velocity difference between fastest and slowest sectors on-water. This was higher for sub-elite at ~8.5% normalised mean velocity. Whilst a reverse J-shape pacing strategy is consistently found in on-water performance the findings of Muehlbauer et al. (2010) and Brown et al. (2010) suggest the pattern of that profile is dependent upon both sex and performance level.

Observing pacing strategy in actual competition does not infer that the established pacing strategy is a physiologically preferred or optimal pacing strategy. Consideration of tactical factors would suggest that this pattern is only observed because of a desire to row in water free of wake produced by other boats and to be in a position where competitors can be observed. Less competitive boats may still show a reverse J-shape strategy as they too would start fast but that may inhibit performance in the mid portion of the event. The inclusion of all boats by Muehlbauer et al. (2010) allowed some differentiation to be made between the pacing strategies used in heats and finals, where an amended pacing strategy may be adopted tactically in response to other competitors whilst also highlighting a difference in strategy between male and female performance.

Despite the variation found by Muehlbauer et al. (2010) and Brown et al. (2010), it can be stated that rowing consistently demonstrates a parabolic pacing strategy which can be defined as a reverse J-shape irrespective of race type, boat rank or boat type, performance level or sex (Brown et al., 2010; Garland, 2005; Muehlbauer et al., 2010; Secher, 1983; Secher et al., 1982). Tactical factors cannot be excluded as the reason for this strategy however observation of ergometer rowing by Secher (1983) Garland (2005) and Brown et al. (2010) also confirm that this parabolic pattern is consistently observed in ergometer rowing performance where the tactical factors of on-water rowing are absent or reduced.

2.3.2 Pacing strategies in ergometer rowing

A reverse J-shape pacing strategy was found by Garland (2005) when observation was made of the top 170 competitors in the British Indoor Rowing Championships of 2001 and 2002. The typical reverse J-shape strategy for ergometer performance is shown (Table 2.2).

Table 2.2 Typical reverse J-shape strategy for ergometer performance (Garland, 2005).

Quarter	Pace (%)
0-500 m	101.5 (1.5)
500-1000 m	99.8 (0.8)
1000-1500 m	99.0 (1.0)
1500-2000 m	99.7 (1.6)

Pace is expressed as a mean (SD) percentage velocity for race as a whole

Note. Reprinted from "An analysis of the pacing strategy adopted by elite competitors in 2000 m rowing." by S. W. Garland, 2005, *British Journal of Sports Medicine, 39*(1), 39-42

Ergometer rowing shows a fast first quarter and slower velocity in subsequent quarters that defines the strategy as reverse J-shape, however the extent of fast start for ergometer rowing is less in amplitude when compared to that observed in on-water performance (Brown et al., 2010; Garland, 2005). The differences observed between on-water and ergometer rowing are the first 500 m of the race is rowed as a mean 5.1 s and 1.7 s faster than the second 500 m for on-water and ergometer rowing, respectively (Garland, 2005). This finding agreed with the work of Brown et al.

(2010) who observed a mean 4 s and 2 s faster pacing than the slowest sector for on-water and ergometer rowing respectively. These findings suggest that management of pacing in ergometer competition is a fast start and attempted maintenance of an overall even pace strategy or less of a decline in performance (Brown et al., 2010; Schabort et al., 1999).

As found in on-water rowing, there is a difference between competitive levels. Elite level rowers performing ergometer rowing tend to demonstrate a more even pace profile of ~2.5% normalised mean velocity difference between fastest and slowest sectors in ergometer rowing (Brown et al., 2010). This difference was higher for sub-elite at ~3.5% and would suggest that the pattern of a reverse J-shape strategy in ergometer rowing is also dependent upon performance level.

The differences observed between the exercise modes of on-water and ergometer rowing can be somewhat explained by the nature of performance in ergometer rowing and the characteristics of the rowing ergometer itself. Performance on a rowing ergometer is generally measured chronometrically and rowers will use splits and various performance data, provided by the performance monitor of the rowing ergometer, to gauge pacing against known personal targets, rather than against other boats in a race. The competitor on the rowing ergometer may or may not know their position compared to other competitors at that time.

Ergometer performance is also often used as selection standard for on-water squads, with specific target times for selection known prior to performance, therefore as rowers become more familiar with the ergometer and testing protocols, a move towards an even pace based on a known target can occur (Brown et al., 2010). In on-water rowing it is simply the final place that is of importance. In essence, ergometer rowing in competition and testing for selection is much more akin to time trial performance rather than the head-to-head competition typical of on-water rowing. It is suggested that specific training and tactics are put into place between the rower and trainer according to the rowers' capabilities and the exercise mode (Brown et al., 2010).

When comparing ergometer and on-water rowing performance it is important that appreciation is made of the greater technical demand and need to be able to maintain skill level and technique when fatigued in on-water performance. The need to be able to maintain skill level and technique is not so great in ergometer rowing compared to on-water performance. The effect of fatigue on technique may be a factor for the greater normalised mean velocity difference observed in lower performance levels in both exercise modes. Consideration should also be made that many ergometer performances are from competitive on-water rowers.

2.3.3 Summary

On-water and ergometer rowing demonstrate similar pacing profiles but the profile is reduced in amplitude in ergometer rowing. Both exercise modes are consistent in demonstrating a reverse J-shape pattern of pacing strategy. However tactical considerations in on-water rowing may cause a greater degree of fast start in this exercise mode. However the reverse J-shape pattern being observed in both exercise modes, where tactical factors are reduced in ergometer rowing, suggests that this pattern is inherent.

Variation of this pattern is observed in performance of men's and women's crews and between levels of performer that suggest the amplitude of the strategy may be specific not only to the exercise mode, but to sex and level of performer. The importance of rowing ergometer performance for squad selection and differences of technique between exercise modes also suggest that pacing strategy may be adapted.

2.4 Even pace strategies in rowing

The adoption of an even pace strategy has intuitive appeal in maximal extended locomotive events such as rowing. Secher (1983) stated that the most economical way to row 2000 m would be to maintain a mean velocity throughout. The utilisation of an even pace strategy would potentially maximise available metabolic capacity, as long as the percentage of time spent in acceleration at the start of the event, relative to total duration, is small and the environmental conditions are relatively stable, yet there is no research that examines the efficacy of an overall even pace strategy in rowing.

Theoretical support for even pace strategies being optimal comes from critical power models and the second law of motion, both of which dictate that velocity is governed by the maximal constant force that an athlete can exert against the resistive forces experienced (Billat et al., 1999). The critical power models of Billat et al. (1999) have shown that performance will be compromised if the power of an athlete drops below their physiological limits (i.e. 'fatigue threshold' or 'critical power') at any point during an endurance event, even if there is an attempt to make up for lost time with a final increase in speed towards the end of an event (Fukuba & Whipp, 1999). Therefore, the ability of a rower to exert a consistent maximal force is vital in determining if an even pace is optimal for rowing. This may be a factor in why the level of performer influences the degree to which an even pace profile is currently held.

The second law of motion also supports an even pace being optimal in rowing, as it is the high resistive force of the water that the rower has to expend energy to overcome and any increase in velocity would require a greater percentage of the power generated to overcome the hydrodynamic drag rather than produce forward motion, therefore once optimal velocity is achieved a minimum of variation in pace is desirable.

The findings of mathematical modelling of power/velocity relationships in cycling and speed skating have suggested an even pace could be an optimal pacing strategy for maximal extended events (de Koning et al., 1999; Hettinga et al., 2006; Hettinga et al., 2009; Hettinga et al., 2011). In modelling pacing strategies for cycling De Koning et al. (1999) used physiological constants for maximal acceleration, velocity, endurance and the rate of fatigue against the resistive forces experienced. It was concluded that the fastest time on the 4000 m cycle pursuit was achieved with an 'all-out' start at a high level of initial power output, followed by a constant anaerobic power output after 12 seconds, resulting in an evenly paced race (de Koning et al., 1999). The pattern of starting at high levels of initial power output, followed by a constant level of anaerobic power would be a similar pattern to that found in rowing.

Examination of cycling performance has supported the findings of De Koning et al. (1999) of an even pace strategy being optimal (Wilberg & Pratt, 1988). International track cyclists competing in 4 km time trials were found to be more successful when a more constant or even paced strategy was used (Wilberg & Pratt, 1988). This has been more recently supported by work examining 1 km time trial and 3 km and 4 km individual pursuit cycling (Corbett, 2009). It was concluded that in the longer events of 3 km and 4 km individual pursuit cycling, small alterations of pacing strategy are important at an elite level because of the narrow margins between success and failure (Corbett, 2009). The limited work that has examined the pacing strategy of longer duration events, such as 1-hour track cycling, also lends support to an even pace strategy being optimal in events of this type, despite the increasing influence of nutritional, hydration and thermoregulatory mechanisms in events of a greater duration (Padilla, Mujika, Angulo, & Goiriena, 2000).

The extrapolation of findings from cycling to rowing has some validity based upon the similar duration and the relatively stable environment in which competition occurs. Also in both events the time to achieve a race pace from a stationary start is relatively small compared to the overall duration. In a review of pacing strategies Abbiss and Laursen (2008) proposed that a constant pace was an optimal pacing strategy for rowing citing evidence from cycling. However, no study has evaluated the effect of an overall even pace strategy on performance outcomes in rowing.

The mathematical modelling of De Koning et al. (1999) was seminal in the conclusion drawn by Abbiss and Laursen (2008) that an even pace would be optimal for rowing as there is no observed evidence in support of that conclusion. Despite theoretical support a number of significant factors that differentiate rowing from cycling, appear not to have been considered.

Extrapolating the findings of De Koning et al. (1999) to rowing is erroneous as the modelling used physiological constants of maximal acceleration, velocity, endurance and the rate of fatigue from elite speed skaters. Whilst the similarity of this population to track sprint cyclists allows transferability of the findings across these populations, the different physiological attributes of rowers compared to speed skaters invalidates transfer of these findings to rowing.

Another significant difference between cycling and rowing is the drag coefficient of water compared to air. The power output needed to overcome hydrodynamic drag from a standing start and achieve an even race pace velocity is high in both sports. Acceleration from stationary to race pace in rowing requires a power output of ~700 W (Steinacker, 1993). Whilst comparable power outputs are found in starts in cycling, rowers have to expend a greater percentage of the power generated to overcome the hydrodynamic drag of water over the total duration of the event where cyclists do not. This high initial power output and the continued higher resistance of water may inhibit the ability to be able to offer a sustained high power output following the start of the event.

Differences in technique between cycling and rowing also should be considered. On-water rowing is technically demanding and fatigue will cause deterioration in technique which may have a greater impact on pacing than a deterioration of technique in cycling. Further research is needed to understand the influence of improved skill and technique on energy cost and pacing strategy, especially during repetitive stroke exercises such as rowing (Abbiss & Laursen, 2008).

These differences may not be the complete reason why an even pace strategy is not adopted in rowing. Tactical consideration could be why an even pace is not observed in rowing. A rapid acceleration to achieve a maximal overall even pace strategy may capitalise on available metabolic capacity in order to complete the event in the fastest time as suggested by De Koning et al. (1999) but faster starting competitors are able to then pace themselves better in response to competitors later in the race. This is due to the backward facing position of the rower in the boat giving observation of competitors' position. A fast starting pace therefore would provide tactical advantage, however too great an intensity or too prolonged duration of that fast start could inhibit the efficient distribution of limited metabolic capacity later in the event and actually may inhibit any later response to actions of competitors. This inhibition may be because of substrate depletion, or more likely in rowing, the effect of the build-up of inhibiting metabolites from the fast start effort (Foster, 1994).

Despite the evidence from both mathematical modelling and observation from cycling and speed skating the suggestion that an optimal pacing strategy would be an even pace strategy is not supported by observation of rowing performance. It is currently unclear if alternative strategies such as an even pace strategy are not adopted for tactical reasons or there are other factors that have not been considered.

2.5 Starting strategies

It is equivocal as to which overall pacing strategy is optimal for rowing but the predominant pattern for both on-water and ergometer rowing is a reverse J-shape pacing strategy. The fast start of rowing is largely responsible for classification of the overall strategy as a reverse J-shape. Therefore, the starting strategy is an important element in defining any overall pacing strategy. Implementation of an effective starting strategy can provide advantage both tactically and in performance outcome.

2.5.1 Defining starting strategy

Similar to how an overall pacing strategy describes distribution of work or energy expenditure throughout an exercise task, the starting strategy describes how work or energy expenditure is distributed throughout the starting phase of an exercise task. As the starting strategy is an element of pacing within an overall strategy it is often described by time or velocity, rather than by work or energy expenditure.

Research using the paradigms of mathematical modelling and experimental manipulation of pacing strategies has examined the effects of various starting strategies on performance outcomes and selected physiological variables (Aisbett et al., 2009a; Aisbett et al., 2009b; Bailey et al., 2011; Bishop et al., 2002; de Koning et al., 1999). This research has used various terms to describe the specific starting strategies, such as fast, even, slow and all-out start. However, there is some variance as to how these terms have been operationally defined. It is important that the constituent parts of a starting strategy are consistently defined so that a transfer of findings across research can occur.

In maximal extended locomotive events there is normally a phase during which acceleration to a mean overall race velocity is achieved. This portion of the event can be considered the starting phase. However, this portion can only be identified relative to the number of sampling points used to measure the overall pacing strategy. Pacing in rowing is nominally split into 500 m splits and whilst a variable pattern may occur within this split distance it is reasonable to assume that performance up to the first 500 m quarter split point can be defined as the starting phase for this event.

Current research has used an arbitrary time component, a fraction of the total event duration, or a work quantity to define the starting strategy phase. In examination of pacing strategy in kayak performance, Bishop et al. (2002) determined that an all-out starting strategy should last 10 s with a 5 s transition to an even pace that was then held for 1 min, in a kayak test of 2 min duration. In examining even, fast and slow start strategies, Bailey et al. (2010) controlled work over the first half of 3 min and 6 min bouts of cycle exercise.

In work modelling performance of 4 km cycling it was determined that in events lasting 4.5-5 min the first quarter split time approximated 20-30% of the finishing time (Schenau et al., 1992). This finding by Schenau et al. (1992) was used by De Koning et al. (1999) and later by Aisbett et al. (2009b) when determining the quantity of work in experimental manipulation of starting strategies in 5 min cycling performance.

Once the starting phase of an event is defined and a mean overall pacing strategy is measured, pacing relative to this value can then be used to define the terms of even, fast, or slow start. This value may represent a velocity, time, or work quantity. Defining a term of even, fast, or slow start relative to mean overall value is straightforward, however a more difficult term to define is the all-out start that has been used in some work.

The term all-out start was used in the mathematical modelling of pacing strategies by De Koning et al. (1999). This work used an earlier developed model of energy flow, using expressions for power production and dissipation (Schenau et al., 1992). This model changed the kinetics of anaerobic power output and the strategy of use of anaerobic capacity with a variable referred to as "time to constant power". It was the time to constant power which indicated the point at which the athlete switched from an all-out starting strategy to constant power output with a set value of energy contribution from anaerobic sources. Other examples of use of the term all-out start include work by Bishop et al. (2002) who in experimental manipulation of starting strategies determined that an all-out start was maximum effort held for 10 sec. When determining the duration and power output profiles in examination of all-out and fast start pacing strategies, Aisbett et al. (2009) used the work of De Koning et al. (1999) and Bishop et al. (2002) to define an all-out start.

The lack of consistent definition as to what constitutes an all-out strategy is unsatisfactory. When modelling performance, a value of a given variable such as anaerobic capacity can be determined as extinguished and therefore pacing can be considered to be all-out at that point. In manipulation of starting strategies the biological variation of participants does not allow for conclusive determination that at a given point a variable is extinguished or not. Therefore, an all-out strategy for one participant may not be all-out for another. It is also known that despite participants being requested to go all-out teleoanticipation suggests that some reserve of energy is kept to ensure completion of the task. All-out should be a term that is avoided in defining a starting strategy. Rather, a value that is relative to an established habitual pacing that identifies an extent of fast start, up to a start considered maximal should be used.

2.5.2 Starting strategies and performance outcomes

A fast starting strategy for rowing would always intuitively appear to have the greatest benefit to performance outcomes. This is because this strategy offers less time in the acceleration phase, it reaches an optimum even pace quicker than other strategies and additionally some time is spent at a pace greater than the overall mean velocity. Therefore a fast starting strategy will result in a quicker overall time, as long as the remaining portion of the event is at an optimum even pace. However, too fast a start can require contribution from available anaerobic capacity that can have detrimental effect later in the exercise task and so an optimum fast starting strategy should be identified for each event. Currently there is no research on the use of specific starting strategies in rowing.

Manipulation of starting strategies may offer competitive advantage but the extent to which the starting strategy utilised in events of extended (≥2 min) maximal performance can have an effect on performance outcomes is currently equivocal (Aisbett et al., 2009a; Aisbett et al., 2003; de Koning et al., 1999; Hettinga et al., 2006; Schenau et al., 1992). In examination of cycling performance over a variety of distances, Aisbett et al. (2009a), De Koning et al. (1999) and Schenau et al. (1992) found a fast start improved performance times, whereas Aisbett et al. (2003) and

Hettinga et al. (2006) found no effect on final performance times with any manipulation of a fast, even or slow paced starting strategy.

The ambiguity of findings is likely due to the variety of protocols used. The experimental design of Aisbett et al. (2003) and Bailey et al. (2011) imposed a workload upon the athlete and therefore constrained the intensity of exercise for up to half the duration of the event. The imposition of workload may mask the natural variation that is a necessary component of effective self-selected pacing. Imposing a workload and constraining intensity offers high internal validity but a given workload for a specific phase can still be achieved with a more naturalistic self-selected pacing pattern. The starting phase of rowing demonstrates high initial power outputs with a gradual decline until the nominal sampling point at 500 m. To constrain a rower to a given specific mean power output for a starting phase would not therefore represent the natural pacing pattern; a point recognised by Aisbett et al. (2009a).

Another factor in the current ambiguity is the typical small sample size ($n \leq 10$) and accompanying lack of statistical power that typifies pacing research. Small sample size may obscure differences in the range of 0.6-3.3% which may be competitively important (Hettinga et al., 2006). In a study of track cyclists Corbett (2009) concluded that in the longer events of 3 km and 4 km individual pursuit cycling, at the elite level small alterations of pacing strategy are important because of the narrow margins between success and failure. Therefore, more specific examination of data using effect size calculations and not only statistical power would enhance the understanding of the effect of variation in starting strategies. Effect size calculations would result in provision of findings that are of both practical and applied importance.

As with the overall pacing strategy any choice of starting strategy should be viewed in the context of the situation in which the athletic performance occurs. The overall duration of rowing would exclude a slow start being an effective starting strategy as it is likely boats would be uncompetitive. A fast start is currently observed but it is possible that a faster start which is closer to maximal or an even paced start could be effective starting strategies for positive performance outcomes.

A faster start than is currently observed could be considered viable for rowing, however it must be achieved without premature development of fatigue and a concurrent reduction in velocity occurring later in the exercise task as this will produce a sub-optimal performance (Aisbett et al., 2009b). Rowers and coaches are aware of this and are reticent to ask crews to start maximally. However, the effectiveness of a fast start strategy necessarily dependent on the initial intensity but more upon the time that the switch from the high level of initial power output to a constant anaerobic power output is made. Consequently, the degree of effort expended to achieve a fast start must be considered in relation to overall intended race velocity, distance and duration. Apart from the effect upon performance outcomes, evidence has suggested that there is physiological benefit to a fast starting pacing strategy and this is an area that needs further research using of an experimental paradigm to determine the validity of those claims (Bishop et al., 2002; Garland, 2005).

An adoption of an even starting pacing strategy has both potential drawbacks tactically and potential benefit to performance outcomes. If an even paced starting strategy is adopted it is likely the boat will be at a tactical disadvantage compared to faster starting competitors. The rear facing seats of the boat will put slower starting competitors at a disadvantage as they will be unaware of competitors' actions. A slower starting boat is also likely to encounter wake from other boats which will impact upon boat velocity. However, an even paced starting strategy is likely to have benefit in the latter stages due to the reduced risk of inhibition of muscular contraction caused by metabolite build up in faster starting competitors. A factor that contributes to the reverse J-shape pacing strategy of rowing is likely to be the inhibition of muscular contraction. An even paced starting strategy may leave more available metabolic capacity for opportunity of a greater degree of end-spurt that could be beneficial to performance outcomes.

2.5.3 Summary

The starting strategy of an event is an important constituent part of any pacing strategy. Research has examined the effect of the starting strategy on performance outcomes using both the mathematical modelling and experimental manipulation paradigms. The findings from those studies have been equivocal. Whilst it may be that there is no difference in performance from use of different starting strategies it is also likely that the equivocal findings are a result of a diversity of definitions of what a starting strategy is, as well as variety of protocols used in starting strategy research. Also, small sample size and a use of statistical significance rather than effect size is a contributing factor to the lack of consistent findings.

Rowers consistently use a fast start strategy. The considerable power output expended initially is a possible cause of inhibition of output later in the event and because of this, coaches are reluctant to ask boats to start at a faster pacing than is necessary to achieve tactical position. However a faster than current start may benefit performance outcomes if no significant deterioration of performance occurs later in the event. Equally an even paced starting strategy may have benefit to performance later in the event, but puts boats at a tactical disadvantage. There is no current evidence of the effect of manipulation of starting strategies in rowing and this is an area that should be addressed.

2.6 Physiological regulation of pacing

Whilst the observed pacing strategies of rowing can be described, it does not offer explanation of what the underlying mechanisms that regulate the consequent pacing of the event are, or if they are optimal in relation to physiological capacity. The capacity to produce and maintain power output decreases rapidly during high intensity exercise, therefore sustaining a high power output throughout 2000 m rowing performance requires understanding of both the conscious and sub-conscious regulation of work output and the complex interaction of multiple peripheral physiological systems and the brain.

Understanding this would elicit whether current strategies are driven tactically or adopted as they are inherently beneficial physiologically. It is beyond the scope of this review to examine the depth of work in this area but discussion of possible mechanisms of regulation of pacing is warranted and what the responses to potential manipulations could be. For comprehensive discussion of fatigue and the possible underlying mechanisms of pacing the reader is directed to Fitts (1994), Noakes (2011) and Shephard (2009).

Currently, ambiguity exists if peripheral fatigue or the Central Governor theory is the major mechanism that underpins the physiological regulation of pacing. Both peripheral fatigue and the Central Governor theory are reviewed briefly here in relation to rowing performance.

2.6.1 Peripheral fatigue

Fatigue can be defined as the inability of a muscle to maintain a required rate of work (Maughan & Gleeson, 2004). Examination of the physiological demand of 2000 m rowing and the pacing strategies employed in the event, suggests that peripheral fatigue is a major influencing factor in this type of performance.

In maximal work lasting 1-2 min, the phosphocreatine (PCr) content of the working muscle falls to almost zero and adenosine tri-phosphate (ATP) content falls by about 40% (Maughan & Gleeson, 2004). The high intensity fast start of rowing is likely to deplete PCr and so the sustained pace after a fast start phase is supplied with energy from both anaerobic glycolysis and oxidative metabolic sources. With PCr stores depleted and any ATP reserve also depleted, this reliance on anaerobic glycolysis to supplement the energy demand provided by oxidative metabolism will cause a rise in lactate and an accompanying rise in hydrogen ion (H^+) concentration.

During intense exercise, the maximum accumulation of lactate within the muscle occurs at the end of exercise of about 3-7 min duration, with lower muscle lactate concentrations seen after exhausting work lasting less than 2 min or more than 10 min (Maughan & Gleeson, 2004). The typical duration of rowing varies between 5.8–7.4 min and therefore it is possible that the accumulation in either lactate ions, H^+ or both within the muscle is a contributing factor to the occurrence of fatigue in 2000 m rowing.

The buffering capability within the cell determines the extent of affect from anaerobic metabolism. Lactate ions and H^+ will begin to diffuse from the cell into the blood. The buffering capacity of the cell is influenced by the capacity of blood to absorb some of the rise in H^+ concentration. However, because of limited intracellular buffering capacity and the intensity of exercise, H^+ concentration will continue to increase and pH will fall in the cell and blood. At the point of fatigue, pH in the muscle cell may be as low as 6.3 (Maughan & Gleeson, 2004). Blood lactate concentrations in rowers have been reported as high as 15 and 17 mmol·L^{-1} after a national regatta and a FISA championship, respectively (Secher & Volianitis, 2009). Whilst blood lactate values are only a reflection of cellular levels this would indicate pH in the muscle will be low.

High H^+ concentrations may cause fatigue by inhibiting muscular contraction and the contractile machinery by interference with the effectiveness of calcium ion activation and at many sites in the excitation-contraction process (Fitts, 1994). They may also interfere with chemical reactions responsible for energy production by anaerobic glycolysis via negative effects on key glycolytic enzymes, such as phosphofructokinase (Spriet, 1987). Increasing concentrations of H^+ also stimulate free nerve endings in the muscle giving rise to characteristic painful sensations that accompany high intensity exercise.

Contrary to these suggested mechanisms, it has been shown that high lactate concentrations and the associated acidosis may actually enhance rather than impair skeletal muscle function (Brooks, 1991; Nielsen, de Paoli, & Overgaard, 2001). In work on isolated muscle in the presence of high concentrations of potassium ions (K^+), concentrations of H^+ have been shown to counteract the negative effect on force production caused by the high concentrations of K^+ (Nielsen et al., 2001). This work is currently limited to in vitro findings and would be applicable to exercise only where high concentrations of K^+ exist.

As anaerobic metabolism precedes the production of excess lactate ions and any consequent increase in H^+, the contribution to the event by anaerobic metabolism is the key factor as to what extent fatigue is ultimately experienced. Anaerobic contribution to 2000 m rowing has been estimated to range anywhere between 12.7-25% with ~9% from anaerobic glycolysis (de Campos Mello et al., 2009; Pripstein et al., 1999; Secher & Volianitis, 2009). It is unclear if the estimated anaerobic contribution is of a value that could be beneficial or inhibiting to performance.

The consequence of premature exhaustion of the anaerobic energy supply is a drop in velocity. An increase in the blood lactate accumulation is usually associated with a drop in velocity (Aisbett et al., 2003). During self-paced 5000 m cycle ergometer time trial performance (~8 minutes) where blood lactate was measured it was concluded that individual variations in the pacing strategies were reflected in the time course of the blood lactate accumulation (Foster, Green, Snyder, & Thompson, 1993). In a later review Foster (1994) proposed that regulation of pace is through the sensing of rising muscle acidity reflected by blood lactate accumulation. This work and the work of Aisbett et al. (2003) suggests that a critically low muscular pH which impairs skeletal muscle contractile function and therefore contributes to regulation of pacing is a reductionist and simplistic explanation of a more complex phenomena. A body of work that counters this reductionist approach and offers evidence and support for a more complex interaction of multiple peripheral physiological systems and the brain is provided by consideration of the Central Governor theory.

2.6.2 The Central Governor theory

The Central Governor theory suggests that to accomplish a given task in the shortest possible time the integrated motor program takes into account the power-producing capabilities of the athlete, past experience with similar efforts, and feedback from both central and peripheral receptors (Joseph et al., 2008). The "Central Governor" is designed to prevent a catastrophic disturbance in homeostasis

(Noakes, Gibson, & Lambert, 2004). A critique of this theory and subsequent rebuttal can be reviewed (Noakes, 2011; Shephard, 2009). A key aspect of the Central Governor Theory is that pace is regulated with reference to the end point of exercise. This concept has also been labelled as teleoanticipation or as internal negotiation (Foster et al., 2003; Noakes & Gibson, 2004; Ulmer, 1996).

The concept of teleoanticipation is important in the regulation of pace. The end of the exercise task offers a reference point to which athletes adjust their work rate in order to ensure optimal performance (Abbiss & Laursen, 2008). The original concept of Ulmer (1996) that exercise is controlled in a teleoanticipatory manner has been expanded upon by Gibson et al. (2004). It has been shown that despite deception of distance, power and heart rate was unaffected, suggesting regulation of pace may be more influenced by the anticipated workload rather than actual distance performed (Nikolopoulos, Arkinstall, & Hawley, 2001).

It is likely that self-selected exercise intensity may be regulated continuously within the brain based upon a complex algorithm involving peripheral sensory feedback and the anticipated workload remaining (Abbiss & Laursen, 2008). To be effective there is a requirement that the athlete is familiar with the task and the more attuned the athlete is to the task, the more effective the pacing (Gibson et al., 2006).

The effectiveness of the mechanisms involved in the Central Governor theory are developed by memories of prior exercise bouts and if indication of time to complete the task is also considered, it suggests that power output and perceived exertion are both set at the beginning of an event (Gibson et al., 2006). As more representations of exercise bouts of different durations are laid down from repeated training bouts and athletic events, the accuracy of the mechanisms are likely to improve.

The typical parabolic pattern shown by rowing would suggest that rowers undertake a fast start to be in a better position tactically, they then regulate their pace based on knowledge of the anticipated workload required to reach a point from which they are able to undertake an end-spurt which is sustained until the end of the event. The mechanisms of the Central Governor theory also offer explanation as to why there are differences in pacing between elite and sub elite athletes.

2.6.3 Physiological responses to fast start strategies

Whilst there are tactical reasons for starting fast in rowing, it is less clear if there is a physiological rationale as to why this is the adopted strategy (Garland, 2005). There is however evidence to suggest that the starting strategy does mediate the physiological responses to an overall event.

With consideration of the potential influence of fatigue, possible mechanisms for enhancing performance by starting quickly include an accelerated increase in ventilation and/or oxygen uptake which may attenuate fatiguing mechanisms later in the race (Jones et al., 2008; Whipp, Ward, Lamarra, Davis, & Wasserman, 1982).

The effect of a fast start on performance outcomes is equivocal (section 2.5.2) yet the evidence for a physiological effect with use of a fast start is more substantial. In examination of $\dot{V}O_2$ response in supra-maximal cycling time trial exercise of 750-4000 m it was found that the larger initial burst in power output in 750 m was accompanied by a faster $\dot{V}O_2$ response (Hettinga et al., 2009). A number of further studies that have experimentally manipulated starting strategies have found agreement with this finding (Aisbett et al., 2009a; Aisbett et al., 2009b; Bailey et al., 2011; Jones et al., 2008).

Jones et al. (2008), studied cyclists who completed a trial to exhaustion. All conditions began with an abrupt increase to the initial target work rate from a baseline (BL) of cycling at 20 W. In the even-pace (ES) condition, the target work rate (estimated to result in exhaustion in 120 s) was held constant throughout exercise. In the slow-start (SS) condition, the work rate was initially increased to a value 10% lower than that in ES and then increased progressively with time until it was 10% above that in ES after 120 s of exercise. In the fast-start (FS) condition, the work rate was initially increased to a value 10% higher than that in ES and then decreased progressively with time until it was 10% below that in ES after 120 s of exercise. In this way, the total work done was the same for the first 120 s of exercise in all conditions (Figure 2.2).

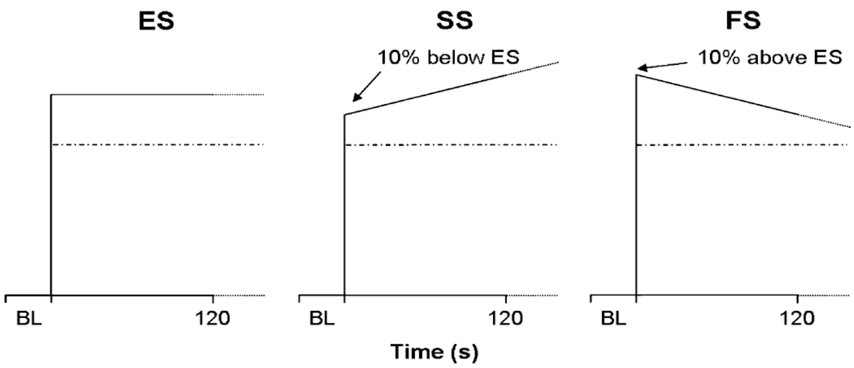

Figure 2.2 Schematic illustration of the experimental protocol used by Jones et al (2008)

Note. Reprinted from "An analysis of the pacing strategy adopted by elite competitors in 2000 m rowing." by A. M. Jones, D. P. Wilkerson, A.Vanhatalo, & M. Burnley, 2008, *Scandinavian Journal of Medicine & Science in Sports, 18*(5), 615-626.

Jones et al (2008) found that the overall time to exhaustion was significantly greater in the fast start strategy compared to the even start and slow start conditions.

This was also accompanied by a more rapid response of and greater value in $\dot{V}O_2$ in the fast start condition.

The short duration of the trials in the work of Jones et al. (2008) has limited applicability to rowing performance where continuation of effort is well beyond the 120 s controlled duration of that study. To be able to validly generalise findings from cycling to rowing performance would require studies where the exercise task is a minimum of 300 s extending to 480 s. Experimental trials in exercise tasks greater than 120 s have been conducted; Aisbett et al. (2009b) examined performance when the first quarter of 5 min cycling was externally controlled to elicit a fast or all-out starting strategy.

The main findings from the study of Aisbett et al. (2009b) were that a simulated all-out start produced significantly faster finishing time and higher mean power output when compared to a more sustained fast start. It was also noted that $\dot{V}O_2$ was significantly greater during the first 25% of the all-out start compared to the fast start trial with the percentage difference in $\dot{V}O_{2max}$ being significantly correlated with differences in overall finishing times between the all-out start and the fast start (Aisbett et al., 2009b).

The larger initial burst in power output in these studies is accompanied by a faster $\dot{V}O_2$ response and the start seems to be of importance in triggering the aerobic system to act maximally. Whilst a faster $\dot{V}O_2$ response is observed it needs to be separated from the requirement of the work to ascertain if it is actually a physiological benefit or simply a response to the manipulation of work.

Work by Bailey et al. (2011) has examined the influence of pacing strategy on pulmonary $\dot{V}O_2$ kinetics in high intensity exercise. The study compared an even pace start (ES), slow start (SS) or fast start (FS) in cycling 3 min or 6 min time trials. An initial 3 min all-out test was carried out so that calculation could be made of work rate that would be expected to lead to exhaustion in 3 min and 6 min. In the schematic of the protocol shown in figure 2.3 group mean work rates are shown for the 3-ES (top left), 3-FS (middle left), 3-SS (bottom left), 6-ES (top right), 6-FS (middle right), and 6-SS (bottom right) conditions. All protocols finished with a 1-min ‘‘end-sprint’’ phase (SPR) in which subjects were encouraged to complete as much work as possible. The dashed vertical lines demarcate the transition between the constituent phases specified by the particular protocol. Note that the mean work rate and hence the total work done were equal across the first 2 min of the 3-min trials and the first 5 min of the 6-min trials, irrespective of the pacing strategy used (Bailey et al., 2011). All work was ended by an all-out sprint opportunity (SPR).

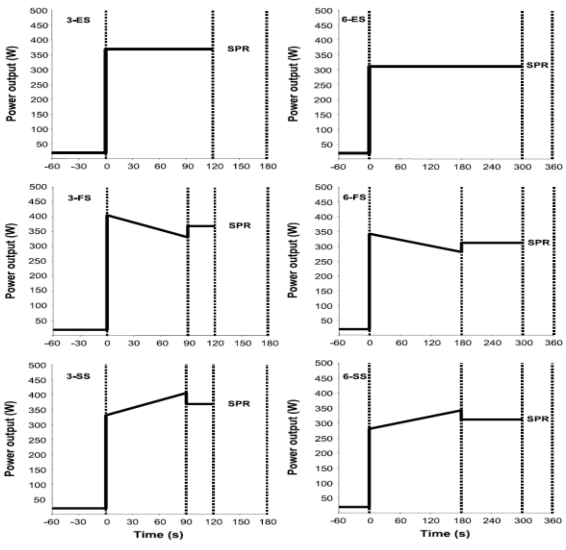

Figure 2.3 Schematic illustration of the experimental protocol used by Bailey et al. (2011)

Note. Reprinted from “Fast-Start Strategy Improves VO_2 Kinetics and High-Intensity Exercise Performance.” by S. J. Bailey, A. Vanhatalo, F.J. Dimenna, D.P. Wilkerson, & A. M. Jones, 2011, *Medicine and Science in Sports and Exercise, 43*(3), 457-467

The work of Bailey et al. (2011) found that in both the 3 min and 6 min trials $\dot{V}O_2$ kinetics were fastest in the FS condition. This indicates that the rate at which $\dot{V}O_2$ increases after the onset of exercise is sensitive to the pattern of work rate imposition, even when the mean rate of work is identical. The design used by Bailey et al. (2011) provided external validity as it allowed for a self-paced element and opportunity for end-spurt.

Aisbett et al. (2009a, 2009b) and Bailey et al. (2011) critically extended the work of the effect of starting strategies from effect on performance outcomes to an understanding of how a fast start can influence physiological response to overall effort. The fixing of work rates utilised by Aisbett et al. (2009a, 2009b) and Bailey et al. (2011) allowed manipulation, measurement and a better physiological understanding of starting strategies, particularly in examining benefit of starting strategies greater than the self-selected pace. This work provides control by which to measure further research against. It has provided internal validity through the control of variables, yet does appear weak in external validity. Therefore caution is needed when generalising findings to actual competition, as the method of fixing of work rates to control the effort of the participant does not allow the habitual self-selected pattern of work.

The work examined so far in relation to the fast start strategy has used cycling extensively due to the ability to control and measure work. Whilst there is a similarity in terms of resistive forces and duration of the exercise task, studies of work in water or replication of the forces encountered in water would have greater applicability to rowing performance. Only one study appears to have examined the effect of manipulation of pacing strategy on $\dot{V}O_2$ that was work by Bishop et al. (2002). Participants completed a 2-min test on a kayak ergometer using an all-out start and an even pace start. The all-out strategy required the participant to work at maximum effort for 10 s, followed by a 5 s transition to an even pace. The even start strategy required athletes to accelerate to an even pace as quickly as possible and hold this pace for the remainder of the first minute. In both conditions, once the first minute was complete athletes were encouraged to complete the final minute in as fast a time as possible. The all-out strategy produced significantly greater mean power during the 2 min test and greater $\dot{V}O_2$ at 30 and 45 s and significantly greater total $\dot{V}O_2$. The all-out strategy appears to maximise use of available metabolic capacity.

The examination of evidence in this review suggests that a fast start strategy is not only beneficial to overall performance because of the shorter time spent in the acceleration phase but also that there is a physiological benefit provided by the faster response in $\dot{V}O_2$ kinetics. The exact mechanism as to why a faster response in $\dot{V}O_2$ kinetics occurs is unclear, but it is suggested that this response provides benefit to performance as it signals a greater aerobic energy supply earlier in the exercise task therefore possibly preserving anaerobic energy capacity until later in the task.

Whilst the findings of Aisbett et al. (2009a, b) and Bailey et al. (2011) show that a fast start or all-out start increases $\dot{V}O_2$ kinetics and this increase is possibly mediated through the products of PCr splitting (McCreary et al., 1996). What is not addressed satisfactorily is differentiating the effect of warm-up to that of the fast start or all-out start in causing this response. In a review of warm-up Bishop (2003) offered the same rationale for the effect of a warm-up as that provided by Aisbett et al. (2009a, b) and Bailey et al. (2011) for the fast or all-out start. That was that active warm-up may improve intermediate performance by decreasing the initial oxygen deficit, leaving more of the anaerobic capacity for later in the task (Bishop, 2003).

However, in further study of the effect of warm-up on cycle time trial performance the results were ambiguous as to the effect of warm-up (Hajoglou et al., 2005).

Ambiguity around the effect of warm-up will always arise in conjunction with examination of self-paced exercise. Therefore a specific warm-up routine could have the same physiological effect on $\dot{V}O_2$ kinetics as the type of starting strategy used, however until the extraneous variables can be more tightly controlled around both the type and intensity of warm-up and more control around the pattern of power output in the early stages of performance elucidating the effect of either is problematic.

2.6.4 Physiological rationale for the benefit of a fast start strategy

Physiological rationale for why the faster response in $\dot{V}O_2$ kinetics is observed is developed from work by McCreary et al. (1996). This work found that there is direct proportionality between the products of phosphocreatine (PCr) splitting and muscle or pulmonary $\dot{V}O_2$ during transitions to and from moderate-intensity constant-load exercise (McCreary et al., 1996). It is also known that greater rates of PCr breakdown occur at higher intensity of exercise (Medbo & Tabata, 1993). The rate of $\dot{V}O_2$ kinetics increases exponentially after the onset of exercise whilst the rate of ATP turnover increases instantaneously at exercise onset, therefore leaving an energy deficit (Whipp et al., 1982). This deficit is compensated for by an increased rate of ATP synthesis through PCr degradation and anaerobic glycolysis. This increased rate of ATP synthesis through PCr degradation and anaerobic glycolysis is the likely signal that initiates the speed of $\dot{V}O_2$ kinetics, therefore the faster and more intense the start the more likely a quicker $\dot{V}O_2$ kinetic response.

2.6.5 Summary

The underlying mechanisms that regulate the pacing of an event are not clearly understood. In a maximal extended event that has a high intensity start such as rowing the mechanisms of peripheral fatigue are likely to be a major factor in performance. The parabolic nature of self-selected pacing strategies in rowing performance suggests that there is some premature development of fatigue and a consequent reduction in velocity and a failure to maintain an even pace, particularly in rowers below an elite level (Muehlbauer et al., 2010). However, as rowing is an extended event there is also likely to be a complex integration of both external and internal cues that regulate power output, such as is suggested by the Central Governor theory. The Central Governor theory provides a fuller consideration of the processing of how pacing is managed but the effect of the intensity of exercise on fatigue cannot be excluded as the major consideration.

Evidence suggests that a fast start to an event is both beneficial to performance outcomes and it is also likely to speed the oxygen kinetic response. The work of Bailey et al. (2011) indicated that the rate at which $\dot{V}O_2$ increases after the onset of exercise is sensitive to the pattern of work rate imposition, even when the mean rate of work is identical. Therefore a fast start may improve an exercise task by signalling greater aerobic energy supply earlier and thereby preserving anaerobic energy capacity until later in the event. Rationale for why the faster response in $\dot{V}O_2$ kinetics is observed is developed from work by McCreary et al. (1996) and it is likely the increased rate of ATP synthesis through PCr degradation and anaerobic glycolysis is the likely signal that initiates the speed of $\dot{V}O_2$ kinetics.

2.7 Overall summary

Rowing is a unique sport that challenges the human body by the involvement of nearly all the muscle groups during intense dynamic exercise. The metabolic demand of the event ensures that those who are successful have large aerobic capacity, exhibit high absolute strength and a high level of muscular endurance when compared to other endurance athletes.

The description of how these athletes distribute the total work or energy across the 2000 m flat-water course is termed the pacing strategy. This strategy is then described by a pacing profile. It is shown that both on-water and ergometer rowing demonstrate similar pacing profiles but the amplitude of the profile is reduced in ergometer rowing. The amplitudes of profiles in both exercise modes do differ between sexes and between performance levels, however both exercise modes consistently demonstrate a reverse J-shape pacing strategy.

Whilst it is a reverse J-shape pattern that is consistently observed it can be hypothesised that an overall even pace strategy would be more effective. The adoption of an even pace strategy has intuitive appeal as the most economical way to complete 2000 m rowing would be to maintain a mean velocity throughout (Secher, 1983). Theoretical support for this claim is found in mathematical modelling studies of cycling and some limited observation of cycling performance, however to date there is no examination of the effectiveness of an overall even pace strategy in rowing.

The starting phase of the overall pacing strategy is of importance because in parabolic profiles it is the degree of fast start that in part defines its classification as a reverse J-shape pattern. Fast starts are typical for rowing. A fast start is of tactical benefit in on-water performance but this is not true for ergometer rowing. As the reverse J-shape pattern is observed in both exercise modes it suggests that the fast start is an inherent part of the strategy.

Whilst a fast start is tactically advantageous and possibly inherent the considerable power output expended initially is a possible cause of inhibition of output later in the event. An even pace start would have lower levels of anaerobic contribution to the effort and so may be beneficial when attempting to hold an optimum even pace and produce a greater end-spurt, however it may be tactically disadvantageous. There is currently no evidence of the effect of manipulation of starting strategies in rowing on performance outcomes.

Variation in pacing strategies and in particular variation of starting strategies has been shown to influence or mediate physiological response to effort. The underlying mechanisms that regulate the pacing of an event are not clearly understood. In a maximal extended event that has a high intensity start such as rowing the mechanisms of peripheral fatigue are likely to be a major factor in performance. The parabolic nature of self-selected pacing strategies in rowing performance suggests that there is some premature development of fatigue and a consequent reduction in velocity and a failure to maintain an even pace (Muehlbauer et al., 2010). However, as rowing is an extended event there is also likely to be a complex integration of both external and internal cues that regulate power output, such as is suggested by the Central Governor theory.

Evidence suggests that a fast start to rowing is both beneficial to performance outcomes and it is also likely to speed the oxygen kinetic response. The work of Bailey et al. (2011) indicated that the rate at which $\dot{V}O_2$ increases after the onset of exercise is sensitive to the pattern of work rate imposition, even when the mean rate of work is identical. Therefore a fast start may improve an exercise task by signalling greater aerobic energy supply earlier and thereby preserving anaerobic energy capacity until later in the event.

3.0 Method

3.1 Participants

Nineteen rowers volunteered to participate in this study. Five male and one female rower provided data for analysis of effects. All participants were recruited from the greater Auckland region and were competitive rowers in club and Regional Performance Centre competition. The sample chosen was a convenience sample and included both open weight and lightweight classifications of rower.

The study was approved by Massey University Human Ethics Committee: Southern A (application 09/14). All participants gave written informed consent and completed a Health Screening Questionnaire prior to commencement of the study. The Health Screening Questionnaire assessed current health status, prior medical issues and any medication taken. Participants who reported current or previous medical conditions that contraindicated them from taking part in the study were excluded. Smokers, or those taking prescription or recreational drugs were also excluded from this study.

Participants were asked to keep a food diary for the two days prior to the first testing session so a similar food intake could be followed in the two days prior to the testing sessions. A 3-hr fast was observed before any testing. Participants were also asked to refrain from hard training sessions for the 24 hr prior to any testing. These requests were to ensure participants came to each trial in the same nutritional and prior-exercise status.

3.2 Experimental overview

The participants attended four separate testing sessions to complete the study (Figure 3.1). Each testing session was separated by a minimum of 1 week. Testing sessions 1 and 2 provided familiarisation to the participant of the methods utilised in the study and also provided measurement of the habitual self-selected pacing strategy that was used as baseline data for subsequent calculation of pacing manipulation and comparison of $\dot{V}O_2$. Testing session 1 also served to provide performance data for the rower and coach. Testing sessions 3 and 4 were pacing manipulation trials.

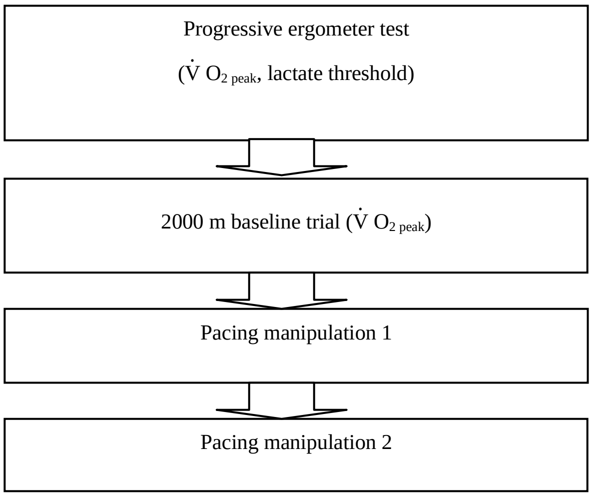

Figure 3.1 Sequence of trials

During all testing sessions $\dot{V}O_2$ (ml·kg^{-1}·min^{-1}) was calculated from absolute $\dot{V}O_2$ to allow comparison within the sample. Heart rate (beat·min^{-1}), and blood lactate (mmol·L^{-1}) was measured and recorded. Rowing ergometer data was also recorded and included total time (min: s), time per sector (min: s), pace per 500 m (min: s·500 m^{-1}), and power output (W). Laboratory environmental conditions, including ambient temperature and pressure were also measured and recorded.

3.2.1 Research design and independent variables

A within-group design was used with 6 participants completing all trials. Independent variables of habitual self-selected start pace, even start pace strategy and fast start pace strategy were manipulated with dependent variables of overall time, work completed, $\dot{V}O_2$, heart rate (HR) and blood lactate for 2000 m ergometer rowing. Each independent variable has within it 20 levels that represent 100 m sectors of the total 2000 m distance.

3.2.2 Rowing ergometer

All rowing simulation was performed on the same Concept II rowing ergometer (model D, Morrisville, USA). All participants had previously used this model of ergometer for both indoor training and performance evaluation. The Concept II is a wind-braked rowing ergometer, providing a fixed resistance and requires no calibration. A damper lever adjusts the degree of wind braking and variation in setting affects simulated drag. The setting for the damper lever is governed in performance evaluation by the specific weight classification of rower (Hahn, Bourdon, & Tanner, 2000). The damper level for each classification of rower and the resultant drag factor recorded in this study is shown (Table 3.1). In order for data to be of value to rower and coach, a decision was made to adhere to performance evaluation protocols for the damper level settings in this study.

Minor variation of drag can occur between testing sessions, dependent on environmental factors. To control this, drag factor was checked through display on the performance monitor of the rowing ergometer (model PM4, Concept II, Morrisville, USA). Damper levels were then adjusted appropriately and drag factor recorded prior to every test to maintain consistency across trials.

Table 3.1 Recommended damper level settings for category of rower (Hahn et al., 2000)

Category	Damper Lever Setting	Resultant Drag Factor	Mean (±SD) recorded drag factor
Open weight female	3	106	106 (0.58)
Lightweight male	3	106	106 (2.48)
Open weight male	4	115	121 (2.65)

Testing well-trained rowers in performance of a 2000 m time trial with the Concept II has been shown to have variability of performance for individual rowers, when expressed as a coefficient of variation, of 2.0% and a test re-test correlation of 0.96 (Schabort et al., 1999). These values indicate that the combination of ergometer, athlete and test protocol are suitable for investigating factors that affect performance in short, high-intensity endurance events.(Schabort et al., 1999)

Prior to any testing the rowing ergometer chain was checked for cleanliness, functionality and oiled. The rowing ergometer slide was also cleaned and checked so that the seat was able to move freely. The rowing ergometer was secured to the floor to prevent slippage during trials. A cooling fan was provided for all trials.

All rowing ergometer data was recorded on a data card and downloaded post trial from the performance monitor.

3.3 Procedures

3.3.1 Testing session 1

The purpose of this testing session was an initial familiarisation of the testing procedures for the participant. The session was a progressive rowing ergometer test to establish $\dot{V}O_{2peak}$. It also provided performance data for the rower and coach by establishment of workloads and HR corresponding to lactate and anaerobic thresholds and the relationship of blood lactate to workload.

The testing session also included specific familiarisation for the participant of the rowing ergometer and collection of expired air using a gas analyser (Metamax 3B. Cortex Biophysik GmbH, Leipzig, Germany). Prior to any testing the gas analyser was calibrated using known gases, ambient air and known volume and prepared for use. The Metamax 3B gas analyser has been shown to provide reliable measurements of metabolic demand with adequate validity for field-based measurements (Vogler, Rice, & Gore, 2010).

On arrival at the laboratory, for all testing sessions, participants were asked to confirm that no changes in health status, as assessed by completion of a Health Screening Questionnaire, had occurred prior to arrival. Height was measured as stretch stature with the measurement taken as the maximum vertical distance from the floor to the vertex of the head, with the head held in the Frankfort plane. The participant was barefoot, standing erect with heels together. Measurement was made with a retractable metal tape stadiometer and measurement read to the nearest 0.01 m. Body mass was measured using a beam-type balance (Seca, Hamburg, Germany) and recorded to the nearest 0.1 kg. Participants were barefoot and weighed in rowing clothing. Calibration of the weighing machine was carried out prior to measurement using reference weights of known mass.

Prior to the commencement of testing, participants were fitted with a HR transmitter belt (Suunto, Vantaa, Finland) that transmitted signals to the performance monitor for HR measurement. Data including HR was downloaded from the performance monitor for the progressive rowing ergometer test. The PM4 monitor records the heart rate at the end of interval work period (S Hamilton, personal communication, October 23 2012). For all testing sessions the participant was asked to adjust the rowing ergometer for fit. They then were asked to sit still on the rowing ergometer for 5-min and HR was measured and recorded throughout the 5th min.

Blood lactate was measured at rest and 5th min of the test using a Lactate Pro portable blood lactate analyser (Accusport, Boehringer Mannheim, Germany). The Lactate Pro has been used with elite athletes under a range of outdoor and indoor testing conditions and is accurate, reliable and exhibits a high degree of agreement with other lactate analysers (Pyne, Boston, Martin, & Logan, 2000). All blood lactate measurements adhered to previously established procedures (Sleivert & Nicholson, 1997). The sampling site for all blood lactate measurements was the finger.

3.3.2 Progressive rowing ergometer test

The progressive rowing ergometer test is a performance evaluation test based on 4 min increments with a maximum of seven stages (Hahn et al., 2000). The stages were separated by 1 min recovery intervals. The test protocol was individualised on the basis of work capacity (Hahn et al., 2000).

Individualisation of the test protocol was determined by ascertaining the best time for 2000 m from each participant. As per the protocol determined by Hahn et al (2000) this time was then converted to a pace for 500 m. Addition of 4 s per 500 m to this base pace gives the targeted pace the rower was required to maintain in the sixth stage of the test. Successive amounts of 6 s·500 m^{-1} were then added to the pace derived initially to calculate the required pace for earlier workloads. Workload at stage 7 is maximal and the participant is asked to maintain the fastest possible pace for the full 4 min period. An example of individualisation for a lightweight male rower with a best time for 2000 m ergometer rowing of 06:36:0 (min:s) is shown (Table 3.2).

Table 3.2 Example of pacing splits used in progressive rowing ergometer test -lightweight rower with best 2000 m of 06:36:0 (min:s)- (Hahn et al., 2000)

Stage	Duration	Target split	Target metres
1	04:00.0	02:13.0	896
2	04:00.0	02:07.0	938
3	04:00.0	02:01.0	984
4	04:00.0	01:55.0	1034
5	04:00.0	01:49.0	1091
6	04:00.0	01:43.0	1154
7	04:00.0	No target split or metres as stage is maximal and the participant is asked to maintain the fastest possible pace for the 4 min period	

Once each individual sector time was calculated for workloads 1-6 they were recorded and displayed at eye level from the rowing ergometer for the participant to refer to during the test. Participants were also provided with target metre splits, should that be their preference for pacing. Participants were allowed to alter the display mode on the performance monitor as to their own preference of display.

No warm up was allowed prior to beginning the progressive rowing ergometer test so that accurate reflection of lactate against workload could be measured. The test is designed to begin at a relatively low workload individualised for each participant and this acted as a warm-up period. Finger prick blood lactate samples were taken at the end of every 4 min stage. The participant then began the test. Adherence to the targeted workload was monitored with similar verbal encouragement given to all participants. Blood lactate was also measured and recorded within 1 min of termination of the test.

Data from the gas analyser for all testing sessions was exported to a Microsoft Excel spread sheet, with 15 s smoothing of sampling. Determination of $\dot{V}O_{2peak}$ in all testing was determined by the mean of the 4 highest consecutive data points. Lactate and anaerobic threshold was calculated as per Lactate-E software (Newell et al., 2007). This software allows determination of lactate threshold as per the Dmax method proposed by Cheng et al (1992).

3.3.3 Testing session 2

The purpose of this testing session was to conduct a second familiarisation of the testing procedures, rowing ergometer and use of gas analysers. It also served to provide baseline data of the habitual self-selected pacing strategy from which the specific calculation of the starting strategies was made.

Participants were instructed for the 2000 m baseline trial and both consequent pace manipulation trials to complete a 10 min self-selected warm-up that also included stretching. Participants were asked to repeat this warm up in consequent trials to maintain consistency. Warm up was not controlled so that participants would provide representative self-selected pacing strategy in this trial. Other preparation of the participant for this and subsequent pacing manipulation trials was as per the progressive rowing ergometer test.

Prior to and throughout the baseline trial the performance monitor was covered to show only distance remaining to the participant. No time or other performance data was shown or visible to the participant. No verbal encouragement was given at any point during the test.

Blood lactate was measured and recorded within 1 min of termination of the 2000 m baseline and pacing manipulation trials.

Downloaded data from the performance monitor for all the 2000 m baseline and pacing manipulation trials was averaged over 100 m sectors. Data from the gas analyser for this and subsequent pacing manipulation trials was as per the progressive rowing ergometer test.

3.3.4 Testing session 3 and 4

The purpose of this testing session was to manipulate the first 500 m pacing strategy to either an even start pace strategy or fast start pace strategy. Specific calculation of pace for either a fast start or even start was based upon the mean velocity of the previous baseline test. The even paced starting strategy was calculated as the mean overall velocity of the baseline 2000 m trial. The fast paced starting strategy was calculated as the mean overall velocity of the first 500 m in the baseline 2000 m trial plus 10%. The value of plus 10% was chosen to ensure a faster than self selected starting pace was used. This was based on work by Mulherbauer et al, (2010) and Brown et al, (2010) who found that elite and sub elite rowers tended to show a variance of ~5% and ~8.5% normalised mean velocity normalised mean velocity difference between fastest and slowest sectors on-water respectively.

Participants were allocated to either the fast start or even start pace condition. Participants were randomised by coin toss. However due to such a large drop out of participants from the 4th subject allocation to condition was made to ensure counter balance. The order of trials was counterbalanced for the whole sample. The remaining 1500 m of the 2000 m rowing ergometer test was to be completed in as quick a time as possible. A schematic of the trial is presented (Figure 3.2).

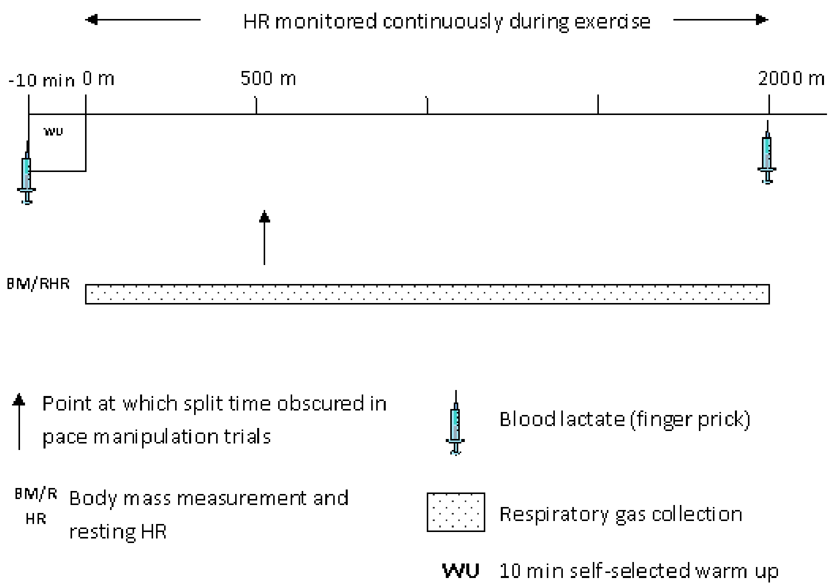

Figure 3.2 Schematic of pacing manipulation trials (testing sessions 3 and 4)

Throughout both the even pace and fast pace initial 500 m of the trials, the only data visible to the participant from the performance monitor was distance remaining and pace per 500 m. After the initial 500 m had been completed the information on the performance monitor was obscured to only show distance remaining from 2000 m. No time or other performance data was shown or visible to the participant. No verbal encouragement was given at any point during the test.

3.4 Data analysis

Where data has been downloaded from the PM4 performance monitor a 100 m sector value is obtained. This includes data for normalised velocity, power and heart rate. Where appropriate to replicate typical performance data of on-water rowing, data has been averaged over 500 m splits. Raw gas analysis data was downloaded with a 3 second sampling setting and due to the difficulty of maintaining reliability to a range of performance times this data was averaged over the 500 m split time for each participant.

Velocity data was normalised as per the method of Garland (2005). The normalisation of data allows comparison of profiles over the whole range of finishing times. The method of normalisation was that data downloaded from the performance monitor was averaged for velocity per 100 m sector. This was then expressed as a percentage velocity relative to the mean velocity for the whole trial.

Analysis of data was carried out using a GLM with repeated measures. Where analysis revealed a significant difference pair wise comparison was made using Fisher's LSD to determine the origin of such effects. Sector comparisons of power was analysed by paired *t*-test. Decision on test selection and assumption checking was carried out as per the method of Atkinson (Atkinson, 2002).

Where appropriate, analysis of data was carried out using a one way ANOVA. Where analysis revealed a significant difference pair wise comparison was made using Fisher's LSD to determine the origin of such effects. Where the assumption of sphericity had been violated the Greenhouse-Geisser correction was applied.

Whilst typically post hoc testing is done where p is significant, where p approached significance in planned comparisons exploratory post hoc testing occurred.

Effect size was calculated using means and standard deviations to provide Cohen's d and the effect-size correlation. Thresholds of small, moderate and large effect sizes were 0.20, 0.50 and 0.80 respectively. All data are presented as mean ± SD. Statistical significance was accepted when $P<0.05$.

4.0 Results

4.1 Subject characteristics

The initial recruitment and subsequent retention of participants in the study is shown (Table 4.1). Six participants provided data for analysis of effects.

Table 4.1 Participant completion of each trial

Progressive rowing ergometer test	**2000 m baseline**	**2000 m even pace start**	**2000 m fast start**
n=19	*n*=8	*n*=6	*n*=6

Descriptive statistics of participants is shown (Table 4.2).

Table 4.2 Mean (SD) participant characteristics

Participants (*N*=6)	**2000 m time (min : s)**	**Age (year)**	**Height (m)**	**Weight (kg)**	**$VO_{2\ peak}$ ($l \cdot min^{-1}$)**	**$VO_{2\ peak}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)**
Open weight female (*n*=1)	07:28.0	23	175.0	64.0	3.93	61.41
Lightweight male (*n*=2)	06:36.0 (0.0)	26 (2.8)	178.0 (1.4)	74.0 (1.4)	4.86 (0.2)	65.78 (3.3)
Open weight male (*n*=3)	06:14.0 (3.4)	24 (5.2)	192.0 (2.6)	97.0 (7.9)	5.77 (0.3)	59.74 (5.1)
***Mean* (*N*=6)**	06:33.0 (32.2)	24 (3.7)	184.5 (8.5)	83.8 (15.7)	5.16 (0.8)	62.03 (4.6)

4.2 Performance variables

4.2.1 Overall time

Overall time to complete 2000 m is shown (Figure 4.1). No significant effect of treatment was found in the overall time to complete 2000 m ergometer rowing ($F_{1,\,2}$ =1.127; P=0.362). Assessment of overall time for practical significance using pairings of baseline to even pace condition and baseline to fast pace condition showed zero or near zero effect in both pairings (Cohen's *d* =0.12, 0.10).

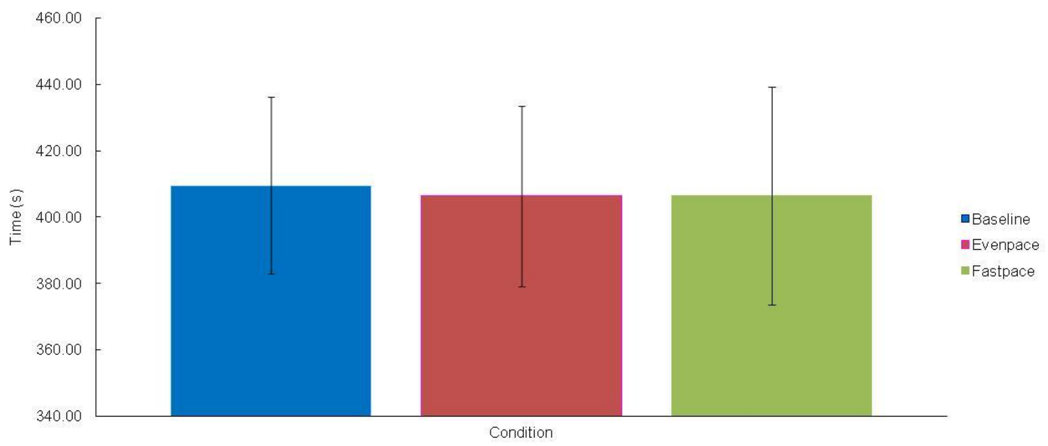

Figure 4.1 Mean overall time 2000 m ergometer rowing (n=6)

However examination of data indicated that wide variance was attributable to data from an open weight female rower. Exclusion of this data and subsequent analysis showed a main effect that approached significance ($F_{1,\,2}$ = 4.161; P=0.058). Post hoc analysis showed significant difference (P=0.041) between baseline (399.22 ± 8.95 s) and fast pace (393.72 ± 11.61 s) conditions in overall time. Analysis of reduced data for practical significance resulted in a small effect in baseline to even pace condition (Cohen's *d* =0.40) and a moderate effect in baseline to fast pace condition (Cohen's *d* =0.59). Overall time to complete 2000 m *(n=5)* is shown (Figure 4.2).

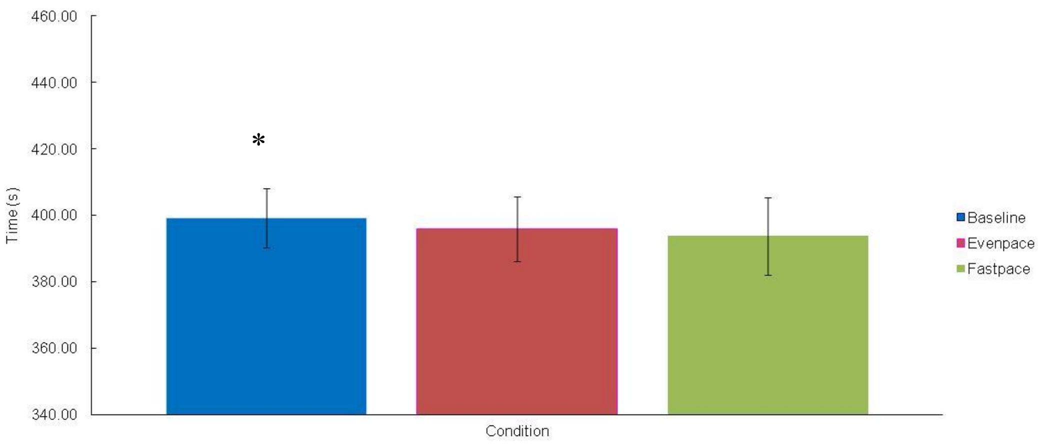

Figure 4.2 Mean overall time 2000 m ergometer rowing (n=5)* P < 0.05, baseline versus fast pace time trials.

4.2.2 Mean overall power

Mean overall power for completion of 2000 m is shown (Figure 4.3). No significant effect of treatment was found in the mean overall power in completion of 2000 m ergometer rowing ($F_{1,2}$ =2.695; P=0.116). Analysis did indicate that data approached significance (P=0.116) however post hoc analysis showed no significant difference (P=0.127) between baseline (329.17 ± 21.65 W) and fast pace (343.43 ± 68.00 W) conditions and no significant difference (P=0.132) between baseline (329.17 ± 21.65 W) and even pace (340.33 ± 57.92 W) conditions. Assessment for practical significance of baseline to even pace condition showed a small effect (Cohen's *d =0.22*). Assessment of baseline to fast pace condition also showed a small effect (Cohen's *d =0.25*).

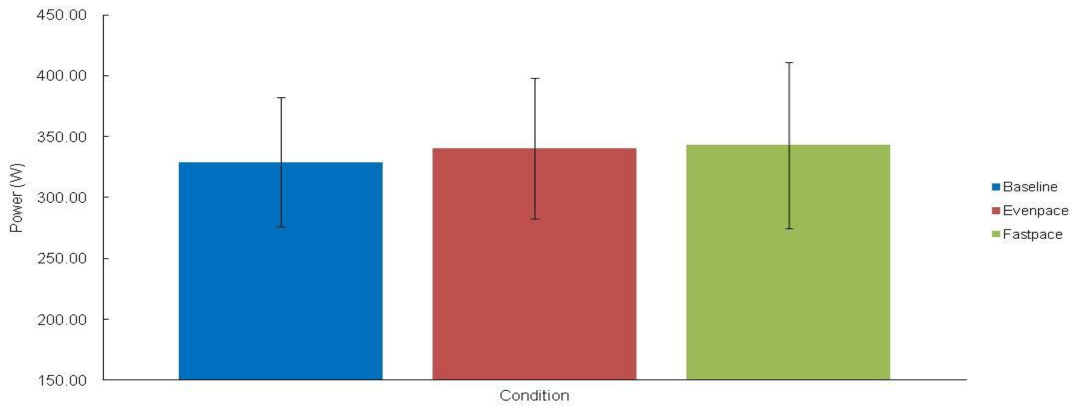

Figure 4.3 Mean overall power 2000 m ergometer rowing (n=6)

As previously noted, exclusion of data of the open weight female rower with subsequent analysis resulted in a significant main effect ($F_{1,2}$ =4.841; P=0.042). Post hoc analysis showed that the fast pace condition had significantly (P=0.048) higher mean overall power (368.4 ± 30.68 W) when compared to baseline (349.4 ± 21.13 W). Mean overall power for completion of 2000 m (*n*=5) is shown (Figure 4.4). Assessment for practical significance found a large effect in baseline to fast pace condition (Cohen's *d* =0.81) and a moderate effect in baseline to even pace condition (Cohen's *d* =0.60).

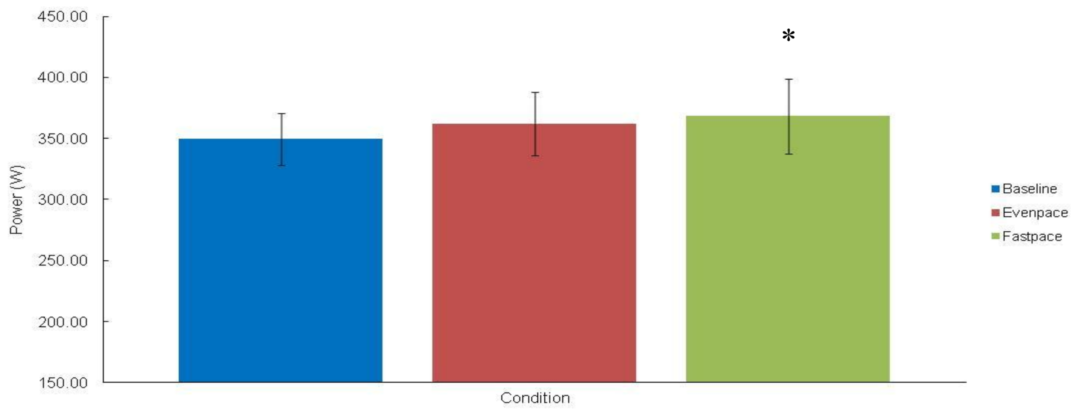

Figure 4.4 Mean overall power 2000 m ergometer rowing (n=5) * P < 0.05, fast pace versus baseline time trials.

4.3 Pacing

4.3.1 Normalised mean velocity

No significant effect was found in the normalised mean velocity between the conditions ($F_{1, 2}$ = 0.746; P=0.499). A significant effect of time ($F_{3, 19}$ = 7.786; P<0.001) was found and there was also a significant interaction of time*treatment ($F_{3, 38}$ = 13.615; P<0.001). Normalised mean velocity in completion of 2000 m is shown (Figure 4.5).

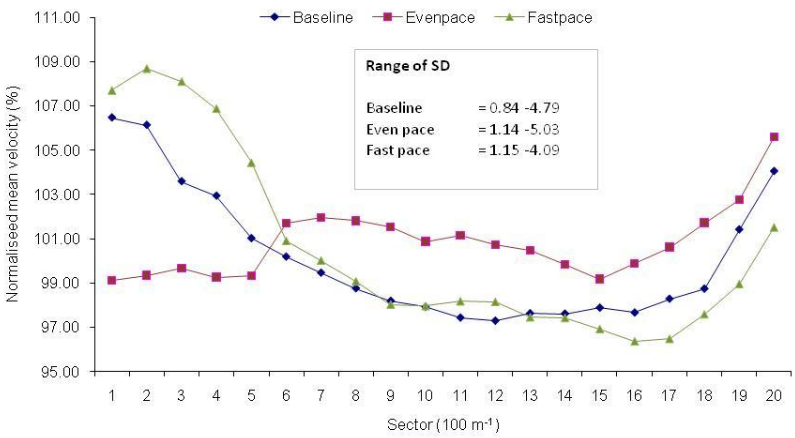

Figure 4.5 Normalised mean velocity 2000 m ergometer rowing

Overall pacing strategy is normally described by time or velocity. The normalised mean velocity allows the description of the pacing strategy, however as the velocity at any given point is as a result of the pacing which can be described by power expended, detailed analysis of sectors within the 2000 m ergometer rowing will be carried out on the power distribution data only.

4.3.2 Power distribution

No significant effect was found in the power distribution between the conditions ($F_{1, 2}$ = 2.743; P=0.112). A significant effect of time ($F_{3, 19}$ = 7.786; P<0.001) was found and there was also a significant interaction of time*treatment ($F_{3, 38}$ = 13.615; P<0.001). Power distribution in completion of 2000 m is shown (Figure 4.6). However, as was previously identified analysis of data with exclusion of the open weight female did then produce a significant treatment effect ($F_{1, 2}$ = 4.584; P=0.047). Post hoc analysis of pair wise comparisons for treatment identified significant difference (P=0.040) in baseline to fast pace condition.

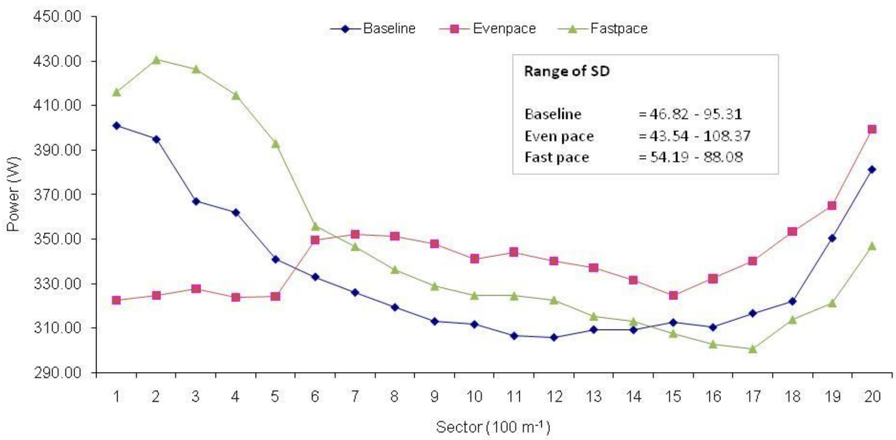

Figure 4.6 Power distribution 2000 m ergometer rowing (n=6)

In order to identify specific 100 m sectors where significant difference occurs between conditions paired *t*-tests were carried out between each sector in each pairing of condition. Where significant difference was found this has been presented (Table 4.3, table 4.4, and table 4.5).

Table 4.3 Sector comparison - baseline to even pace

Sector	Baseline (W)	Even pace (W)	*t*	df	Sig
1	400.83 ± 78.81	322.50 ± 48.50	4.773	5	0.005
2	394.67 ± 58.78	324.67 ± 47.02	4.737	5	0.005
3	366.83 ± 52.54	327.50 ± 45.30	4.084	5	0.010
4	361.83 ± 63.74	323.67 ± 44.88	3.180	5	0.025
6	333.00 ± 49.90	349.67 ± 59.00	-2.585	5	0.049
7	326.00 ± 49.49	352.17 ± 59.40	-4.434	5	0.007
8	319.33 ± 50.76	351.17 ± 62.07	-3.197	5	0.024
9	313.00 ± 47.25	347.83 ± 57.54	-2.938	5	0.032
11	306.50 ± 46.82	344.17 ± 60.13	-3.004	5	0.030
12	305.83 ± 48.96	340.00 ± 58.96	-3.938	5	0.011
13	309.33 ± 52.67	337.00 ± 56.22	-4.107	5	0.009
14	309.17 ± 51.65	331.33 ± 57.88	-3.640	5	0.015
15	312.50 ± 56.17	324.50 ± 54.94	-2.798	5	0.038

Table 4.4 Sector comparison - baseline to fast pace

Sector	Baseline (W)	Fast pace (W)	*t*	df	Sig
2	394.67 ± 58.78	430.67 ± 61.60	-4.268	5	0.008
3	366.83 ± 52.54	426.50 ± 55.88	-11.148	5	<0.001
4	361.83 ± 63.74	414.67 ± 67.97	-9.184	5	<0.001
5	340.83 ± 51.52	393.00 ± 81.02	-4.067	5	0.010
19	350.33 ± 77.95	321.33 ± 62.94	3.625	5	0.015
20	381.17 ± 95.31	347.00 ± 83.20	5.092	5	0.004

Table 4.5 Sector comparison – even pace to fast pace

Sector	Even pace (W)	Fast pace (W)	*t*	df	Sig
1	322.50 ± 48.50	416.17 ± 70.57	-7.358	5	0.001
2	324.67 ± 47.02	430.67 ± 61.60	-8.048	5	<0.001
3	327.50 ± 45.30	426.50 ± 55.88	-8.995	5	<0.001
4	323.67 ± 44.88	414.67 ± 67.97	-6.608	5	0.001
5	324.17 ± 43.54	393.00 ± 81.02	-3.785	5	0.013
13	337.00 ± 56.22	315.33 ± 69.00	3.368	5	0.020
14	331.33 ± 57.88	313.00 ± 66.06	3.487	5	0.018
15	324.50 ± 54.94	307.67 ± 61.72	3.009	5	0.030
16	332.17 ± 64.22	302.83 ± 58.83	2.73	5	0.041
17	340.00 ± 66.85	300.67 ± 54.19	3.596	5	0.016
18	353.33 ± 79.85	313.83 ± 61.60	3.474	5	0.018
19	365.00 ± 84.29	321.33 ± 62.94	2.925	5	0.033
20	399.33 ± 108.37	347.00 ± 83.20	3.242	5	0.023

4.3.3. Pacing strategy - baseline

The overall pacing strategy of each condition as described by mean power for each 500 m is presented (figure 4.7).

In the baseline condition significant differences were found between 500 m sectors, however the assumption of sphericity had been violated and the Greenhouse-Geisser correction applied ($F_{1, 1.445}$ = 8.995; P=0.014). Post hoc analysis showed that the baseline condition had significantly (P=0.013) higher mean power per 500 m sector 1 (373.2 ± 60.10 W) when compared to sector 2 (320.5 ± 48.85 W) and sector 3

(P=0.017) (308.7 ± 51.19 W). Significantly (P=0.023) higher mean power per 500 m was identified in sector 4 (336.2 ± 69.53 W) when compared to sector 3 (308.7 ± 51.19 W).

4.3.4. Pacing strategy – even pace

In the even pace condition no significant difference ($F_{1, 3} = 0.028$; P=0.062) was found between each 500 m sector, however post hoc analysis showed that the mean power per 500 m in sector 1 (324.3 ± 45.61 W) was significantly (P=0.044) lower when compared to sector 2 (348.3 ± 58.58 W). No other significant difference was found in the even pace condition.

4.3.5. Pacing strategy – fast pace

In the fast pace condition significant differences were found between 500 m sectors ($F_{1, 3} = 28.435$; P<0.001). Post hoc analysis showed that the fast pace condition had significantly (P=0.003) higher mean power per 500 m sector 1 (416.2 ± 66.54 W) when compared to sector 2 (338.3 ± 78.45 W), sector 3 (P=0.003) (316.5 ± 67.69 W) and sector 4 (P=0.001) (317.3 ± 63.33 W). Significantly (P=0.046) higher mean power per 500 m was identified in sector 2 (338.3 ± 78.45 W) when compared to sector 4 (317.3 ± 63.33 W).

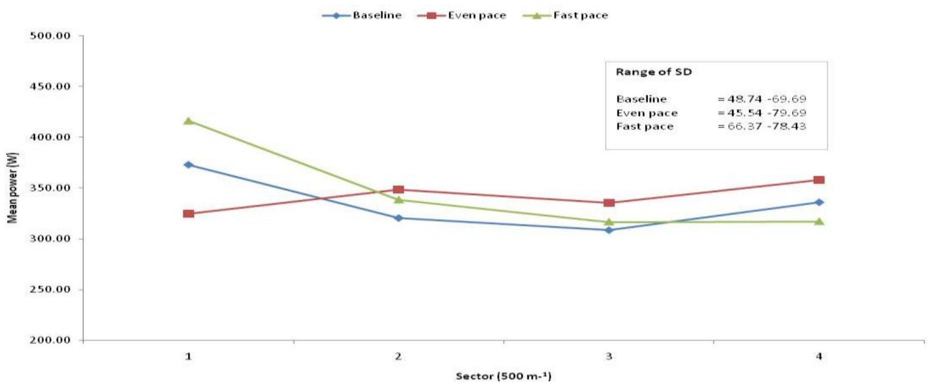

Figure 4.7 Pacing strategy as per mean power per 500 m sector in 2000 m ergometer rowing

4.4 Physiological effects

4.4.1 Post trial blood lactate

Post-trial blood lactate is shown (Figure 4.8). No significant effect of treatment was found in the Post trial blood lactate on completion 2000 m ergometer rowing ($F_{1, 2}$ =2.137; P=0.169).

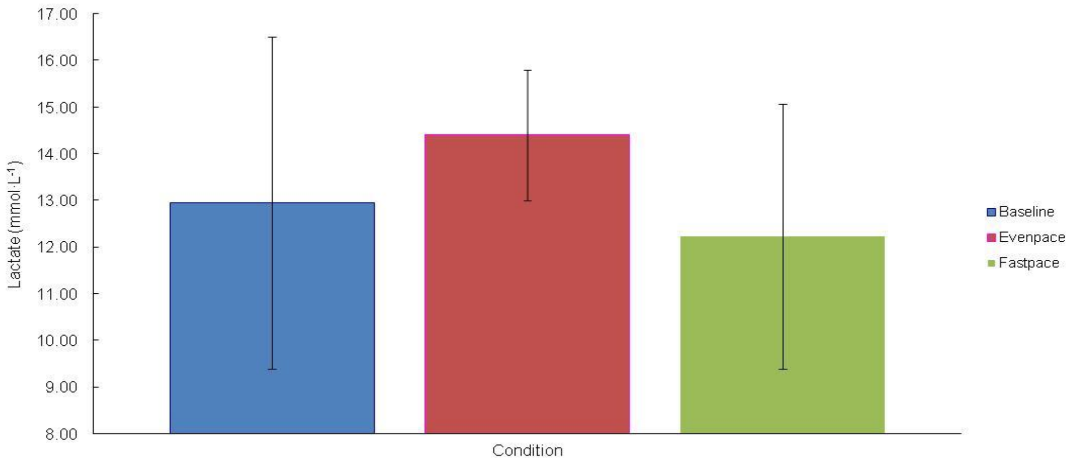

Figure 4.8 Post-trial blood lactate - 2000 m ergometer rowing

4.4.2 Heart rate

Heart rate for 2000 m ergometer rowing is shown (Figure 4.9). No significant effect was found in heart rate between the conditions ($F_{1, 2}$ = 1.507; P=0.268). A significant effect of time ($F_{3, 19}$ = 66.736; P<0.001) was found and there was also a significant interaction of time*treatment ($F_{3, 38}$ = 32.452; P<0.001).

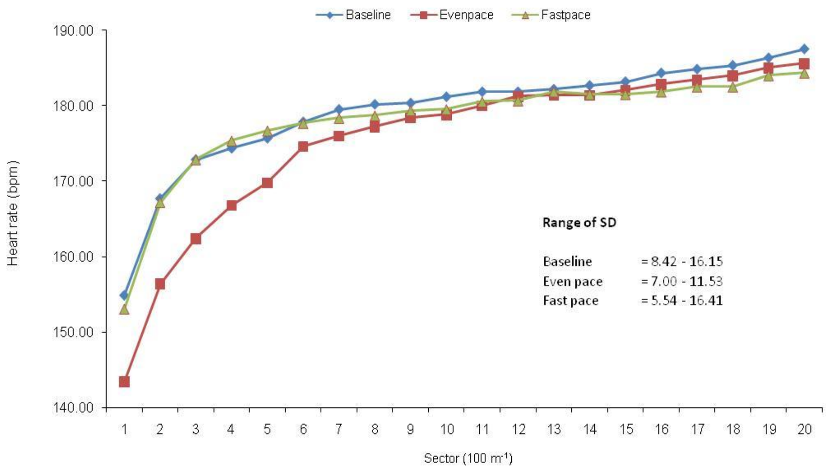

Figure 4.9 Heart rate - 2000 m ergometer rowing

4.4.3 Oxygen uptake response

Oxygen uptake response for 2000 m ergometer rowing is shown (Figure 4.10). No significant effect was found between the conditions ($F_{1, 2} = 0.505$; P=0.618). A significant effect of time ($F_{3, 19} = 56.022$; P<0.001) was found. No significant interaction of time*treatment was found ($F_{3, 6} = 2.095$; P<0.083).

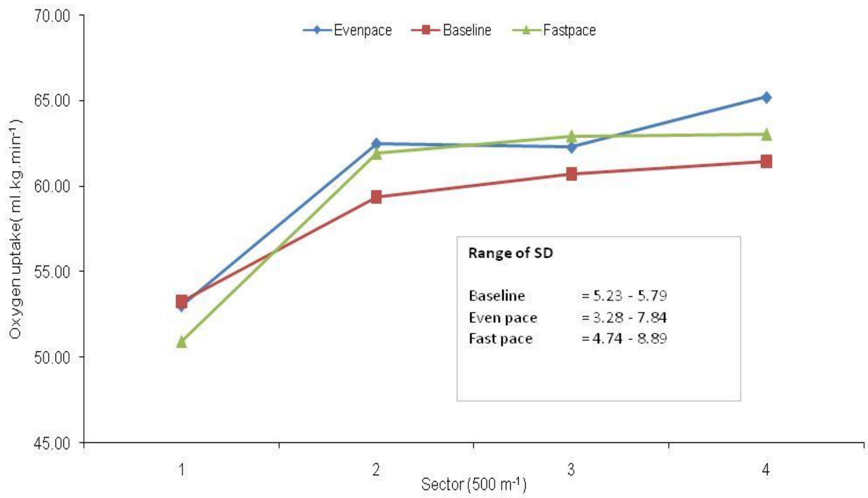

Figure 4.10 Oxygen uptake response - 2000 m ergometer rowing

5.0 Discussion

The aim of this study was to investigate the effect of different starting pace strategies on overall performance and the distribution of metabolic capacity in 2000 m of ergometer rowing. Specifically, it aimed to compare the effects of a fast start and an even pace start, relative to overall mean velocity of baseline, on performance outcomes and compare the physiological responses to those starts.

5.1 Performance outcomes

There is evidence that the null hypothesis of that there is no significant difference in overall time between a fast paced start and an even paced start in 2000 m of ergometer rowing is supported. There was no significant effect on overall time and this would suggest that both a fast start or even paced start can be utilised and a similar end result is still produced.

Hypothetically a fast paced start should produce the fastest overall time, dependent on how well a pace relative to the desired overall mean velocity is held after the starting phase. Examination of the power distribution (figure 4.6) demonstrates that whilst the fast start was significantly greater compared to baseline in the 200, 300, 400 and 500 m sectors no significant difference was then found until 1900 and 2000 m where baseline was significantly greater.

Previous research has described a typical reverse J-shape strategy in both on-water and ergometer rowing (Brown et al., 2010; Garland, 2005; Muehlbauer et al., 2010; Secher, 1983). It would appear that the current degree of fast start used in that strategy allows recuperation of capacity so that an end-spurt greater than that if a fast or near maximal starting strategy is used.

The use of an even paced start should reduce the degree of inhibiting metabolites that cause a drop in velocity during the mid portion of the event, thereby allowing an earlier start and greater degree of end-spurt. Examination of the power distribution (figure 4.6) demonstrates that an even paced start enables significantly greater power output compared to baseline in the mid-portion of the event (600 – 1500 m) but no significant difference from that point was then found. This suggests that there is no significant difference in the final 500 m between an even paced and the habitual strategy.

Both the overall time and mean overall power were analysed for both statistical significance and effect size. With inclusion of all data the degree of effect size would not suggest that use of a different starting strategy would have any substantial impact on performance. This is not only because of the effect size itself but also because, in the case of on-water rowing performance, greater relevance to performance outcomes would come about because of tactical responses to competitors.

A confounding factor with these findings however is the heterogeneity of the sample. Sample size was small ($n=6$) and inclusion of data from a female open weight rower gave wide variance to the findings. It had previously been identified by Muehlbauer et al. (2010) that females demonstrated different pacing strategies to males, possibly tending towards a more even pace. Exclusion of the data from this participant did alter the findings both statistically and in effect size. Notable was the change in effect size from Cohen's d =0.25 to 0.81 after exclusion of this data. A large effect in mean overall power may have relevance to on-water performance and is likely to have greater relevance in ergometer rowing where tactical influences are less.

5.1.1 Pacing strategy

Examination of the overall pacing strategy using mean power per 500 m sector demonstrated that the baseline condition demonstrated a typical reverse J-shape strategy (figure 4.7). Significant differences in mean power of sectors 1 to 2 and 3 showed a fast start, however sector 4 was only greater than 3 and not 2. Male crews would typically show faster and therefore greater power in sector 4 compared to sectors 2 and 3 (Muehlbauer et al., 2010). Again this suggests that the pacing strategy of the baseline trial was slightly altered to what was expected, possibly due to the female open weight rower.

The even pace start showed a significant increase in pace in sector 2 compared to sector 1. This is of note as it would indicate that rowers prefer a fast start rather than a more controlled pacing.

The pacing strategy of the fast start was as expected with significantly greater power in sector 1 when compared to 2, 3 and 4. There was no significant difference but the values of mean power in sectors 3 and 4 suggest that a fast start inhibits power output in the second half of the event.

5.2 Physiological outcomes

There is evidence that the null hypothesis of that there is no significant difference in the pattern of $\dot{V}O_2$ between a fast paced start and an even paced start in 2000 m of ergometer rowing is supported.

It was hypothesised that rowing adopts a fast start partly due to the effect if has on $\dot{V}O_2$ uptake. The faster start signals a faster $\dot{V}O_2$ uptake thereby sparing anaerobic metabolism contribution to the overall effort (Jones et al., 2008; Whipp et al., 1982). There was no significant treatment effect and no significant interaction effect on $\dot{V}O_2$ uptake.

Closer examination of the data is of interest however. As rowing is weight supported absolute values of $\dot{V}O_2$ are the important measure but to allow comparison amongst a heterogeneous group relative values haven been used. The pattern of $\dot{V}O_2$ uptake in the baseline condition stays below the mean $\dot{V}O_{2peak}$ of the sample (62.03 $ml.kg.min^{-1}$). However in both the even pace and fast pace condition this value is exceeded. The even pace condition shows values higher than the sample mean in sectors 2, 3 and 4. The fast start condition shows values higher than the sample mean in sectors 3 and 4. This would indicate that $\dot{V}O_2$ uptake is sensitive to work rate imposition, as suggested by Bailey et al. (2011).

5.2.1 Post-trial blood lactate and heart rate

No significant findings were made in regard to post-trial blood lactate or heart rate. Blood lactate did not show significant difference however any difference would have been likely as a result of the timing of sampling and the pattern of previous effort to the sample. The higher values seen in the even pace trial are likely a result of the greater end-spurt in that condition.

No significant effect for heart rate for 2000 m ergometer rowing was found but as could be expected a significant effect of time ($F_{3, 19}$ = 66.736; $P<0.001$) was found. The lower intensity of the even paced start is reflected in lower heart rate response in the first 500 m. Whilst the end spurt was greater in the even pace trial, heart rate is highest for the baseline.

5.3 Experimental limitations

This study is limited in its findings for a number of reasons. These reasons include;

- High dropout rate of participants. A priori analyses suggested a sample size of 24 would be required to examine performance changes between each condition. Initial participant recruitment was positive however the dropout from the initial incremental test to later trials was high. Resulting in a sample size insufficient to examine performance changes. No clear reason can be determined for the drop out rate however feedback from participants indicated that there is a reluctance to complete maximal 2000 m rows unless specifically for squad selection.
- Heterogeneity of the sample. Due to the low retention of initial participants the sample that provided data was very heterogeneous. Differences in performance variables between light weight and open weight males were not as great as between open weight females and open weight males.
- Learning effect. The design of the study may have elicited a learning effect. The initial test was a incremental test to establish peak oxygen uptake which was then followed by the baseline trial. Higher reliability of baseline may have been established with at least one further baseline 2000 m trial.
- Use of the Concept II ergometer. It was highlighted that performance on the rowing ergometer tends to be muted when compared to on-water performance (Garland, 2005). Greater ecological validity and more direct application of findings around pacing strategy would come from use of on-water performance.

- Variance in warm up routine. Participants were allowed to use their own normal warm up routine prior to each trial. Whilst the same routine was repeated prior to each trial, variance in the timing, intensity and starting point following completion of the warm up may have influenced physiological response.
- Matching of $\dot{V}O_2$ data to performance data. The averaging of $\dot{V}O_2$ data across a 500 m split for performance appears to be too crude. Future methodologies should attempt to match data from gas analysis to performance data so that a reliable analysis of 100 m splits can be carried out in the starting phase.

5.4 Recommendations for further research

It is likely that the findings of this study have been confounded by attempting to measure both pacing strategy and physiological variables. It is recommended that further research clearly delineate if the purpose is investigation of pacing and pacing strategy or the physiological variables that in some way may regulate or mediate pacing.

Analysis of data did highlight that in certain variables an effect was found. Using effect size rather than statistical significance is likely to be a more productive approach when examining sports performance research. However in a sport such as rowing where conditions are so variable that the use of time as a performance measure becomes unreliable and therefore defining what would be an effect size that has benefit to performance also becomes unreliable.

The use of the rowing ergometer in combination with experienced rowers provides a reliable platform to examine self-paced performance. Without the inconvenience of gas analysis this combination of testing can provide valuable data around the psychological aspects as well as the performance measures of self-paced performance. Further the investigation of other components of pacing strategy, such as end-spurt could offer further understanding of pacing strategy.

However for the investigation of the physiological variables that may regulate or mediate pacing the inability of the Concept II rowing ergometer to control power creates variability in performance variables. This may be controlled by the use of a homogenous sample and a number of familiarisation trials.

5.5 Practical recommendations

The findings of this study, in particular around pacing strategies may have some practical relevance for coaches in rowing. It is still unclear whether the choice of starting strategy has any effect on overall performance outcome when considering a female crew, however for a male crew a fast start may be of importance. In any recommendation the coach must consider the nature of the crew, the likely water conditions, and possible opposition tactics.

Variance in starting strategy, such as a more even pace may be employed when water conditions are choppy. The resistive force of turbulent water would reduce velocity from the baseline or fast start. An even paced start would allow better judgement as well as metabolic capacity should a more aggressive second half of a race be required. Alternatively when crews are known to respond better from positions of dominance within a race, a fast start strategy may be a viable option.

5.6 Conclusion

The aim of the study was to investigate the effect of different starting pace strategies on overall performance and the distribution of metabolic capacity in 2000 m ergometer rowing. Neither hypothesis of a significant difference in overall time or a significant difference in the pattern of $\dot{V}O_2$ between a fast paced or even paced start in 2000 m ergometer rowing was supported.

It is possible that the small and mixed sample masked potential difference in performance outcomes. It does appear that the $\dot{V}O_2$ response is sensitive to workload imposition however as the duration of rowing can vary between 5.8–7.4 min and $\dot{V}O_{2\ peak}$ is normally attained within the event, any benefit from the faster $\dot{V}O_2$ response in the second and third quarters is unlikely to have significant impact on performance outcomes. With the variable nature of performance athletes would benefit from attempting different starting and pacing strategies about their own performance.

6.0 References

Abbiss, C. R., & Laursen, P. B. (2008). Describing and understanding pacing strategies during athletic competition. *Sports Medicine, 38*(3), 239-252.

Aisbett, B., Le Rossignol, P., McConell, G. K., Abbiss, C. R., & Snow, R. (2009a). Effects of starting strategy on 5-min cycling time-trial performance. *Journal of Sports Sciences*, *27*(11), 1201-1209. doi:10.1080/02640410903114372

Aisbett, B., Le Rossignol, P., & Sparrow, W. A. (2003). The influence of pacing during 6-minute supra-maximal cycle ergometer performance. *Journal of Science and Medicine in Sport*, *6*(2), 187-198.

Aisbett, B., Lerossignol, P., McConell, G. K., Abbiss, C. R., & Snow, R. (2009b). Influence of All-Out and Fast Start on 5-min Cycling Time Trial Performance. *Medicine and Science in Sports and Exercise, 41*(10), 1965-1971. doi:10.1249/MSS.0b013e3181a2aa78

Åstrand, P.-O., & Shephard, R. J. (2000). *Endurance in sport* (2nd ed.). Osney Mead, Oxford, OX ; Malden, Mass: Blackwell Science.

Atkinson, G. (2002). Analysis of repeated measurements in physical therapy research: multiple comparisons amongst level means and multi-factorial designs. *Physical Therapy in Sport, 3*(4), 191-203. doi:10.1054/ptsp.2002.0123

Bailey, S. J., Vanhatalo, A., Dimenna, F. J., Wilkerson, D. P., & Jones, A. M. (2011). Fast-Start Strategy Improves VO_2 Kinetics and High-Intensity Exercise Performance. *Medicine and Science in Sports and Exercise, 43*(3), 457-467. doi:10.1249/MSS.0b013e3181ef3dce

Billat, L. V., Koralsztein, J. P., & Morton, R. H. (1999). Time in human endurance models - From empirical models to physiological models. *Sports Medicine, 27*(6), 359-379. doi:10.2165/00007256-199927060-00002

Bishop, D. (2003). Warm up II: performance changes following active warm up and how to structure the warm up. *Sports Medicine, 33*(7), 483-498.

Bishop, D., Bonetti, D., & Dawson, B. (2002). The influence of pacing strategy on VO_2 and supramaximal kayak performance. *Medicine and Science in Sports and Exercise, 34*(6), 1041-1047.

Brooks, G. A. (1991). Current concepts in lactate exchange. *Medicine and Science in Sports and Exercise, 23*(8), 895-906.

Brown, M. R., Delau, S., & Desgorces, F. D. (2010). Effort regulation in rowing races depends on performance level and exercise mode. *Journal of Science and Medicine in Sport, 13*(6), 613-617. doi:10.1016/j.jsams.2010.01.002

Corbett, J. (2009). An Analysis of the Pacing Strategies Adopted by Elite Athletes During Track Cycling. *International Journal of Sports Physiology and Performance, 4*(2), 195-205.

de Campos Mello, F., de Moraes Bertuzzi, R. C., Grangeiro, P. M., & Franchini, E. (2009). Energy systems contributions in 2,000 m race simulation: a comparison among rowing ergometers and water. *European Journal of Applied Physiology, 107*(5), 615-619.

de Koning, J. J., Bobbert, M. F., & Foster, C. (1999). Determination of optimal pacing strategy in track cycling with an energy flow model. *Journal of Science & Medicine in Sport, 2*(3), 266-277.

Fitts, R. H. (1994). Cellular mechanisms of muscle fatigue. *Physiological Reviews, 74*(1), 49.

Foster, C. (1994). Pacing strategy and athletic performance. *Sports Medicine, 17*(2), 77-85.

Foster, C., De Koning, J. J., Hettinga, F., Lampen, J., La Clair, K. L., Dodge, C., et al. (2003). Pattern of energy expenditure during simulated competition. *Medicine and Science in Sports and Exercise, 35*(5), 826-831. doi:10.1249/01.mss.0000065001.17658.68

Foster, C., Green, M. A., Snyder, A. C., & Thompson, N. N. (1993). Physiological responses during simulated competition. *Medicine and Science in Sports and Exercise, 25*(7), 877-882.

Fukuba, Y., & Whipp, B. J. (1999). A metabolic limit on the ability to make up for lost time in endurance events. *Journal of Applied Physiology, 87*(2), 853-861.

Garland, S. W. (2005). An analysis of the pacing strategy adopted by elite competitors in 2000 m rowing. *British Journal of Sports Medicine*, *39*(1), 39-42. doi:10.1136/bjsm.2003.010801

Gibson, A. S. C., Lambert, E. V., Rauch, L. H. G., Tucker, R., Baden, D. A., Foster, C., & Noakes, T. D. (2006). The role of information processing between the brain and peripheral physiological systems in pacing and perception of effort. *Sports Medicine*, *36*(8), 705-722.

Hagerman, F. C. (1986). *Applied physiology of rowing*. Belconnen, A.C.T.: Australian Sports Commission.

Hahn, A., Bourdon, P., & Tanner, R. (2000). Protocols for the physiological assessment of rowers. In *In, Gore, C. (ed.), Physiological tests for elite athletes, Champaign, IL, Human Kinetics, 2000, p.311-326.* Australia

Hajoglou, A., Foster, C., De Koning, J. J., Lucia, A., Kernozek, T. W., & Porcari, J. P. (2005). Effect of warm-up on cycle time trial performance. *Medicine and*

Science in Sports and Exercise, 37(9), 1608-1614. doi:10.1249/01.mss.0000177589.02381.0a

Hettinga, F. J., De Koning, J. J., Broersen, F. T., Van Geffen, P., & Foster, C. (2006). Pacing strategy and the occurrence of fatigue in 4000-m cycling time trials. *Medicine and Science in Sports and Exercise, 38*(8), 1484-1491. doi:10.1249/01.mss.0000228956.75344.91

Hettinga, F. J., De Koning, J. J., & Foster, C. (2009). VO_2 Response in Supramaximal Cycling Time Trial Exercise of 750 to 4000 m. *Medicine and Science in Sports and Exercise, 41*(1), 230-236. doi:10.1249/MSS.0b013e3181831f0f

Hettinga, F. J., De Koning, J. J., Schmidt, L. J. I., Wind, N. A. C., MacIntosh, B. R., & Foster, C. (2011). Optimal pacing strategy: from theoretical modelling to reality in 1500-m speed skating. *British Journal of Sports Medicine, 45*(1), 30-35. doi:10.1136/bjsm.2009.064774

Jones, A. M., Wilkerson, D. P., Vanhatalo, A., & Burnley, M. (2008). Influence of pacing strategy on O_2 uptake and exercise tolerance. *Scandinavian Journal of Medicine & Science in Sports, 18*(5), 615-626. doi:10.1111/j.1600-0838.2007.00725.x

Joseph, T., Johnson, B., Battista, R. A., Wright, G., Dodge, C., Porcari, J. P., et al. (2008). Perception of fatigue during simulated competition. *Medicine and Science in Sports and Exercise, 40*(2), 381-386. doi:10.1249/mss.0b013e31815a83f6

Lacour, J. R., Messonnier, L., & Bourdin, M. (2009). Physiological correlates of performance. Case study of a world-class rower. *European Journal of Applied Physiology, 106*(3), 407-413. doi:10.1007/s00421-009-1028-3

Maughan, R. J., & Gleeson, M. (2004). *The biochemical basis of sports performance*. Oxford: Oxford University Press.

McCreary, C. R., Chilibeck, P. D., Marsh, G. D., Paterson, D. H., Cunningham, D. A., & Thompson, R. T. (1996). Kinetics of pulmonary oxygen uptake and muscle phosphates during moderate-intensity calf exercise. *Journal of Applied Physiology, 81*(3), 1331-1338.

Medbo, J. I., & Tabata, I. (1993). Anaerobic energy release in working muscle during 30 s to 3 min of exhausting bicycling. *Journal of Applied Physiology, 75*(4), 1654-1660.

Meur, Y., Hausswirth, C., Dorel, S., Bignet, F., Brisswalter, J., & Bernard, T. (2009). Influence of gender on pacing adopted by elite triathletes during a competition. *European Journal of Applied Physiology, 106*(4), 535-545. doi:10.1007/s00421-009-1043-4

Muehlbauer, T., Schindler, C., & Widmer, A. (2010). Pacing pattern and performance during the 2008 Olympic rowing regatta. *European Journal of Sport Science, 10*(5), 291-296. doi:10.1080/17461390903426659

Newell, J., Higgins, D., Madden, N., Cruickshank, J., Einbeck, J., McMillan, K., & McDonald, R. (2007). Software for calculating blood lactate endurance markers. *Journal of Sports Sciences, 25*(12), 1403-1409.

Nielsen, O. B. (1999). pH after competitive rowing: the lower physiological range? *Acta Physiologica Scandinavica*, *165*(1), 113-114.

Nielsen, O. B., de Paoli, F., & Overgaard, K. (2001). Protective effects of lactic acid on force production in rat skeletal muscle. *Journal of Physiology-London, 536*(1), 161-166. doi:10.1111/j.1469-7793.2001.t01-1-00161.x

Nikolopoulos, V., Arkinstall, M. J., & Hawley, J. A. (2001). Pacing strategy in simulated cycle time-trials is based on perceived rather than actual distance. *Journal of Science and Medicine in Sport, 4*(2), 212-219.

Noakes, T. D. (2011). Is it Time to Retire the AV Hill Model? A Rebuttal to the Article by Professor Roy Shephard. *Sports Medicine, 41*(4), 263-277.

Noakes, T. D., & Gibson, A. S. (2004). Logical limitations to the "catastrophe" models of fatigue during exercise in humans. *British Journal of Sports Medicine, 38*(5), 648-649.

Noakes, T. D., Gibson, A. S., & Lambert, E. V. (2004). From catastrophe to complexity: a novel model of integrative central neural regulation of effort and fatigue during exercise in humans. *British Journal of Sports Medicine, 38*(4), 511-514. doi:10.1136/bjsm.2003.009860

Padilla, S., Mujika, I., Angulo, F., & Goiriena, J. J. (2000). Scientific approach to the 1-h cycling world record: a case study. (vol 89, pg 1522, 2000). *Journal of Applied Physiology, 89*(6), U11-U11.

Pripstein, L. P., Rhodes, E. C., McKenzie, D. C., & Coutts, K. D. (1999). Aerobic and anaerobic energy during a 2-km race simulation in female rowers. *European Journal of Applied Physiology and Occupational Physiology, 79*(6), 491-494.

Pyne, D. B., Boston, T., Martin, D. T., & Logan, A. (2000). Evaluation of the Lactate Pro blood lactate analyser. *European Journal of Applied Physiology, 82*(1), 112-116. doi:10.1007/s004210050659

Schabort, E. J., Hawley, J. A., Hopkins, W. G., & Blum, H. (1999). High reliability of performance of well-trained rowers on a rowing ergometer. *Journal of Sports Sciences, 17*(8), 627-632.

Schenau, G. J. V., De Koning, J. J., & Degroot, G. (1992). The distribution of anaerobic energy in 1000 and 4000 meter cycling bouts. *International Journal of Sports Medicine, 13*(6), 447-451.

Secher, N. H. (1983). The physiology of rowing. *Journal of Sports Sciences, 1*(1), 23-53. doi:10.1080/02640418308729658

Secher, N. H., Espersen, M., Binkhorst, R. A., Andersen, P. A., & Rube, N. (1982). Aerobic power at the onset of maximal exercise. *Scandinavian Journal of Sports Sciences, 4*(1), 12-16.

Secher, N. H., & Volianitis, S. (2009). *Rowing : Olympic Handbook of Sports Medicine*. Retrieved from http://unitec.eblib.com.au/patron/FullRecord.aspx?p=428167

Shephard, R. J. (2009). Is it Time to Retire the 'Central Governor'? *Sports Medicine, 39*(9), 709-721.

Sleivert, G., & Nicholson, R. M. (1997). *An Introduction to Blood Lactate Testing and Blood Sampling Procedures*. Wellington: Sport Science New Zealand.

Spriet, L. L. (1987). Muscle pH glycolytic ATP turnover and the onset of fat (sic). *In, Macleod, D.A.D. (ed.) et al., Exercise: benefits, limits and adaptations, London, E. & F.N. Spon, 1987, p. 85-103., 19870101*

Steinacker, J. M. (1993). Physiological aspects of training in rowing. *International Journal of Sports Medicine, 14,* S3-S10.

Ulmer, H. V. (1996). Concept of an extracellular regulation of muscular metabolic rate during heavy exercise in humans by psychophysiological feedback. *Experientia, 52*(5), 416-420. doi:10.1007/bf01919309

Vogler, A. J., Rice, A. J., & Gore, C. J. (2010). Validity and reliability of the Cortex MetaMax3B portable metabolic system. *Journal of Sports Sciences, 28*(7), 733-742.

Whipp, B. J., Ward, S. A., Lamarra, N., Davis, J. A., & Wasserman, K. (1982). Paramteters of ventilatory and gas exchange dynamics during exercise. *Journal of Applied Physiology, 52*(6), 1506-1513.

Wilberg, R. B., & Pratt, J. (1988). A survey of the race profiles of cyclists in the pursuit and kilo track events. *Canadian Journal of Sport Sciences-Revue Canadienne Des Sciences Du Sport, 13*(4), 208-213.

Appendices

Massey University
COLLEGE OF SCIENCES

INSTITUTE OF FOOD, NUTRITION
AND HUMAN HEALTH
Private Bag 102 904
North Shore Mail Centre
Auckland
New Zealand
T 64 9 443 9770
F 64 9 443 9640
www.massey.ac.nz

Pacing Strategy and Exercise Tolerance in Rowing

PARTICIPANT INFORMATION SHEET

Invitation to Participate in Research Study

My name is Mr. Chris Lynch and I am currently conducting a research study with rowers in order to complete a Masters by dissertation award through Massey University. I am also employed by Unitec as a lecturer in sport.

Rowing is unique in the pattern shown in the pacing strategy when completing 2000m on-water rowing. It demonstrates a fast start and an increase in pace towards the end, relative to the mid section of the race. There is evidence to show that the fast start has a physiological advantage by quickening the contribution of aerobic metabolism to the total energy expenditure. Investigating the fast start strategy and the differences in physiological variables with that start, compared to other starting strategies has implications for rowing and other athletic events of a similar duration and exercise intensity. The specific aim of this study is to investigate different starting pacing strategies in 2000m of simulated rowing.

Participant Recruitment

All participants (male, competitive on-water rowers) will be recruited from within the Greater Auckland area. Smokers, or those taking prescription or recreational drugs are excluded from this study. All participants will be aged between 18 and 35 years old. Approximately 15 participants will be recruited in order to give statistical significance to any findings. From participation in this study you will learn more about your fitness levels when performing 2000m simulated rowing. All participants will be reimbursed for travel expenses with MTA Vouchers.

If you are a student or employee of Massey University or Unitec, participation or non-participation in this study will in no way affect grades, employment status or academic relationships.

Risks/Discomforts of the study include:

- Feeling fatigued following 120 minutes running
- Mild soreness from finger prick sampling
- Dehydration

Project Procedures and Participant Involvement

Before taking part in this study you will also be asked to complete a Heath Screening Questionnaire relating to health status, prior medical issues, and medications taken. This screening questionnaire is used to ascertain information that may conflict with the study, (i.e. if you are taking any medications that may interfere with the outcome of the study), and may ultimately prohibit you from participating. If you have any medical condition listed in the Health

Screening Questionnaire, then we will have to exclude you from taking part. The information obtained on all study questionnaires is strictly confidential and will be used for the purposes of the present study only.

There will be an initial session of preliminary tests during which a lactate threshold and maximal oxygen uptake test will be used to determine your fitness level. On a second visit, and three more subsequent visits, you will be asked to perform 2000m of simulated rowing on a Concept II rowing ergometer (each visit lasting approximately 2-hours); while physiological and perceptual measurements are taken. During the experimental trial you will have respiratory gases collected at pre-determined points. Blood (finger prick method) samples will be collected and used for measuring metabolic and physiological variables and will be disposed of immediately afterwards. A total of 4 finger prick samples are taken during each trial.

Expectations: You will be asked to keep a food diary two days prior to the first trial, then follow the same dietary intake on days prior to the second trial. If testing in the morning, you will be asked to complete a 10-hour overnight fast, prior to the testing. If testing later on during the day, you will be asked to observe a 3-hour fast beforehand.

Individuals trained in resuscitation (NZ Red Cross First Aid, Level 2) will be present for all trials. A defibrillator is available during normal hours at the sport centre on the Unitec campus and the medical centre (adjacent to Building 60 Oteha Rohe) on the Massey University campus, and after hours, by calling security. The researchers will be constantly monitoring physiological and perceptual variables that will aid in identifying any major issues.

All participants will receive a written summary of their personal measures shortly after completion of the three main trials. A written summary of the overall study findings will be provided shortly after completion. Where applicable this information will be provided as an attachment to an e-mail or be sent by post.

Participant's Rights

You are under no obligation to accept this invitation. Should you choose to participate, you have the right to;

- decline to answer any particular question
- withdraw from the study at any time, even after signing a consent form (if you choose to withdraw you cannot withdraw your data from the analysis after the data collection has been completed)
- ask any questions about the study at any time during participation
- provide information on the understanding that your name will not be used unless you give permission to the researcher
- be given access to a summary of the project findings when it is concluded

Confidentiality

All data collected will be used solely for research purposes and has the possibility of being presented in a professional journal. All personal information will be kept confidential by assigning numbers to each participant. No names will be visible on any papers on which you provide information. All data/information will be dealt with in confidentiality and will be stored in a secure location for five years on the Massey University Albany campus. After this time it will be disposed of by an appropriate staff member from the Sport and Exercise Science department.

Project Contacts

If you have any questions regarding this study, please do not hesitate to contact either of the following people for assistance:

Mr Chris Lynch (Lecturer Department of Sport, Unitec)
021 1070 905; clynch@unitec.ac.nz

Dr. Ajmol Ali (Sport and Exercise Division, IFNHH, Massey)
(09)414-0800 ext.41184; a.ali@massey.ac.nz

Dr. Andrew Foskett (Sport and Exercise Division, IFNHH, Massey)
(09)414-0800 ext.41104; a.foskett@massey.ac.nz

Committee Approval Statement
This project has been reviewed and approved by the Massey University Human Ethics Committee: Southern A, Application 09/14. If you have any concerns about the conduct of this research, please contact Professor Julie Boddy, Chair, Massey University Human Ethics Committee: Southern A, telephone 06 350 5799 x 2541, email humanethicsoutha@massey.ac.nz.

Compensation for Injury
If physical injury results from your participation in this study, you should visit a treatment provider to make a claim to ACC as soon as possible. ACC cover and entitlements are not automatic and your claim will be assessed by ACC in accordance with the Injury Prevention, Rehabilitation and Compensation Act 2001. If your claim is accepted, ACC must inform you of your entitlements, and must help you access those entitlements. Entitlements may include, but not be limited to, treatment costs, travel costs for rehabilitation, loss of earnings, and/or lump sum for permanent impairment. Compensation for mental trauma may also be included, but only if this is incurred as a result of physical injury.

If your ACC claim is not accepted you should immediately contact the researcher. The researcher will initiate processes to ensure you receive compensation equivalent to that to which you would have been entitled had ACC accepted your claim.

Participant code

Massey University
COLLEGE OF SCIENCES

INSTITUTE OF FOOD, NUTRITION AND HUMAN HEALTH
Private Bag 102 904
North Shore Mail Centre
Auckland
New Zealand
T 64 9 443 9770
F 64 9 443 9640
www.massey.ac.nz

This consent form will be held for a minimum period of five (5) years

I have read the Information Sheet and have had the details of the study explained to me. My questions have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I understand that I have the right to withdraw from the study at any time and to decline to answer any particular questions.

I agree to provide information to the researcher on the understanding that my name will not be used without my permission. (The information will be used only for this research and publications arising from this research project).

I agree to participate in this study under the conditions set out in the Information Sheet.

Signature: ____

Date___________________

Full Name (printed)

____

Phone Number______________________ **Age** _______________

Date of Birth _________

Address____

____

INSTITUTE OF FOOD, NUTRITION AND HUMAN HEALTH
Private Bag 102 904
North Shore Mail Centre
Auckland
New Zealand
T 64 9 443 9770
F 64 9 443 9640
www.massey.ac.nz

Pre-Exercise Health Screening Questionnaire

Name:____

Address: ____

Phone: ________________________________

Age: ________________

Please read the following questions carefully. If you have any difficulty, please advise the medical practitioner, nurse or exercise specialist who is conducting the exercise test.

Please answer all of the following questions by ticking only one box for each question:

This questionnaire has been designed to identify the small number of persons (15-69 years of age) for whom physical activity might be inappropriate. The questions are based upon the Physical Activity Readiness Questionnaire (PAR-Q), originally devised by the British Columbia Dept of Health (Canada), as revised by [1]Thomas *et al*. (1992) and [2]Cardinal *et al*. (1996), and with added requirements of the Massey University Human Ethics Committee. The information provided by you on this form will be treated with the strictest confidentiality.

Qu 1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?

Yes ☐ No ☐

Qu 2. Do you feel a pain in your chest when you do physical activity?

Yes ☐ No ☐

Qu 3. In the past month have you had chest pain when you were not doing physical activity?

Yes ☐ No ☐

Qu 4. Do you lose your balance because of dizziness or do you ever lose consciousness?

Yes ☐ No ☐

Qu 5. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?

Yes ☐ No ☐

Qu 6. Do you have a bone or joint problem that could be made worse by vigorous exercise?

Yes ☐ No ☐

Qu 7. Do you know of any other reason why you should not do physical activity?

Yes ☐ No ☐

Qu 8. Have any immediate family had heart problems prior to the age of 60?

Yes ☐ No ☐

Qu 9. Have you been hospitalised recently?

Yes ☐ No ☐

Qu 10. Do you have any infectious disease that may be transmitted in blood?

Yes ☐ No ☐

You should be aware that even amongst healthy persons who undertake regular physical activity there is a risk of sudden death during exercise. Though extremely rare, such cases can occur in people with an undiagnosed heart condition. If you have any reason to suspect that you may have a heart condition that will put you at risk during exercise, you should seek advice from a medical practitioner before undertaking an exercise test.

I have read, understood and completed this questionnaire.

Signature: ____ Date: ___________________

References

1. Thomas S, Reading J and Shephard RJ. Revision of the Physical Activity Readiness Questionnaire (PAR-Q). *Can J Sport Sci* 17(4): 338-345.
2. Cardinal BJ, Esters J and Cardinal MK. Evaluation of the revised physical activity readiness questionnaire in older adults. *Med Sci Sports Exerc* 28(4): 468-472