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CHANGES OF DRIVE TO RECOVERY RATIO DURING 2000M ERGOMETER ROWING AMONG JUNIOR NATIONAL ROWERS

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Abstract

Rowing has two stroke phases: the drive phase and recovery phase. The objective of our study was to evaluate the changes of drive to recovery ratio during rowing on a dynamic ergometer. Ten male national junior rowers participated in the study. Three-dimensional motion was recorded using nine infrared cameras. Rowing motions were captured in ten strokes for every 500m section of 2000m rowing time trial on a dynamic ergometer. Two-way ANOVA was performed to compare the duration of drive and recovery phases across 500m sections of 2000m time trial. The findings showed that there were no significant interactions between drive and recovery phases and distance covered. However, there was significant interaction between the duration of the recovery phase and distance covered. Participants were consistent in maintaining the duration of drive and recovery phase at 500m, 1000m, and 1500m; in the final 500m section, the rowers sprinted as fast as possible with high stroke rates. Drive to recovery ratio across 2000m dynamic ergometer rowing was 1:1. From the study, the strategy to minimise time to completion may be managed by adjusting the time spent during drive and recovery phases in each section of the 2000m time trial. Crew pairings can be conducted according to personal drive to recovery ratio to enhance rowing synchronisation.

Keywords: Coordination, in phase, out of phase, synchronisation

Introduction

Rowing emphasises coordinated movements and requires perfect synchronisation between rowers in a boat and also within each rower (e.g., inter-joint coordination). The degree of synchronisation is generally regarded as an important determinant for optimal crew performance which increased the chances to win (Wing and Woodburn, 1995; Hill, 2002). Furthermore, it has been shown that uncoordinated movement could hinder performance even in a team with strong and technically skilled rowers (Cuijpers et al., 2015).

Coordination among rowers is divided into joint coordination and time coordination. Joint coordination is important for applying a skill that requires the coordination of multi-joint movements. Meanwhile, time coordination is defined as changes in time coordination between body segments over a sustained period, which are frequently attributed to fatigue (Caldwell, McNair & Williams, 2003; Holt, Bull, Cashman & McGregor, 2003; McGregor, Patankar & Bull, 2005). One method of quantifying time coordination in rowing is the evaluation of the ratio between the duration of the drive phase and recovery phase. The time coordination is crucial particularly for sports such as rowing which determine the winner based on fastest time recorded. The changes are specifically related to the trunk, trunk flexor, and extensor muscle fatigue have been suggested as significant contributing factors to alter coordination of trunk (Bull & McGregor, 2000; Caldwell et al., 2003; McGregor et al., 2005). Furthermore, changes in the timing of execution of leg drive, trunk extension and arm pull may also influence the coordination of pelvic and spinal segments (Pollock, Jenkyn, Jones, Ivanova & Garland, 2009). Hill (2002) found that time differences for the beginning and end of the force patterns were generally lower for the catch than for the finish. This is because the catch is the main trigger for following the rhythm of each crew member during a rowing stroke.

Nowadays, rowing ergometers are widely used by rowers not only for simulation of on-water rowing but also as a part of their training (particularly during bad weather), team selection and strength and conditioning programmes (Cosgrove, Wilson, Watt & Grant, 1999). A number of studies have compared the biomechanical aspects of rowing on ergometer and on-water rowing (Dawson, Lockwood, Wilson & Freeman, 1998; Mello, Bertuzzi, Grangeiro & Franchini, 2009; Urichianu and Vladimir, 2010; Fleming, Donne & Mahony, 2014) and also biomechanical comparisons between types of ergometer (Holsgaard-Larsen and Jensen, 2010; Benson, Abendroth, King & Swensen, 2011; Shaharudin and Agrawal, 2016). There are two types of ergometer commonly used by rowers: dynamic and stationary. Dynamic ergometer consists of two sliders that is mounted underneath a stationary ergometer as an improvisation to bridge the gap of mechanics between ergometer and on-water rowing (Dawson et al., 1998; Fleming et al., 2014; Shaharudin, Zanotto & Agrawal, 2014). Furthermore, similar physiological (e.g. heart rate, oxygen consumption and blood lactate concentration) (Mahony, 1999; Benson et al., 2011), muscular activity (Turpin, Guevel, Durand & Hug, 2011; Fleming et al., 2014) and biomechanical aspects (Lamb, 1989; Dawson et al., 1998) were identified while rowing on dynamic ergometer and rowing on-water. Thus, in this study, a 2000m time trial test was conducted on dynamic ergometer because of the similarities in terms of rowing characteristics, muscle activity, physiological and biomechanical aspects as rowing on-water.

To the best of our knowledge, information regarding changes of drive to recovery ratio during ergometer rowing is scarce. Hence, the purpose of this study was to compare the drive to recovery ratio across 500m sections of 2000m time trial test on dynamic ergometer among junior national rowers. We hypothesised that the ratio would change particularly at the start and end of 2000m time trial.

Methods

Recruitment of participants

Participants were voluntarily recruited through national coach. Ten male junior national-level rowers participated in the study. Rowers of age 13 – 17 years old with no serious musculoskeletal injuries within the previous year were included in the study. Consent was obtained from the participants and their guardians. The study protocol was reviewed and approved by Human Research Ethical Committee of a local university. The research was conducted in compliance to Declaration of Helsinki.

Study protocol

Participants were asked to provide information about their medical history and any medications being taken. Participants were advised to wear fit clothing for accurate marker placement on the body. Prior to the test day, they were asked to have at least six hours of sleep. They also need to take a light meal two hours before the test. Participants underwent a physical check-up, which include the evaluation of weight, height, circumference (i.e., hip, waist and thigh) and segments' length (i.e., leg and thigh). Standing height and body weight were measured using Seca Stadiometer (Model 224, Germany). During measuring standing height, participants were instructed to take a deep breath for measuring actual standing height. Then, the body mass index (BMI) of each participant was calculated by division of body weight (in kilograms) over standing height squared (in centimetres). The leg-thigh length ratio was measured based on the markers attachment by using anthropometrical tape. The length of thigh was measured from greater trochanter marker to lateral epicondyle marker while the length of leg was measured from lateral epicondyle marker to the lateral malleolus marker. Hence, leg-thigh ratio was determined by the length of shank divided with the length of thigh.

Next, 24 passive reflective markers (model hard marker 15mm, QUALISYS AB, Sweden) were attached bilaterally on the anterior superior iliac spine, posterior superior iliac spine, greater trochanter, lateral epicondyle, medial epicondyle, tibial tubercle, lateral malleolus, medial malleolus, calcaneous, second metatarsal head and fifth metatarsal head. One passive reflective marker was attached on the posterior section of ergometer. Correct positions of the markers were the key factor in achieving a good quality of motion capture.

After placement of markers, participants stood stationary to capture the full-body static pose. Participants were asked to stand in the anatomical standing position. The static pose was captured for two seconds. Then, four reflective markers were removed prior to the rowing trial once the static pose was captured. These markers were located on the medial anatomical landmarks which include right and left medial epicondyle and medial malleolus. The markers were removed for the ease and smoothness of rowing motion. Another 20 markers on the selected anatomical landmarks and one marker on the ergometer remained.

Next, participants went through 2000m rowing time trial on dynamic ergometer (Model D, Concept 2 Inc., Morrisville, VT). Participants warmed up for three minutes on the ergometer, followed by a minute of active rest. After that, standardise drag factor (e.g., resistance) referred from Australian Rowing Team Ergometer Protocols (2013) was added according to the body weight of each participant. The test began once the participant was ready. During the test, the 3D rowing motion was captured for ten consecutive rowing strokes for every 500m section covered during 2000m rowing (Greene, Sinclair, Dickson, Colloud & Smith, 2009). The time to completion was recorded after the participant reached 2000m of rowing.

Finally, the trajectory of reflective markers that were captured was identified using QTM software (Qualisys AB, Sweden) to build a musculoskeletal modelling. Each marker was identified according to the anatomical landmarks. After the identification of markers was completed, the motion captured was further analysed using Visual3D software (Standard v4.90.0, C-Motion Inc, Gothenburg, Sweden) to create a musculoskeletal model which allowed detailed analysis of time coordination.

Determination of drive and recovery phases

Following markers identification, data from QTM software were exported to Microsoft Excel. A set of ten consecutive stroke cycles was extracted and averaged to obtain a representative pattern for each 500m sections. Then, the rowing phases (e.g., drive and recovery) were defined through the analysis of position and orientation of the wrist joint marker projected along the longitudinal axis of the ergometer and knee flexion angle (Shaharudin et al., 2014, Shaharudin & Agrawal, 2016). Each phase of the rowing cycle (e.g., drive and recovery) was interpolated to 100 time points separately following technique by Turpin et al. (2011). Therefore, the complete stroke was composed of 200 time-points. The interpolation and graphs were created by using MATLAB software (R2014b, version 8.3, The MathWorks, Inc., United States). The ratio of drive to recovery phase was the duration of drive phase divided by the duration of recovery phase.

Statistical analysis

Statistical tests were conducted using IBM SPSS version 23. Significance value was set at $\alpha = 0.05$. The Kolmogorov-Smirnov test was employed to determine the normality of the data. The descriptive statistics were applied on the anthropometric data and rowing performance. All data were expressed as mean ± standard deviation (SD).

One-way ANOVA was conducted to compare stroke rates for every 500m sections. Pearson’s correlation coefficient was applied to evaluate whether there was any correlation between stroke rates for each section and 2000m time trial. Next, a comparison of the duration between rowing phases (e.g., two levels: drive and recovery) across sections (e.g., four levels: 500m, 1000m, 1500m 2000m) was analysed using two-way ANOVA. The level of significance was adjusted at $p < 0.01$. Levene's test was used to test for homogeneity of the data. Next, Tukey test was applied for ANOVA post hoc test.

Results

Physical Characteristics of Participants

The physical characteristics for all participants are presented in Table 1.

Table 1: Physical characteristics of overall participants (N=10)

	Mean ± SD
Age (years)	16.4 ± 0.5
Height (m)	1.73 ± 0.05
Weight (kg)	70.2 ± 9.2
BMI (kg/m^2)	23.44 ± 2.67
Hip circumference (cm)	97.9 ± 12.2
Thigh circumference (cm)	42.3 ± 2.45
Shank length (m)	0.43 ± 0.03
Thigh length (m)	0.49 ± 0.04
Shank to thigh ratio	0.9 ± 0.1

m = metre; kg = kilogram; cm = centimetre; values in mean ± standard deviation

Stroke rates across 2000m time trial

Participants took 7.57 ± 0.42 minutes to complete 2000m rowing time trial, with an average stroke rate of 33.05 ± 4.03 strokes per minute (spm). There was a strong negative correlation between average stroke rates of 2000m time trial and time to completion ($r = -0.651$, $N = 15$, $p = 0.009$). This showed that shorter time to completion was observed with higher stroke rates. Specifically, stroke rates for each 500m section of 2000m time trial are presented on Table 2.

Table 2: Stroke rates at each 500m during 2000m rowing time trial (N=10)

Stroke rates (spm)	Mean ± SD
500m	32.2 ± 3.2
1000m	31.2 ± 3.2
1500m	31.2 ± 2.7
2000m	37.6 ± 7.0

spm = strokes per minute; values in mean ± standard deviation

In Table 2, participants managed their stroke rates consistently from the 500m to 1500m sections. Then, at 2000m section, they increased their stroke rate. There was a statistically significant difference between stroke rates for every 500m section of 2000m time trial as determined by one-way ANOVA ($F(3,36) = 4.880$, $p = 0.006$). Stroke rates for the last section (i.e., 2000m) was significantly greater than the stroke rates for the 500m ($p = 0.044$), 1000m ($p = 0.013$), and 1500m ($p = 0.013$) sections as revealed by Tukey's honestly significant difference (HSD) post hoc test.

Changes of the duration of drive and recovery phases during 2000m rowing on dynamic ergometer are presented in Table 3.

Table 3: Duration of drive and recovery phases and its ratio across sections in 2000m time trial (N=10).

Section	Duration of drive phase (s)	Duration of recovery phase (s)	Drive to recovery ratio
500m	0.94 ± 0.14	1.11 ± 0.26	0.85
1000m	0.96 ± 0.11	1.11 ± 0.23	0.86
1500m	0.94 ± 0.09	1.04 ± 0.12	0.90
2000m	0.85 ± 0.11	0.82 ± 0.19	1.04

s = seconds; values in mean ± standard deviation

Levene's test was used to test for homogeneity of the data. Levene's test of equality of error variances showed a significant value (*F* = 4.115, *p* = 0.001); hence, data were appropriate for two-way ANOVA. There was no significant interaction between drive and recovery phases and sections. However, the duration of recovery phase and sections showed significant interaction (Figure 1). Post hoc Tukey's test was conducted only for the interactions that were significant. Recovery phase during the last section (i.e., 2000m) was significantly shorter than the recovery phase for the 500m (*p* = 0.001), 1000m (*p* = 0.001), and 1500m (*p* = 0.001) sections, as revealed by Tukey's honestly significant difference (HSD) post hoc test.

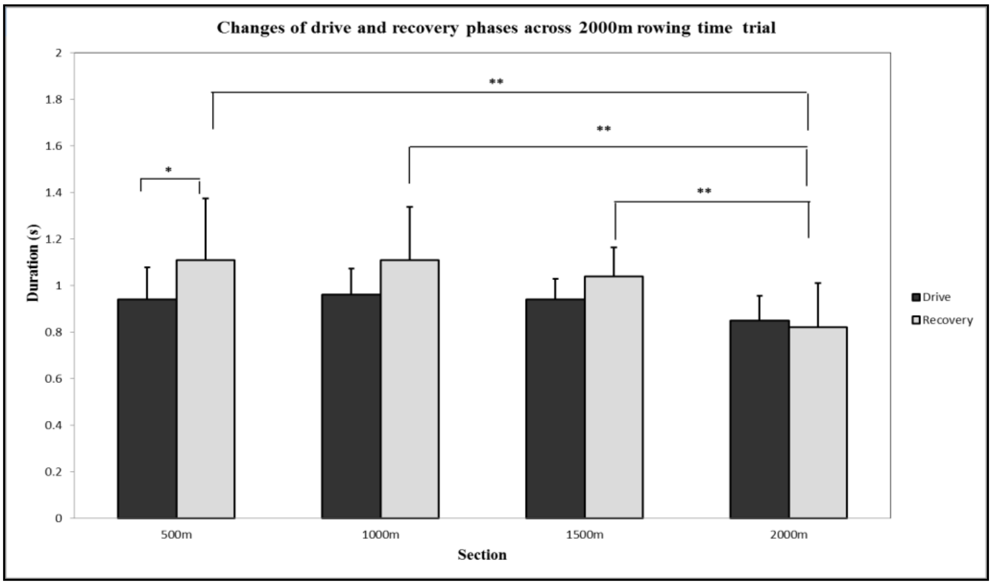

Figure 1: Duration for drive and recovery phase for every 500m section of 2000m time trial.

*P-value is significant across drive and recovery phases within a section.
**P-value is significant between recovery phases of 500m, 1000m, 1500m sections and 2000m section. Significant of p-value: $p < 0.01$.

Discussion

Physical Characteristic of Participants

Standing height is an important anthropometric variable in rowing because long levers have abilities to generate more torque for powerful strokes. From our findings, the male participants were shorter in standing height (1.73 ± 0.05 m) compared to previous study by Mikulić (2008). Their elite junior rowers' heights were about 1.89 ± 0.36 m, while Soper, Reid & Hume (2004) subjects' height was 1.80 ± 0.65 m and Cerne, Kamnik, Vesnicer, Zganec & Munih (2013) subjects' heights averaged 1.83m. The differences of standing height may be due to the types of ethnicity of participants as our participants were Asian whereas previous studies involved Caucasian rowers. Tall rowers are able to make longer rowing strokes which is closely identified with high-level rowing performance (Bourgois et al., 2000; Ingham, Whyte, Jones & Nevil, 2002). Furthermore, timing differences were observed in rowers with different standing height as well as body weight (Greene et al., 2009). During the 1997 World Junior Rowing Championship, Bourgois et al. (2000) found that the finalists were taller in terms of length compared to the non-finalists.

Participants were categorized as having normal BMI (23.44 ± 2.67 kg/m^2). Despite ergometer rowing is a non-weight bearing activity, the body mass has to be accelerated horizontally (van Soest and Hofmijster, 2009). High BMI affected knee flexion angle, whereby it was found that obese people execute significantly smaller knee flexion angles compared to lean individuals during rowing (Roemer, Hortobagyi, Richter, Munoz-Maldonado & Hamilton, 2013). Participants had less than 1.0 of shank to thigh ratio, which is categorised as low (Greene et al., 2009). Moreover, rowers with a low leg-to-thigh ratio demonstrated high power generation during the early part of drive phase, which may affect their time to completion (Greene et al., 2009). However, we did not measure stroke power in our present study, which is a limitation of this study.

Rowing Performance on Dynamic Ergometer

Stroke rate is the number of strokes in a minute. Results showed that average stroke rate is inversely correlated to time to completion, meaning that a faster stroke rate will reduce time taken to complete 2000m race. Stroke rate and velocity are directly related, as a high stroke rate will increase boat velocity (Soper et al., 2004). Previous studies showed negative correlation between stroke rate and stroke length (Thompson, Haljand & MacLAren, 2000; Fritzdorf, Hibbs & Kleshnev, 2009). As the participants of the current study were shorter than rowers from previous studies (Mikulić, 2008; Soper et al., 2004; Cerne et al., 2013), perhaps increasing stroke rates is a strategy to increase forward velocity.

Changes of Drive to Recovery Ratio on Dynamic Ergometer

The specific objective of the study is to evaluate the changes of drive to recovery ratio across 500m sections of 2000m time trial rowing on dynamic ergometer. The duration of recovery phase was significantly longer than the duration of drive phase during 500m, 1000m, and 1500m sections (Table 3). However, the duration of drive phase was slightly longer than the duration of recovery phase during the last section (Figure 1). Furthermore, participants were consistent in maintaining the duration of drive and recovery phases at 500m, 1000m, and 1500m sections. However, at the last section of the 2000m time trial, the rowers sprinted as fast as possible with high stroke rates (Table 2). This strategy reduced the duration of both drive and recovery phases at the last 500m distance of 2000m time trial. During the first three 500m sections, their strategies were aimed to conserve energy expenditure. Then, they went all out during the last section of the 2000m time trial. However, energy expenditure was not measured in this study to objectively quantify our assumptions.

It is customary for rowers to spend approximately twice as long in the recovery phase than the drive phase (Dawson et al., 1998). The 1:2 ratio is the best strategy option for rowers to avoid fatigue at the middle of rowing competition (Dawson et al., 1998). This is because the rowers may actively rest during the transition from finish to catch position and ready themselves for the drive phase in the next stroke cycles. However, the variability of the recovery phase id lower on the ergometer than on the water (Dawson et al., 1998). This is because it is more challenging for rowers to maintain the duration of drive and recovery phases during on-water rowing due to water conditions. Hence, more variability of the duration of drive and recovery phases was observed during on-water rowing (Dawson et al., 1998). Furthermore, a 1:1 ratio was observed during rowing on Concept 2C and Rowperfect ergometers by collegiate rowers (Nowicky, Burdett & Horne, 2005), which is similar to the recent findings.

Conclusions

In the present study, changes of drive to recovery ratio of national junior rowers were analysed for every 500m section of 2000m rowing time trial on a dynamic ergometer. The results showed noticeable changes especially during the last section as compared to the first three sections. It has been demonstrated that all participants recorded a consistent drive to recovery ratio during 500m, 1000m and 1500m sections, but the duration of recovery phase was significantly shorter during the last section. Future studies should incorporate measurements of stroke power, stroke length, oxygen consumption, kinetic and muscle activity to further enhance understanding of time coordination and related strategies during rowing.

Practical Application

From the findings, a strategy to minimise time to completion can be managed by adjusting the time spent during drive and recovery phases in each section of a 2000m time trial. Furthermore, pairings can be conducted following personal time coordination to enhance boat synchronisation.

Conflicts of Interest

There are no conflicts of interest to declare.

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