ORIGINAL ARTICLE

Comparison of Lower Limb Kinematics during Early and Late Phases of 2km Time Trial on Stationary Rowing Ergometer among Male National Rowers

Amirah Zahiran, Fara Liana Zainuddin, Shazlin Shaharudin

Exercise & Sports Science Programme, School of Health Sciences, Universiti Sains Malaysia, 16150 Kota Bharu, Kelantan, Malaysia

ABSTRACT

Introduction: In this study, we evaluated the kinematics of lower limb during early and late phases of 2km time trial on stationary rowing ergometer among Malaysian male rowers. **Methods:** Seventeen national-level rowers voluntarily participated. Three dimensional lower limb kinematics data were collected to represent the first 400 m (i.e., early) and the last 400m (i.e., late) phases of 2km time trial on a stationary ergometer. The kinematics data at sagittal, frontal and transverse planes of dominant leg during catch and finish positions were compared across early and late phases of the time trial using paired T-test. **Results:** The kinematics of lower limb joints at three planes were not significantly different during early versus late phases of 2km time trial among male senior rowers except for hip flexion at finish (p=0.411), ankle rotation at catch (p=0.779) and ankle abduction at finish (p=0.677). **Conclusion:** Lower limb kinematics particularly the hip flexion, ankle rotation and ankle abduction may change across early and late phases of 2km time trial due to fatigue. Coaches and rowers should monitor these motions during fatiguing rowing piece and develop necessary injury prevention measures.

Keywords: Biomechanics, Injury prevention, Rowing, Youth athletes

Corresponding Author:
Shazlin Shaharudin, PhD
Email: shazlin@usm.my
Tel: +609-767 7578

INTRODUCTION

Rowing is a complex sports because it demands high endurance, great power production, efficient technique, strong willpower, and shrewd race strategy (1). Moreover, the velocity of the rowing shell is also influenced by stroke characteristics such as stroke power, rate, length, velocity and propulsion per stroke (2). Biomechanical evaluation is carried out to ascertain the quality of techniques in sports (3). In a 'closed chain' activity whereby the pattern of motions can be predicted such as rowing, identification of optimal technique through biomechanical tests may assist in enhanced performance (4). Hence, studying a rower's kinematics is crucial to recognise wrong technique, and emphasise correct technique which may improve performance and reduce injury risks (4).

Rowing has evolved from the simple boat and oar to a very sleek and methodical sequence of the whole body to generate the most powerful and efficient stroke (5). Rowing is unique from other sports because the athlete is facing backwards, moving their boat in the forward direction. The back of a rower acts as a lever to connect the applied force from the face of the blade to the foot stretchers (6). The forces placed on the rower's body over time, in conjunction with the cyclic rowing sequence, can lead to potential injuries on the rowers' body (6). Therefore, a thorough understanding of the kinematics of the rowing stroke will give better insight to the causes of injuries among rowers and could reveal potential modifications to the rowing technique to reduce injury risk.

Rowing is often studied unilaterally (7). Previous studies applied two-dimensional biomechanical analysis to discriminate good and poor rowing technique (8), changes of kinematics during prolonged rowing (9), high intensity rowing (10), influence of longitudinal training (11) and gender differences (12). Rowing is a cyclic motion that consists of two distinct phases, namely drive and recovery. Catch is the starting position for the drive phase. At this position, the lower limb and lumbar joints are in maximum flexion while of the upper limbs are in maximum extension. The drive phase ends with the maximum extension of lower limb and maximum extension of the upper limb, which indicates finish position. When the rower returns from finish to catch position, it is called the recovery phase. A full rowing stroke consists of periodic repetition of these positions (13). It is necessary to evaluate each position biomechanically to determine the ideal rowing technique. However, due to the high physiological demands during a rowing race, the kinematics of rowing technique may change particularly at the lower limb joints. This is because lower limb muscles are the main propulsive force generator during rowing (14). Hence, the goal of this work was to compare the lower limb kinematics during early and late phases of 2km time trial on stationary rowing ergometer among Malaysian male national rowers.

MATERIALS AND METHODS

Study design

A priori sample size calculation indicated that 17 participants are appropriate to yield 0.8 power with the effect size of 1.05. Effect size was based on Cohen et al. (1988) (15). Thus, 17 Malaysian male senior rowers with age range between 18-25 years old were recruited. Only participants with at least one year of experience in representing national team were included. Rowers with current lower limb injuries and those with any serious musculoskeletal injuries that required surgery within the past year were excluded.

The research procedure was approved by Human Research Ethics Committee of Universiti Sains Malaysia (USM/JEPeM/17030194) and in accordance with with the Declaration of Helsinki. Participants were informed of the experimental procedures and upon agreement of participation, their written consent was obtained. They provided information about their medical history, and health conditions. The study was carried out at a sports science laboratory of a local university.

This cross-sectional study consisted of a 2km time trial conducted on a stationary rowing ergometer. Three dimensional rowing motions were captured and compared between the early section (i.e., the first 400m piece) and the last section (i.e., the last 400m piece). The test took approximately one hour to be completed including the preparation time. During the tests, participants were advised to wear tight clothes, take light meal at least 2 hours before the tests and had at least 6 hours of sleep during the night prior to the tests.

Study Procedure

The 2km time trial with 3D motion analysis was conducted. The reflective markers were placed on sacrum, both sides of posterior superior iliac crest, greater trochanter, medial and lateral knee, ankle, metatarsal, and heel. The trajectory of the markers were monitored and recorded by six infrared cameras (Qualisys Motion Capture Systems, Oqus 311, Sweden). Then, participants stood stationary for three seconds to capture their static pose.

Next, participants were equipped with a Polar heart rate monitor (Electro Oy, Finland) around their chest. Then, they warmed up for three minutes on a stationary rowing ergometer (Concept 2 Model D, Morrisville, USA) with preferred load. After warmed up, the resistance (i.e., drag factor) was added based on the participants' body weight as recommended by Australian Rowing Team Ergometer Protocols for Concept 2 ergometers (16) (Table I). The test was initiated following instruction from the researcher. During the test, the screen of the ergometer was set to display the remaining metres, time split, and accumulated distance. Participants were encouraged to complete the 2km rowing test in the shortest time possible. The time taken to complete the trial, heart rate, and stroke rate were recorded by the ergometer. The test was attenuated upon their completion of the rowing distance. Then, they cooled down on the ergometer with less resistance.

Table I: The drag factor and category of rowers for stationary rowing ergometer based on the Australian Rowing Team Ergometer Protocols

Category	Drag Factor
Heavyweight Men	110 – 140
Lightweight Men	100 – 130
Heavyweight Women	100 – 130
Lightweight Women	85 – 115
Junior Men	100 – 130
Junior Women	85 – 115

Data and Statistical Analysis

The trajectory of the reflective markers was identified using Qualisys Track Manager Software which was then used to develop a musculoskeletal model using Visual 3D Software (version 5, Gothenburg, Sweden). A set of at least ten consecutive stroke cycles was extracted for each 400 metres of rowing distance and the ensemble averaged were obtained for each joint kinematics. The position of the wrist markers indicate the catch position, whereby the period between two successive catches corresponded to a rowing cycle (17). Time normalisation for the drive and recovery phase was conducted using MATLAB, whereby each drive and recovery phases of rowing cycle was interpolated to 100 timepoints (The Mathworks Inc., R2014b, version 8.3, Natick, MA, USA) (18,19). This is to allow comparison across participants and rowing phases by comparing their drive and recovery according to rowing phase percentage (18).

Statistical tests were conducted using statistical software (SPSS version 22, Chicago, IL). The data distribution was checked via Shapiro-Wilk test. Joint angles and range of motion (ROM) of the lower limb joints in three planes of motions were compared using paired T-test at early and late phases of 2 km time trial. P-value of less than 0.05 indicates a statistically significant difference .

RESULTS

Physical characteristics of participants were presented on Table II. Participants completed the 2km time trial in

Table II: Physical characteristics of participants (N = 17)

Variables	Mean ± SD
Age (years)	19.1 ± 2.0
Experience in competitive rowing (years)	2.7 ± 0.9
Height (cm)	173.3 ± 3.09
Weight (kg)	72.06 ± 6.0
BMI (kg/m^2)	23.7 ± 1.3
Body Fat (%)	18.3 ± 6.0
Fat Mass (kg)	13.6 ± 3.23
Hip circumference (cm)	23.4 ± 2.0

Note: kg=kilogram, cm=centimeter, %= percent, values in mean ± standard deviation

7.20 min ± 0.39 with stroke rate 29.1 ± 2.86 strokes per minute. The kinematics of dominant lower limb were compared across early and late phases of 2km ergometer rowing and presented on Table III.

DISCUSSION

Overall, we observed that the knee kinematics were significantly different at catch and finish position across late and early phases. For the catch position, knee and ankle kinematics were significantly different across phases except for ankle rotation. For the finish position, all kinematics variables were significantly different across phases except for hip and ankle abduction. However, for the finish position, all kinematics variables were significantly different across phases.

Hip, knee and ankle kinematics were influenced by ergometer design and rowing intensity (20). At catch position, the back muscles are relaxed to allow trunk flexion, while the knees flexed due to hamstrings and gastrocnemius contraction (21). At the same time, the quadriceps are extended, while the rectus femoris is controlling the hip flexion and the tibialis anterior contracts to dorsiflex the ankles.

A previous study showed that the knee angles during finish position were different at the 500m and 2000m, as well as 500m and 1500m during ergometer rowing (22). Moreover, the ankle angles during finish position changed from the early split of rowing piece compared to other splits (22) which is similar to our findings.

A number of studies have examined the rowing stroke kinematics (4, 10, 11), particularly on ergometer (10, 23, 24). It was found that the range of motion (ROM) for lower limb kinematics at the sagittal plane for both right and left sides were similar in a small group of seven national rowers (25). Only few studies investigated the bilateral asymmetry of the lower limbs kinematics, whereby measurements were usually made unilaterally (9, 26) or combining joint kinematics for both sides of the body to estimate the average for each joint (27). Furthermore, it may be inaccurate to assume that the body execute rowing motions symmetrically, especially among club level and novice rowers who had less technical experience compared to elite rowers. Therefore, since our study only involved the dominant side, the results should be interpreted with caution.

The rowing stroke is comparable to a lifting task whereby lifting with symmetrical and coordinated motions is required to diminish torsional loading and lower back problems (28). Accordingly, asymmetrical lower limb motion during rowing stroke may caused compensatory pelvic motions and co-contractions of spinal muscles to stabilised the trunk (4). It was shown that increased in lumbar pelvic flexion may deteriorate rowing technique especially during higher work rates (10) and further increase risks for rowing injuries (29). Moreover, fatigue

Table III: Comparison of lower limb kinematics across early and late phases of 2km ergometer rowing for male rowers (N=17)

	Catch			Finish		
	Early phase	**Late phase**	**p-value**	**Early phase**	**Late phase**	**p-value**
Hip Joint:						
Flexion (°)	50.2 ± 7.2	60 ± 8.2	**0.003***	57.5 ± 6.7	61.3 ± 9.1	**0.000***
Abduction (°)	4.6 ± 2.2	5.6 ± 2.2	**0.000***	5.1 ± 2.3	5.0 ± 1.5	0.411
Rotation (°)	15.7 ± 2.0	29.1 ± 4.4	**0.000***	15.7 ± 2.9	32.5 ± 7.4	**0.003***
Knee Joint:						
Flexion (°)	43.1 ± 8.9	37.8 ± 6.0	**0.000***	49.5 ± 4.8	42.2 ± 9.1	**0.000***
Abduction (°)	6.5 ± 2.2	3.4 ± 1.7	**0.000***	4.7 ± 1.8	5.3 ± 2.0	**0.000***
Rotation (°)	28.4 ± 3.6	17.2 ± 2.9	**0.000***	23.8 ± 5.5	19.8 ± 4.0	**0.000***
Ankle Joint:						
Flexion (°)	29.4 ± 5.4	21.5 ± 8.1	**0.000***	33.6 ± 4.9	23.8 ± 9.0	**0.001***
Abduction (°)	30.9 ± 8.4	21.1 ± 6.0	**0.000***	25.0 ± 3.9	26.4 ± 10.9	0.677
Rotation (°)	3.9 ± 3.6	3.6 ± 5.0	0.779	11.41 ± 3.6	4.1 ± 5.3	**0.000***

Note:*P <0.05, values in mean ± standard deviation of lumbar extensor may lead to impaired awareness of excessive flexion (30, 31). Based on our result, lower limb kinematics was significantly different at catch and finish position between the early and late phases of the 2km time trial which may indicate the influence of fatigue on lower limb kinematics. Hence, healthy level of hip flexion can be achieved with adequate hip ROM and endurance of lumbar extensor which should be the focus of physical fitness training among rowers (32).

The environmental influences such as water resistance, wind, and change of temperature were not considered in the current study. Hence, healthy level of hip flexion and endurance of lumbar extensor should be the focus of physical fitness training among rowers (32).

CONCLUSION

The kinematics of lower limb joints at three planes (i.e., frontal, sagittal, transverse) were significantly different during the early versus late phases of 2km time trial among male senior rowers except for hip and ankle abduction at finish position and ankle rotation at catch position. Coaches and rowers should monitor these motions during fatiguing rowing piece and develop necessary injury prevention measures.

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