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TWO-DIMENSIONAL KINEMATIC ANALYSIS OF CATCH AND FINISH POSITIONS DURING A 2000M ROWING ERGOMETER TIME TRIAL

Bergun M. BINGUL[1], Cigdem BULGAN[2], Mensure AYDIN[1],
Tacettin BUYUKDEMIRTAS[1] & Aydın OZBEK[3]
[1]*School of Physical Education and Sport, Kocaeli University, Umuttepe, Kocaeli, Turkey*
[2]*School of Physical Education and Sport, Halic University, Istanbul, Turkey*
[3]*Department of Anatomy, School of Medicine, Kocaeli University, Umuttepe, Kocaeli, Turkey*

ABSTRACT

The kinematic variables of the catch and finish positions of the 2000m rowing techniques in every 500m single ergometer rowing stroke were identified. Five male rowers from the Turkish National Team (Age 21.0±2.0 years; Stature 180.6±3.1 cm; Mass 76.6±5.0 kg; Training experience 7.0±1.0 years), performed a time trial on a Concept IID rowing ergometer. It was recorded by one camera at 100 Hz speed. The 500m, 1000m, 1500m and 2000m rowing strokes were analysed by means of the Simi Motion 6.2 programme. In the catch and finish positions, segments' angles, stroke time, stroke power, stroke velocity and stroke rate were evaluated by using the Friedman test with repeated measures, followed by Wilcoxon test and Spearman correlation coefficient. Significant differences (p<0.05) for the distance were found for ankle and elbow angles in the catch position; for knee and ankle angles in the finish position; and stroke time, stroke power, stroke rates between distances. For all measured distances, negative correlations were found between stroke power and ankle angle on the finish position. Positive correlations were found with wrist angle on the catch position at 1500m and 2000m. Elite rowers' performances were not enough to increase the frequency of drive. As the rowing distance got longer, rowers started to change their body angles and action. Performance could be improved by maintaining suitable rowing technique during competition.

Key words: Biomechanics; Rowing; Catch and finish positions; Concept IID rowing ergometer.

INTRODUCTION

For centuries rowing coaches have tried to develop techniques to increase rowing performance with the intention to have effective races, even in bad weather during rowing training (Elliott *et al*., 2003). Rowing is an endurance sport in terms of training science. Although all body muscles are active during rowing, more leg power and less arm power is used. In a successful rowing race, cardiovascular endurance, anaerobic power and technique for the fastest rowing (Page & Hawkins, 2003), as well as forces which are generated through the extension of the legs and trunk and flexion of the arms (Pollock *et al*., 2012), are needed.

Considering energy use in rowing, it has been observed that aerobic energy is used most in a 2000m rowing race. A race lasts 6 to 7 minutes depending on the type of racing boat and standard of the rowers. During racing, 70% of the total energy is aerobic and the remaining 30% is anaerobic energy (Cosgrove *et al*., 1999).

For an effective rowing performance, physical capacity, energy use and application of movements, cardiovascular capacity and a suitably designed boat in terms of mechanics are essential (Baudouin & Hawkins, 2003). Therefore, suitable movement profiles should be designed by analysing the body motion for the sport. Rowing is a cyclical movement (Cerne *et al*., 2013), and the technique consists of positions when catching, driving, finishing and recovery (Smith & Loschner, 2002). A biomechanical evaluation of each position will help to develop suitable techniques for the rower.

Many biomechanical investigations have evaluated both rowing performance on water (Dawson *et al*., 1998; Elliott *et al*., 2003), or on ergometers (Attenborough *et al*., 2012; Pollock *et al*., 2012; Cerne *et al*., 2013; Wilson *et al*., 2013). Ergometer rowing is a complex motor skill. A rower must have a good command of technique, timing and power on an ergometer (Cerne *et al*., 2013). These machines are designed to make rowers move like they would on water (Smith & Loschner, 2002), by simulating the rowing action used on water (Upson, 2003). Although these ergometers have been recognised as a common cause of soft muscle injuries (Bernstein *et al*., 2002; Hase *et al*., 2004; Nowicky *et al*., 2005), they are very useful in performance tests and technical exercises (Elliott *et al*., 2003; Soper & Hume, 2004).

While ergometers, such as *Row Perfect* (Bernstein *et al*., 2002; Elliott *et al*., 2003) and *Stanford* (Nelson & Widule, 1983), have been used in some studies, most researchers have preferred the *Concept II* ergometer in the determination of rowing technique (Smith & Spinks, 1995; Cosgrove *et al*., 1999; Page & Hawkins, 2003; Hase *et al*., 2004; Nowicky *et al*., 2005; Cerne *et al*., 2013). Monitoring systems to collect real-time kinetic and kinematic data have been developed on the ergometer by researchers.

While the rower rows, a two-dimensional stick figure of the rower is displayed above the power profile produced during the drive (power-producing) position of the stroke (Hawkins, 2000). Each sport has its own biomechanical features (Upson, 2003) and these optimum features should be identified. Most rowing experts agree that the proper sequence of motion, in order to maximise both stroke power and efficiency, is to start the row by driving with the legs, then extending the hips and then pulling with the arms last (Martin & Andrews, 2012).

RESEARCH PROBLEM

The aim of this study was to identify the kinematic variables of the catch and finish positions, affecting success in rowing techniques for 2000m and to analyse the continuity of these parameters throughout a time trial by applying a two-dimensional recording technique every 500m of a single ergometer rowing stroke.

METHODOLOGY

Participants

Five male rowers from the Turkish National Team (category of coxless) participated in this study voluntarily. Their mean age was 21.0±2.0 years, mean stature was 180.6±3.1cm, mean mass was 76.6±5.0 kg and their mean training experience was 7.0±1.0 years. All subjects had previous competitive rowing experience in national and international competitions. The rowing performances of the subjects were measured at the Sports Sciences Research Centre, School of Physical Education and Sports, Kocaeli University. All subjects had no significant musculo-skeletal injury according to their recent medical history.

Procedures

The current study was conducted consistently to comply with the recommendations of the declaration of Helsinki. Before participating in the study, the subjects were informed of the potential risks and benefits of the study. Time trials were done in Kocaeli University's Biomechanic Laboratory in the afternoon at 16h00. Subjects had to refrain from using alcohol, caffeine and ergogenic aids the day before the test.

Subjects performed a 2000m rowing stroke on the *Concept II D* rowing ergometer. The warm-up intensity and duration were self-selected on the ergometer, but were approximately 15 minutes in length. After being given sufficient time for warm-up, their one rowing stroke at the end of 500m, 1000m, 1500m and 2000m were recorded by using one *Basler* A602f 100hz high-speed camera. The camera was placed to the right side of the rowers at a 90º angle of the position of the ergometer. The distance from ergometer to the camera was about 4m. For field calibration, Direct Linear Transformation technique was used and developed by Abdel-Aziz and Karara (1971) and Shapiro (1978). Four calibration points were calculated by using 2m x 2.5m calibration sticks and it was recorded with all rowing positions, which consisted of catching, driving, finishing and recovery.

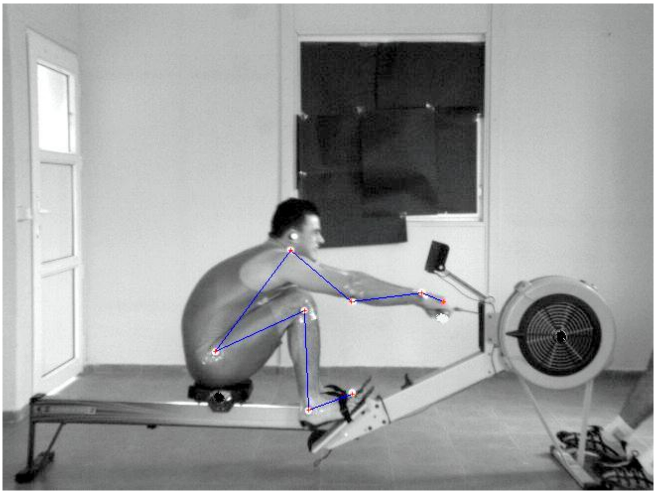

FIGURE 1. **MARKER LOCATIONS AT CATCH POSITION**

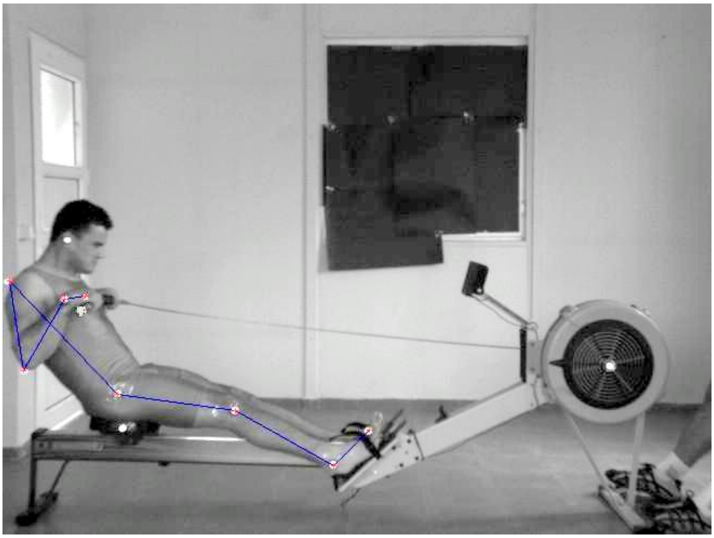

FIGURE 2. **MARKER LOCATIONS AT FINISH POSITION**

Only the catch and finish positions of performance were analysed two-dimensionally using the Simi Motion program (Version 6.2, Reality Motion System, Germany). The angular position changes of the body, knee, hip, ankle, elbow and wrist segments in the catch position and changes of the body, knee, hip, ankle and femur segments in the finish position were evaluated in degrees. Also, stroke power (watt), stroke rate (stroke/second) and stroke time (seconds) were collected from the *Concept II D* screen for each single stroke cycle of the selected distances. In addition, stroke velocity was evaluated by calculating it as m/sec (distance/time).

Joint angles

Reflector markers with a 3cm diameter were attached to the joints of rowers and they were placed on the position of the acromion on the shoulder, olecranon on the elbow, processus styleoideus on the wrist, trochanter major on the hip, epicondylus lateralis on the knee, malleolus lateralis on the ankle, the distal phalanx V, caput phalangae V (Figure 1 & Figure 2).

The ankle angle was connected with the distal phalanx V, malleolus lateralis and epicondylus lateralis; the knee angle was connected with epicondylus lateralis and trochanter major and malleolus lateralis; the hip angle (front side) was connected with trochanter major and acromion and epicondylus lateralis and trunk angle with respect to the vertical; the elbow angle was connected with acromion, olecranon and caput phalangae V, and lastly the wrist angle was connected with olecranon, processes styleoideus and caput phalangae V (Figure 3). The connected segments were brought into motion analysis frame by frame and the segment angles were calculated.

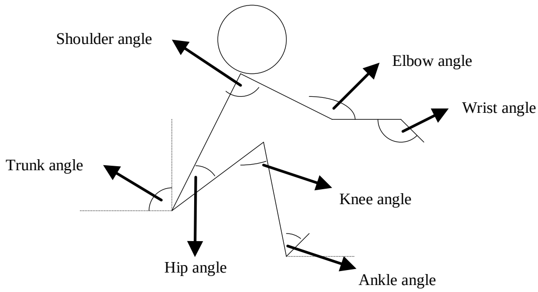

FIGURE 3. **JOINT ANGLES**

Statistical analysis

SPSS version 11.5 for windows (SPSS, Chicago, IL) was used to analyse the data. The statistical analysis was performed using the Friedman Test with repeated measures (non-parametric repeated-measures, ANOVA), followed by Wilcoxon Test to determine significant differences of kinematic and performance variables with each of the distances. The Spearman correlation coefficient between the angular displacement and the performance variables (power, stroke rate, stroke time, stroke velocity), at each of the distances were calculated. The statistical significance level was set at 0.05.

RESULTS

The parameters at 500m, 1000m, 1500m and 2000m were compared using the Friedman Test. Differences were found for the ankle and elbow angle during the catch position at the distances of 500m and 2000m. Also, there were significant differences in the knee angle at the distances of 500m and 2000m, as well as 500m and 1500m in the finish position ($p<0.05$). In the same position, there were significant differences in the ankle angle between the distance of 500m and all the other distances ($p<0.05$) (Table 1 & Table 2).

TABLE 1. **VALUES OF KINEMATIC VARIABLES AT CATCH POSITION**

	Mean ± Standard Deviation for distances covered (m)				
Variables	500m	1000m	1500m	2000m	Overall
Trunk (deg)	42.7±5.0	30.6±7.0	30.8± 6.5	28.4±5.9	33.1±6.48
Knee (deg)	43.3±3.0	43.4±2.0	44.0±4.2	42±3.3	43.2±0.85
Hip (deg)	26.5±5.7	25.6±5.0	27.0±4.0	25.4±5.7	26.1±0.75
Ankle (deg)	67.2±10	73.1±8.2	70.9±7.3	79.5±12	72.7±5.15*
Elbow (deg)	144.5±8.7	143.5±9.6	142.5±8.6	140.4±10	142.7±1.78*
Wrist (deg)	138.7±6.4	134.2±5.6	135.0±12.7	134.9±13.5	135.7±2.02

*$p<0.05$

TABLE 2. **VALUES OF KINEMATIC VARIABLES AT CATCH POSITION**

Variables	**Mean ± Standard Deviation for distances covered (m)**				
	500m	1000m	1500m	2000m	Overall
Trunk (deg)	44.3±4.4	44.3±6.1	47.7±7.0	51.6±1.9	47.0±3.5
Knee (deg)	152.8±8.8	152.8±6.4	146.2±8.3	147.4±8	149.8±3.5*
Hip (deg)	135.5±6	134.3±7.2	133.6±13.6	132.0±10.7	133.8±1.4
Ankle (deg)	117.9±10.6	124.9±8.2	124.7±10.5	124.1±7.2	122.9±3.3*
Thigh (deg)	3.1±2.2	2.7±2.3	2.8±1.6	3.0±1.5	2.9±0.1

*p<0.05

In addition, there were significant differences between the distances in stroke power values, especially between 1500m and 2000m. Stroke power values continued to decrease after 500m, until 1500m, and it reached the highest value at 2000m (Table 3). Furthermore, significant differences in stroke rate values between the distances of 1000m and 2000m; 1500m and 2000m were found (Table 3).

TABLE 3. **VALUES OF PERFORMANCE VARIABLES**

Variables	**Mean ± Standard Deviation for distances covered (m)**				
	500m	1000m	1500m	2000m	Overall
Power (W)	314.8±4.0	288.4±5.0	271.0±60	324.8±97	299.7±24.5*
Stroke rate (str/min)	28.6±2.9	27.8±2.4	27.8±2.4	29.8±3.1	28.5±0.9*
Stroke time (s)	114.4±1.0	95.4±7.0	222.8±22.0	202.4±13	158.7±6.2
Stroke velocity (m/s)	4.3±0.6	2.38±0.2	1.57±0.2	1.17±0.3	2.3±1.4

*p<0.05

Negative correlations (r= -0.90, -1.00, -1.00, -0.90 respectively) were found between stroke power and ankle angle in the finish position for all measured distances. Positive correlations (r= 0.90, 0.90 respectively) were found for the wrist angle at the catch position of 1500m and 2000m.

DISCUSSION

Rowing is generally divided into four positions, namely catching, driving, finishing and recovery and a full rowing stroke consists of periodic repetition of these positions (Smith & Loschner, 2002; Deakin *et al*., 2004). It is necessary to evaluate each position biomechanically to determine the ideal rowing technique. While some studies have dealt with drive and recovery positions to determine the drive and recovery time ratio (Dawson *et al*., 1998), some studies have studied the catch and finish positions when evaluating body angles (Elliott *et al*., 2003). Similarly, the current study analysed the catch and finish positions of the rowers.

Considering that the determining factors affect success at different distances of the 2000m rowing races, maintaining these factors would be important to improve performance. It was necessary to take a complete row-cycle at the end of 500m, 1000m, 1500m and 2000m into consideration.

Although the value for the upper body segment angle (42.7º) during the catch position, to gain acceleration, was found to decrease at the end of the 2000m (28.0º), no significant difference was found. Elliott *et al*. (2003) found a body angle of 32.4±1.7º in their study and in the study of Upson *et al*. (2003) this parameter was 36.7±8.7º. Similar to these studies, the mean body angle at 2000m was found to be 33.15±6.48º in the current study.

At the catch position, no significant differences were found in angular values of the knee (43.0º), hip (26.2º) and ankle (72.7°). In a study where the 2000m row race on water was assessed, Barrett and Manning (2004) reported knee angles of 47.0±5.0º and hip angles of 25.0±4.0º at the catch position. Upson *et al*. (2003) reported the hip angle to be 26.7±4.2º and Elliott *et al*. (2003) reported the knee angle as being 51.0±2.3º in their study covering 500m. Bell *et al*. (2013) investigated the different intensities for two different inclined back positions of rowing performance. In their study, they found the knee angles at 47.0±8.0º and hip angles as 33.0±7.0º at the catch position. Angular values of segments showed consistency in studies with similar distances, since stroke rate increased as distance in the catch position and, therefore, knee angular values increased. Additionally, the ankle angle, which was initially low (67.3º), increased (79.6º) at the end of 2000m in the catch position. The elbow angle was high at the beginning (144.6º) and decreased (140.4º) at the end of 2000m. These differences were significant ($p<0.05$). In the first period of the race, when the rower moved to the front to produce more speed, the ankle angle was narrower and wider. The reason for this is that the body movement, which is required for the forward motion decreases and the distance increases, thus the ankle angle becomes wider and the elbow angle becomes narrower at the end of 2000m.

At the finish, there were no significant differences in the body, hip and femur angles ($p>0.05$). Barrett and Manning (2004) found the hip angular value to be 110.0±6.0º and Elliott *et al*. (2003) found the femur angle to be 4.0±0.7º and the body angle to be 31.9±2.0º. Bell *et al*. (2013) found a knee angle of 163.0±5.0º and a hip angle of 116.0±5.0º in their study. While values for the body and hip angles were greater than that reported in the literature, the femur angles were similar. This shows that in the finish position in the current study, the rowers moved their bodies into extension, while they also moved their legs to the appropriate extension position.

Significant differences were found in the ankle and knee segment angles at the finish position ($p<0.05$). As the rowing distance increases, the knee angle becomes narrower and ankle angle widens. This can be attributed to the fact that rowers move to a recovery position without bringing their knees to an appropriate extension position, in order to increase rowing rate towards the end of the race.

Rowing power and rowing rates that were high at the end of 500m, decreased at 1000m and 1500m and reached maximum levels at 2000m. Therefore, significant differences were found ($p<0.05$). In their study, Bell *et al*. (2013) found that rowing with a greater inclined back position produced a significant increase in power output. In the present study, the significant differences of stroke power at the end of 2000m may be due to the greater inclined back position of the rowers, which is similar to findings in the literature. Pollock *et al*. (2009) suggest that coordination of the extensors of the spine and the pelvis, after the catch position, may be an effective strategy to support the spine as forces increase with the initiation of the drive.

Rowing performance depends on the development of the rowers skill and increasing the speed of the boat. The power that rowers apply to the oars and kinetic and kinematic synchronisation among rowers affect rowing speed (Baudouin & Hawkins, 2003). In the current study, since the drive time of rowers shortened as the speed increased, a negative correlation was found between power and drive time. In the study of Schabort *et al*. (1999), which evaluated 2000m drive time, power and heartbeats of well-trained rowers, they established that heartbeat decreased and power increased, although their time improved. By analysing the correlation between angle sizes of the body segments and power, a negative correlation was found between power and the dorsi-flexion angle of the ankle at the finish position. It was observed that rowers reduced the dorsi-flexion angle of the ankle to enable them to apply more power, which did cause the rowers to apply more power. While the angle size of the elbow positively affected speed at 1500m and 2000m, there was a negative correlation for all measured distances between the angles of the ankle at the finish position and speed.

Rowing training can influence kinematic chains and different physiological adaptations can result from training at different stroke rates (Bell *et al*., 2013).

PRACTICAL APPLICATION

The effective transfer of force to the handle of a rowing ergometer is very important for performance. The positions of the rowing stroke start in the catch position at the beginning of power development, followed by muscular actions repeated at various stroke rates depending on the speed and power output. In rowing performance, the stroke rate required for the physical training of a rower and the determination of kinematic parameters are important for the performance rowers achieve. In the mid-distance and long-distance races, the trunk may be used more actively to generate force as compensation for the power loss of knee extension and the fatigue of the quadriceps muscles, especially as a primary force-generating muscle during the stroke, would enhance the understanding of altered stroke kinematics related to fatigue. As the end of the competition approaches, technical defects occur in rowers. These could be eliminated if appropriate training methods had been applied.

CONCLUSIONS

As the rowing distance increased, rowers began to change their body angles (e.g., a greater dorsi-flexion angle of the ankle and a decreased angle of the elbow). Particularly in the finish position, rowers end their motion without completing the leg extension positions. When this occurs, there is a greater inclined back position as evidenced by a higher range of movement and angle of the hip. A significant increase in power output is produced at the end of the rowing stroke. This seems to have had a positive effect on power output on the ergometer.

However, during the real on-the-water event, it could have a negative effect caused by changing the centre of gravity when on water. Performance could be improved by producing and maintaining suitable and effective rowing techniques during competitions.

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Prof Bergun Meric BINGUL: The School of Physical Education and Sports, Kocaeli University, Umuttepe, Kocaeli, TURKEY. Tel.:+902623033602, Fax.:+902623033603, E-mail: bergunmeric@gmail.com

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