Journal of Physical Education and Sport ® (JPES), 18(1), Art 25, pp. 193 - 202, 2018
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Biomechanics of rowing: kinematic, kinetic and electromyographic aspects

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Published online: March 30, 2018
(Accepted for publication February 04, 2018
DOI:10.7752/jpes.2018.01025

Abstract:

This systematic review present and discuss research results with observational and/or experimental designs on kinematic, kinetic and electromyographic aspects in rowing. We performed this study used the following databases: PubMed, Scopus, SportDiscus, PsycINFO, and Medline PsycARTICLES. The research was performed using the following keywords: "biomechanics", "kinematics", "kinetics" and/or "electromyography" (EMG) in combination with the terms "rowing" and/or "rower". A total of 36 peer-reviewed articles on experimental or original descriptive studies were considered. The main evidences indicated that stationary ergometers showed an increasing standard error with an increase of distance in the official 2,000-meter race. Ergometers with mechanical slides showed a mechanical lag compared to stationary, and increased fatigue when compared to boats. The angle modification of the joints along the rowing action could be modified with variation in the foot cradle height. Electromyography analyse showed a higher activation in the recto femoral, dorsal, paravertebral, vast lateral, and gluteus Maximus muscles. The ergometer training increases the risk of injury to the hip, spine and knee regions. In conclusion, the information from preceding studies about participants, designs, implemented procedures and results were discussed to clarify knowledge. Coaches can apply the results summarized here to preventing injuries and planning a specific training.

Key words: ergometer, training/conditioning, injuries, muscle power.

Introduction

Rowing is a cyclical sport where 14 Olympic medals are competed for in races of 2,000 meters. Approximately 80% of the total energy comes from the aerobic system, but high intensity intermittent efforts are performed at strategic moments of the race (*e.g.* to start the race and/or to pass opponents' boats) (Smith & Spinks, 1995). Moreover, a technical skill analysis of the movement biomechanics can help improve strength application (to boost the boat) and the energy reserves used by contracting unrelated muscles. Maximizing performance along the course is a critical performance factor because the average speed is dependent to the propulsion generated by the rowers, which must be greater than the drag force (drag factor) acting on the boat's mechanical system (Torres-Moreno, Tanaka, & Penney, 2000). In fact, world-rowing performance is divided into before and after biomechanical analyses, as rowers and coaches began to benefit from structural modifications to their boats upon their own initiative (Celentano, Cortili, Di Prampero, & Cerretelli, 1971). Early studies of high-speed cinematography showed that rowing efficiency is related to the proximity between peak force and the perpendicular position of the paddle with the water, which presents the importance of kinematic analysis and forces acting during movement (Mahler, Parker, & Andresen, 1985).

Relative to cine-anthropometric differences and angular modifications, studies have shown the relationships between anthropometric data, muscle power, angular and linear speed with the electromyographic (EMG) activity of rowing. In fact, EMG has been widely applied to compare efficacy of modifications in recruitment of motor units due to differences in equipment, which may alter the angular stroke speed (Gauthier, 1985). Knowledge about inter and intramuscular coordination in rowers reports the profile of muscle activities during specific actions of the sport, and from this information the form and level of muscular activation can improve performance, as well as reduce the risk of injuries (Vinther et al., 2006). To the best of our knowledge, this is the first study to analyse the three main biomechanical factors related to rowing – the kinematic, kinetic and electromyographic aspects – aiming to improve performance. Therefore, a summarization of the literature pertinent to these biomechanical aspects in rowing is justified. It is assumed that showing results of research combined with methodological data can provide an important reference for establishing strategies for the development of this sport. Therefore, the objective of this systematic review was to show and discuss experimental designs and results from research on kinematic, kinetic and electromyographic factors in rowers. The results discussed and summarized hear can help coaches in planning a specific training.

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Materials & Methods

Search strategy

The data revised were found in scientific journals (until June 2015) in the following databases: PubMed, Scopus, SportDiscus, PsycINFO, PsycARTICLES and Medline, where the following indexed terms were used: "biomechanics", "dynamometer", "Pressure kinematics, kinematics, kinetics and/or electromyography", in combination with the terms "rowing" and/or "rower" to be found anywhere in the articles.

Inclusion and exclusion criteria

Only studies published in English with observational descriptions or whose experimental tests showed intervention effect on kinematic, kinetic and/or electromyographic measures were included. The articles were examined by internal validity under the following criteria: (1) research with a control group; (2) randomized control studies; (3) studies using instruments with high reliability, and; (4) descriptive investigations with minimal experimental sample loss. Each study was analysed in order to evaluate the effects of the interventions in the biomechanical patterns, as well as the characteristics of each study in the respective methods, subjects and effects. Those which did not meet the criteria were excluded.

Results

From 812 papers related to rowing, 239 dealt with non-specific power tests of the paddling and technical aspects with analyses that were neither kinematic, or kinetic and/or electromyographic, and 67 papers described kinematic, kinetic and/or electromyographic. Thus, 36 articles were analysed in total. Figure 1 presents the paper prism selection for the present study:

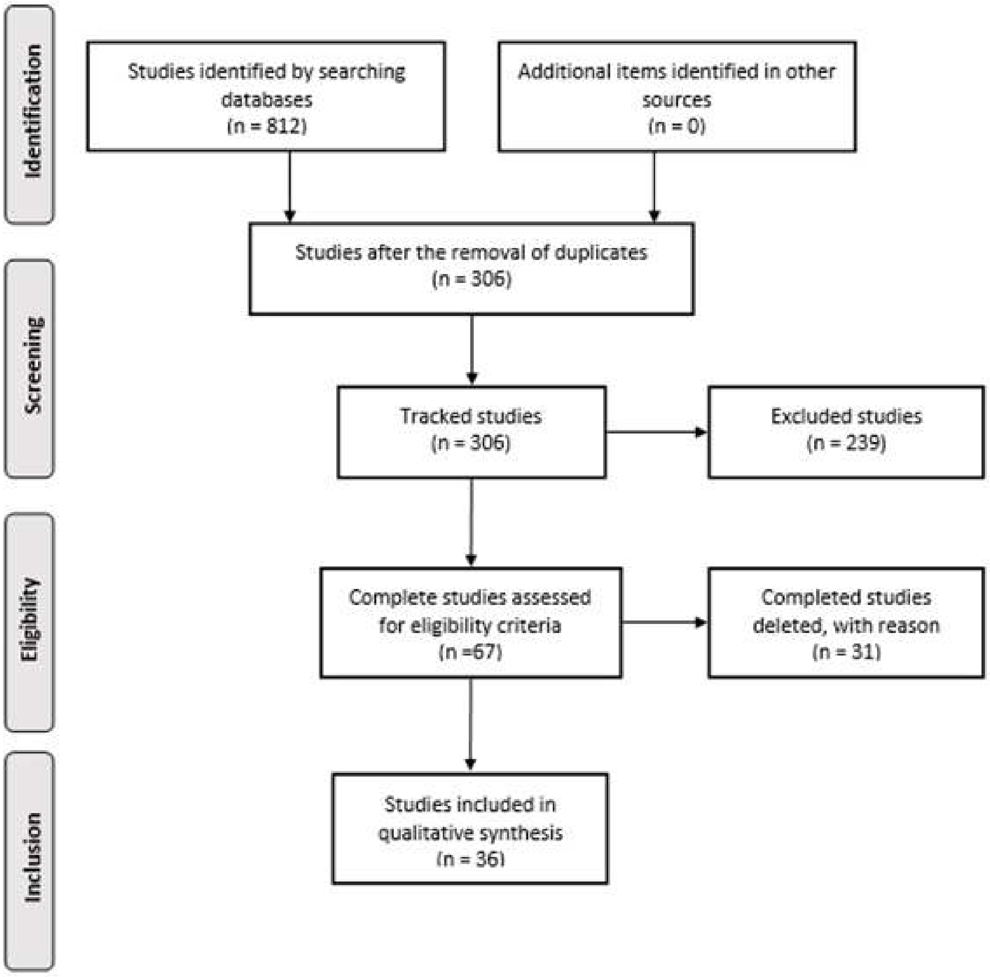

Fig. 1. Prism of studies selection and criteria.

The summary of articles involving kinetics is presented in Table 1 with sample data, designs, applied procedures and results. The set of results indicates the influence of biomechanical aspects on performance. There are differences when comparing ergometer or boat performance, athletes' levels and rowing frequency.

Table 1. Studies involving equipment kinetics and their respective sample, experimental design, procedures and main results.

Study	Sample	Experimental design	Procedures	Main results
(Anderson, Harrison, & Lyons, 2005)	12P	Comparison RowPerfect: Feedbacks: no-feedback vs. detail Feedback vs. resumed Feedback.	Measures during a 2,000-m test.	↑ performance in detail feedback vs. others.
(Černe, Kamnik, Vesnicer, Gros, & Munih, 2013)	5E 5JE 5P	Technical Comparison E vs JE.	Biochemical Analysis in ergometer at 20, 26 and 34 rpm.	E<JE<P in technical variability at different rpm. P: changes in the length of the row and force curve.
(Colloud et al., 2006)	25E	Comparison between foot cradle mechanism With floating vs. no floating.	Analysis of the inertia of forces during transition, propulsion and recovery.	↑ Maximum power and average power during the rowing on non-floatation mechanisms.
(Lamb, 1989)	30P	Comparison: Boat vs. Ergometer.	Kinematic analysis in the water vs. Ergometer.	≠ Arm and forearm segments ≠ at the end of the stroke, but without major differences between the two conditions.
(Lormes, Buckwitz, Rehbein, & Steinacker, 1993)	11P	Comparison: Gjessing vs. Concept II	Incremental test.	Max power: 255w Gjessing >294w Concept II Rpm: Gjessing (33/min) >Concept II (29 /min).
(Martin & Bernfield, 1979)	8x8E	Boats with 8 rowers and 1 helmsman 37 vs. 39 vs. 41rpm/min.	Speed-time analysis in competition.	Correlation (r = 0.66) between rpm and mean velocity.
(Martindale & Robertson, 1984)	2E 2ME	Gjessing simulator vs. Ergometer Vs. Boat.	Kinematic Comparison.	↓ Energy coast on the boat vs. ergometer. No effect simulator vs. ergometer.
(Steer, McGregor, & Bull, 2006)	12E	2 ergometers: Concept II vs. WaterRower.	three tests applied (2 on Concept II and 1 on WaterRower), with (18-20 and 28-30 strokes). Kinematic of the lumbar and pelvic region.	Concept II demonstrated high repeatability. WaterRover affects rowing technique; however, we do not know the practical implication between ergometer differences.
(Vinther et al., 2013)	14E 8ME	Male and female in fixed vs. Slide ergometer.	EMG and strength rate.	With slides, ↓ Peak force 76 (57-95) N in male and 20 (8-31) N in female. ↑ rpm (+ 10.7%) in male. ↓ Speed of strength (-20.7%) men. ↓ Neuromuscular activity in the vastus lateralis from 59% to 51% of the maximum of EMG in male and from 57% to 52% in the female.
(Wilson, Gissane, Gormley, & Simms, 2013)	19E	Lumbar kinematics to fatigue Ergometer vs. Boat.	Maximum lumbar flexion range was recorded. Heart rate and power were recorded during the test.	↑ Maximum lumbar flexion with the ergometer (4.4±0.9^{o}) vs. the boat (1.3±1.1^{o}), ↑1.3% (ergometer) and 4.1% (boat) in the stretching of the lumbar and spine.

Notes. For studies in which there was no specification of the situation in a boat or on an ergometer with slide, the analyses were performed on an ergometer; * Not specified in article E = elite male, ME = elite female JP = young practitioner, P = practitioners, EP = Paralympic elite, rpm = rowing per minute.

The studies involving kinematics are presented in Table 2 with information about the sample, experimental design, applied procedures and results. Differences are observed in the different studies when comparing elite versus other athletes, which can be used as a reference for achieving maximum performance.

Table 2: Studies involving kinematics as the main component and their respective sample, experimental design, procedures and main results.

Study	Sample	Experimental fashion	Procedures	Main results
(Attenborough, Smith, & Sinclair, 2012)	7E 8EL	E vs. EL	Biomechanical analyses of strength.	rpm E: 33.7 rpm x EL: 33.9 rpm ↑ Peak force on wrist (26.2-30.2%) in E. ↑ Relative strength (18.7-22.1%) in EL. ↑ Work and Power (26-29.2%) in E.
(Buckeridge, Bull, & McGregor, 2014)	5EM 6EL 6E	EM vs. EL vs. E	Analysis of force application in incremental test.	↑ Relative forces resulting vertical and horizontal in EL rowers. Asymmetries at 5.3% for the force of 28.9% for the vertical sync of peak force. The asymmetries were not sensitive to rpm or to the group.
(Buckeridge, Hislop, Bull, & McGregor, 2012)	22P E*	E vs P	Kinematics of the knees, hips, lumbar-pelvic joints and pelvic torsion. Seat strength, stroke length, mid-lateral seat drift, and external power.	↑ E: strength in the fist. E and P presented asymmetries of lower limbs, with higher significantly hip asymmetries in front of the knee.
(Hartmann, Mader, Wasser, & Klauer, 1993)	20ME 81E	ME vs. E During a max test of 6-min.	Peak power.	Max Strength E:1.350N> ME:1.020N; Max Speed Peak E:3.80m/s>ME: 2.90 m/s; Peak power E:3.230N>ME:1860N.
(Kane, MacKenzie, Jensen, & Watts, 2013)	5E 5EM	E vs. EM	Incremental tests on an ergometer.	E > EM in rpm frequency and heart rate.
(McGregor, Bull, & Byng-Maddick, 2004)	10E	B1 vs. B3 vs. Competitive race.	Race on an ergometer in three different rpm: 17-20, 24-28, 28-36.	Changes in the force and kinematics curve in the lumbospore region, but there was no difference in the peak force.
(Nelson & Widule, 1982)	9P 9E	E vs. P.	Kinematic analysis of rowing.	≠ Horizontal linear rowing speed (E: 2.6±0.2m vs. P: 2.2 0.2m). ≠ knee extension (E: 4.2±0.5 P: 3.0±0.1 rad.S^{-1}). ≠ angular speed of the knee extension and extension of the upper trunk (E: 7.3±0.8 vs. P: 5.9±0.6 rad.S^{-1}). Max angular speed of the knee and trunk (P: 0.2±0.1 vs. E: 0.2±0.04 s).
(Ng, Campbell, Burnett, & O'Sullivan, 2013)	20JPM 20JP	20JPM vs. 20JP	The kinematics of each phase of rowing action on an ergometer.	JP positions your pelvis with more posterior slope and thoracic spine with more flexion when compared to JPM.
(Seiler, Spirduso, & Martin, 1998)	2.487P 1615 MP	Age and gender: P aged 24-93 Vs. MP 24-84.	Analysis of the ranking of indoor, national and international indoor competitions.	Correlation between time and age P: r = 0.58, MP: 0.46, with small and curvilinear decline pattern for P and linear for MP.
(Tachibana, Yashiro, Miyazaki, IKEGAMI, & Higuchi, 2007)	39P 21PM	Descriptive correlation between performance and use of muscle groups	Creation of a regression model between performance and transversal muscular section.	Performance vs. Posterior thigh and lower back (r^2 = 0.51). Ballistic movement of trunk (r^2 = 0.49). Elbow extensors (r^2 = 0.19) Potential activation by muscles of the mmss (r^2 = 0.42). Ballistic movement of trunk and posterior thigh (r^2 = 0.34).

Notes: For studies in which there was no specification of the boat or on an ergometer with slide, the analyses were performed on an ergometer; * Not specified in the article E = elite male, ME = elite female JP = young practitioner, P = practitioners, EP = Paralympic elite, rpm = rowing per minute; B1 = rowing training in frequency of 17-19 strokes per minute; B3 = rowing training in frequency of 23-25 strokes per minute, mmss = lower limbs.

Studies on electromyography as the main component of analysis are presented in Table 3 with information about the sample, experimental design, applied procedures and main results. Together, the results indicated that there is a difference when using an ergometer or a boat, differences in the type of paddle handgrip and paddling intensity.

Table 3. Studies on electromyography as the main component and its respective sample, experimental design, applied procedures and main results.

Study	Sample	Experimental fashion	Procedures	Main results
(Bazzucchi et al., 2013)	9E	1000 m: Boat vs. Ergometer	(EMG) of the upper trapezius, large dorsal, biceps brachii, rectus femoris, vastus medialis, and lateral, biceps femoris and tibialis anterior.	Time in water 218.4±3.8s> ergometer 178.1±5.6 s. Muscle activation in water<ergometer.
(Bompa et al., 1990)	E*	Handgrip: pronate vs. supinate vs. Semi-pronate.	EMG in 1RM test with change of handgrip in rowing.	↑ Muscle activation and strength using the semi-pronate position.
(Caldwell, McNair, & Williams, 2003)	16JP	Muscle activation in the prone process lumbar muscles.	EMG in spinous processes of L1 and S1 during maximal isometric effort until fatigue.	↑ lumbar flexion ↑ lumbar multifidus activation ↑ lumbar iliocostal activation ↑ long activation of the thorax.
(Gauthier, 1985)	E*	Without feedback vs. with feedback.	8 weeks with intervention and EMG analysis.	↑higher muscle activation with feedback.
(Gerževic, Strojnik, & Jarm, 2011)	6E	6min simulation race (all-out) vs. 6min submax.	EMG of medial gastrocnemius, rectus femoris, vastus lateralis, femoral biceps, maxillary gluteus, paraespinals, lower dorsal, latissimus superior dorsi, brachioradialis and biceps brachialis.	Activation in rectus femoris, large dorsal, vastus lateralis and gluteus maximus during the submaximal test < activation of the gastrocnemius, rectus femoris, vastus lateralis, inferiors of the large dorsalis, upper latissimus of the dorsalis and biceps brachii in the all-out test.
(Guével et al., 2011)	9E	Comparison of trials: 1: 10 min 65-75% HRmax. and 16-18 strokes.min vs. 2: 10 min 75-85% HRmax and 18-20 strokes.min.	EMG in the quadriceps and hamstrings and mechanical aspects of the paddling action.	No significant effect.
(Halliday et al., 2004)	1P 5EP	Spinal cord injury with electrostimulation in mmii vs. Practitioners	EMG analysis in mmiis and trunk region.	No effect on activation, only on force application of mmiis.
(Janshen, Mattes, & Tidow, 2009)	7EJ	Comparison between asymmetric strength in the course of the rowing; mi left vs. mi right.	EMG in six muscles of each leg and pressure distribution under both feet were measured. Data were collected two times (30-second) from 1 and 5 min after the test began.	No effect on joint range of motion of the hip, knee and ankle. ↑ 20-45% in the acceleration phase, activation of the muscles associated with the knee, hip and ankle of the inner leg (supporting). ↑ 56-91% mean pressure values under the arch of the foot of the inner leg of the rowing.
(Lander, Butterly, & Edwards, 2009)	9P	5.000m controlled by RPE 15 (difficult) vs. 5.000m controlled by average power (EXT).	EMG and analysis of physiological aspects every 30s.	↑ Muscle activation and energy consumption in RPE situation, with equivalent power.
(Mäestu et al., 2006)	P*	Comparison of activation in: 2000m vs. 1000m vs. 500 m.	EMG of vastus lateralis and power analysis.	2000m (248.9 ± 26.67 W) and 1000m (258.89 ± 27.13W) < 500m (302.25 ± 45.10 W). ↑ vastus lateralis activity.
(Peltonen et al., 1997)	6 E*	Comparison of the 2,500m in: Normoxia Vs. Hypoxia vs. Hyperxia.	EMG every 500 m, with different oxygen environment.	↓ Gradual strength for all three conditions. No effect on muscle activation.
(Pollock et al., 2012)	9ME	2000m test, comparison between muscle activation at: 250m vs. 1500m	EMG and angular speed in extension-flexion mmii, mmss and trunk.	At 1500m compared to 250m, ↓ angular speed in delayed extension in the T4-T7 and L3-S1 spine segments and increase in the T10-L1 and L1-L3 of the spine segments and increased activation in the abdominal muscles.
(Rodriguez, Rogriguez, Cook, & Sandborn, 1990)	5E	Single muscle vs. Diverse muscle groups.	EMG	↑ Muscle activation and power with the stroke distributed by diverse muscle groups.
(Sprague et al., 2007)	E P	Fatigue patterns of muscles in rowing during	EMG in the brachioradialis, biceps brachii medial deltoid,	↑ muscle activation and biodynamic compensation in E, distributing the

		the 6 min effort: E vs. P.	rectus abdominis, spine erectors, rectus femoris, femoral biceps, gastrocnemius.	load by a higher number of muscle groups.
(Turpin et al., 2011b)	7E 8P	E vs. P in three activities of constant load of 2 min realized in 60, 90 and 120% of the average energy production during a 2,000-m max test.	EMG in 23 muscles and mechanical analysis.	↑ power for 22 of 23 muscles in correlation with increased load No effect on activation patterns and EMG activation time.
(Vinther et al., 2006)	E* P*	Pattern of contraction E Vs. P	EMG and kinematics of the rowing action	≠ Speed in the initial phase of the acceleration (E: 0.25±0.03 m/s vs. P: 0.15±0.06 m/s). ≠ Co-contraction of anterior serratil and Trapezium in the middle of the stroke (E: 47.5±3.4 vs. P: 30.8±6.5). ≠ In relation to knee extension and elbow flexion (E: 4.2±0.22 vs P: 4.8±0.16).

Notes: For studies in which there was no specification of the situation being in a boat or on an ergometer with slide, the analyses were performed on an ergometer; * Not specified in the article E = elite male, ME = elite female JP = young practitioner, P = practitioners, EP = Paralympic elite, rpm = rowing per minute; EMG = electromyography; RPE = rating of perceived exertion; EXT = average power; W = watts; B1 = rowing training in frequency of 17-19 strokes per min; B2 = rowing training in frequency of 20-22 strokes per minute; L = lumbar; T = thoracic; S = sacral, mmii = upper limbs, mmss = lower limbs.

Discussion

This review analysed factors, experimental designs and results from research on kinematic, kinetic and electromyographic aspects of rowers. We performed a synthesis on the main evidence in these investigations. The articles indicated the main effects in evaluations of elite male and female rowers. The studies revealed differences between the genders and competitive level; such EMG studies show a higher muscle activation and technical constancy, even with modifications of equipment or conditions of use in varying distances between 500 and 2,000 meters. Therefore, the discussion of these studies was organized from the main component and separately evaluated into three topics: kinetics, kinematics and electromyography.

Kinetics

Since the development of the first indoor rowing simulator variations and implements were created, and kinetics has been used to examine the forces acting on the boat, rower, and paddle. Information is still limited on the use of equipment , boat type and anthropometric variables being able to increase power and energy production (Pelz & Vergé, 2014). The comparisons between ergometers are not consensual in the results of average power, or even in the counter-clock time (Table 1). For example, in a comparison of Concept II and RowPerfect ergometers, the results highlighted an increasing standard error with increasing distance in both, with 2.8% and 3.3% in 500m, respectively, and a common standard error of 1.3% and 3.3% in 2000m, respectively (Soper & Hume, 2004). Although the standard error is different between devices, both perform similar muscle activation when comparing measurements of erector spine, recto abdominal, rectus femoral, biceps femoral, and contributions of antagonist and agonist muscles in flexion and trunk extension (Nowicky, Burdett, & Horne, 2005). Thus, these ergometers can be used for training and tests with metabolic and kinematic demand correlated to those found in boats (Table 1). On the other hand, slide ergometers were originally created to fill in the gap in the movement mechanics of the fixed ergometer, but they showed to increase fatigue when compared with the boats (Holsgaard-Larsen & Jensen, 2010). Specific mechanical restrictions with or without a slide can affect the muscle recruitment pattern, coordination and possible adjustments made in water (Table 1). During the 6-minute maximal test on a slide ergometer there was an increase in the heart rate with higher muscle activation of the lower limbs when compared to the fixed ergometer, and the fixed one also presented higher muscular activation in the dorsal region (Bull & McGregor, 2000).

Regarding technical performance, it is required that athletes of the same boat (called trim) have perfect synchronicity between paddles (Torres-Moreno et al., 2000). In order to mimic the specific condition of rowing in the water and assuming that 5-6% of the power produced by the rower is lost to paddle fluctuations in the return phase, an unbalanced rowing simulator was developed to verify which aspects associated with synchronization can affect performance (Baudouin & Hawkins, 2004). Theoretically, a possible way for the trimmings to increase the average speed of the boat would be to correct fluctuations, paddling in lateral coordination to balance the boat. However, nine pairs of rowers performed a maximum of two minutes at 36 rpm in two coupled ergometers, and no effect was observed on power in relation to the change in the height of the float in the return phase (Brown, Delau, & Desgorces, 2010). In this context, the technical adjustments that improve performance in the boat do not always present the same behaviour in the technique on an ergometer, even if the simulators have a lateral unbalanced effect. Therefore, implements were also studied in addition to the ergometer. It is known that the paddle design affects the course and the applied power, and this encouraged the creation of diverse models. Although the results do not present comparisons for the different types of paddle blades, studies have shown some interference; for example, with the Big Blade, which generates a significant increase in paddle angle when compared to other paddles (Caplan & Gardner, 2007). Although the influence of the blade design does not show significant increases in force coefficients in the water, this discussion allows to present results that provide higher individual comfort in choosing equipment according to the rower's appreciation. In relation to the paddle size, an increase of the rod length allows more prolonged course of the blade in the water (between 15-19 cm), which can improve the production of force by 40-80 N (McGregor, Patankar, & Bull, 2007).

Kinematics

In kinematics, biomechanical investigations have analysed the forces acting on a system such as the relationship between bodies and the boat and/or equipment. Therefore, it is essential to summarize information on technology and methodological implements that aid in technical improvements which can increase the force application and muscular activation throughout competition (Cabrera, Ruina, & Kleshnev, 2006; Caplan & Gardner, 2005; Roemer, Hortobagyi, Richter, Munoz-Maldonado, & Hamilton, 2013). Furthermore, the use of instrumental innovations of kinetics and predictive models of kinematics to create models of average speed of the boats allows for improving boat slipping (Cabrera et al., 2006). In order to ensure the accuracy of measured speed, kinetic studies bring important equipment validations and present accurate results on which factors would affect the paddling efficiency, such as angular variations combined with cine-anthropometric and mechanical aspects (Roemer et al., 2013). The complexity in developing studies in kinematics (Table 2) begins with the need for equipment such as high-resolution cameras, markers, force transducers, potentiometers and electrogoniometers connected to the rowers' joints to provide signals which are proportional to the main angles that interfere in speed. However, they are important elements to provide feedback to coaches and athletes, with the possibility of estimating performance and reconstructing an animated puppet with kinematic and kinetic overlap. Newly developed software allows rapid mechanical change and is used to evaluate images during movement, with calculations of the dependent variables observed in position, orientation, speed and acceleration of the rower's body and/or segments, as well as the effect of the technical change on the power produced by the athletes (Hawkins, 2000).

The reviewed studies indicate that it is possible to measure kinematic parameters from the images acquired during the movement by calculating the dependent variables of the observed data such as position, orientation, speed and acceleration of the body or segments (Table 2). For example, rowing efficiency can be affected with angular modification of the knee joint throughout the rowing action, with varying the height where the feet are supported on the boat (foot cradle). This assertion is confirmed by a study with 10 rowers, which verified that the acceleration and the fatigue produced during 3min and 30s at three different heights in relation to the position of the foot cradle obtained better results in the highest position with no change in velocity, and increased efficacy by fatigue reduction (Halliday, Zavatsky, & Hase, 2004). In addition to altering the foot cradle, the mechanics of the ergometers change the fatigue associated to the competitive level; meaning higher expertise results in lower interference of the fatigue (Colloud, Bahuaud, Doriot, Champely, & Chèze, 2006).

Studies that combine kinematic and kinesiology analysis associated to mechanical efficiency such as in strength training are rare. Only one study investigated the efficacy in the performance of finishing the stroke using different handgrips in the semi-pronate, supinate and pronate positions conventionally used in training with resistance training. According to the results, the semi-pronate position generates higher acceleration and muscle activity, thus being superior to the classic pronate handgrip, which reinforces the premise about training specificity for performance improvement (Bompa, Borms, & Hebbelinck, 1990). Kinematic analyses has provided significant motivation for rowing adherence in recent years; not only in high performance, but also in practitioners having some type of motor limitation, since they showed that the sport did not result in sudden accelerations combined with ballistic impact forces that are associated with traumatisms (Boykin et al., 2013; Christiansen & Kanstrup, 1997). In rowers with disabilities, studies with functional electrostimulation and modified indoor rowing machines have been performed (van Soest & Hofmijster, 2009). In comparing muscle activation between university rowers and a subject with a spinal cord injury using functional electrical stimulation in the leg musculature, Halliday et al. (2004) observed similarities in movements of the upper limbs, ankles and knees, with the only differences in the forces applied to the ergometer. However, no significant changes were observed implementing electrostimulation to reduce the frequency of strokes per minute.

Electromyography (EMG)

Electromyography studies help coaches to technically develop athletes in order to make muscular actions focusing on large muscle groups more effective (Turpin, Guével, Durand, & Hug, 2011a); in addition, showing the relation between the action mechanics combined with fatigue (Di Prampero, Cortili, Celentano, & Cerretelli, 1971) together with the physiological characteristics of the rowers can reveal differences in the kinematic pattern during training and improve performance by biofeedback (McGregor, Anderton, & Gedroyc, 2002). Moreover, an analysis of protocols and results stimulates future research (Cabrera et al., 2006; Caplan & Gardner, 2005; Roemer et al., 2013). According to Caplan and Gardner (2005), EMG is an essential method for analysis of neuromuscular activity in rowers by measuring the forces produced by the activated muscle groups. Despite being essential, studies show restrictions on the replicability of protocols in the ways and methods still under development; for example, many modifications occur in the protocol for EMG signal acquisition. The first studies were performed with only 12 points, but more recently they are being done using 23 observation points (Turpin, Guével, Durand, & Hug, 2011b).

The use of EMG in rowing presupposes that the superficial muscles are the most important for performance (Table 3). However, a deep neuromuscular evaluation shows that an increase of training sessions on an ergometer is correlated with a higher probability of injury in the knee and spine (Sprague, Martin, Davidson, & Farrar, 2007). Hip injuries in rowers between 2003-2010 show a higher prevalence in young rowers (14-23 years), and in women affecting the hips (85%). In addition, this study observed a higher occurrence of injury in preparatory school rowers (44%) and high school rowers (56%) (Boykin et al., 2013).The injuries were mostly related to tendonitis in the wrist, intersection syndrome of the forearm and fractures in the ribs (Christiansen & Kanstrup, 1997). EMG, isokinetic muscle strength, and video analysis performed on an ergometer by seven international level rowers and seven controls showed that all higher means in elite athletes for muscle acceleration and activation, including co-contraction of the anterior serratus and trapezium, indicating a higher predisposition to the occurrence of a stress fracture (Vinther et al., 2006). In high performance women, a 2,000 m test presented minimal coactivation of the trunk flexors and extensors, and most of the muscular activations of the spinal segments occurred between L3-S1, which may make this region more susceptible to soft tissue injuries (Pollock, Jones, Jenkyn, Ivanova, & Garland, 2012).

Conclusion

The present study has discussed factors, experimental designs and results from research on kinematic, kinetic and electromyographic aspects of rowers. Regarding kinetic aspects, stationary ergometers showed an increasing standard error with an increase of distance in the official 2,000-meter race, but with similar muscular activation in relation to a rower in the water and in comparison between different types of equipment. However, ergometers with mechanical slides showed a mechanical lag compared to stationary ergometers, and show increased fatigue when compared to boats. These observations are important for practical application because the specific mechanical restriction of slides and/or non-slide ergometers can affect the muscle recruitment pattern, coordination and possible adjustments made during a water race. Regarding kinematic components, the research results showed that angular modification of the joints along the rowing action could be modified with variation in the foot cradle height. Studies of electromyography showed greater activation in the recto femoral, dorsal, paravertebral, vast lateral, and gluteus Maximus muscles. In turn, studies using electromyography show that ergometer training increases the risk of injury to the hip, spine and knee regions. Furthermore, the results of assessing neuromuscular activation show differences between competitive level, age and gender. Coaches and athletes can use this information's in prophylaxis for injuries, as well as in planning a specific training.

Conflict of interest

The authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest, or non-financial interest in the subject matter or materials discussed in this manuscript.

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