All-out Test in Tethered Canoe System can Determine Anaerobic Parameters of Elite Kayakers

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Key words
- anaerobic evaluation
- tethered ergometry
- all-out
- performance
- canoe slalom

Abstract

The aims of this study were to use a specific all-out 30-sec tethered test to determine the anaerobic parameters in elite kayakers and verify the relationship between these results and sports performance. Twelve elite slalom kayakers were evaluated. The tethered canoe system was created and used for the all-out 30-sec test application. Measurements of peak force, mean force, minimum force, fatigue index and impulse were performed. Performance evaluation was determined by measuring the time of race in a simulated race containing 24 gates on a white-water course. Blood was collected (25-µl) for analysis of lactate concentration at rest and at 2, 4, 6, 8 and 10-min intervals after both the all-out test and the simulated race. The Pearson product moment correlation shows a inverse and significant relationship of peak force, mean force and impulse with time of race. Blood lactate concentrations after the all-out test and the simulated race peak at same time (4 min). Additionally, no interaction was visualized between time and all-out test/simulated race for blood lactate concentrations ($P<0.365$). These results suggest a relationship between the parameters of the all-out test and performance. Thus, the tethered canoe system is a useful tool for determining parameters that could be used in training control of slalom kayakers.

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Introduction

Protocols for evaluating physiological indicators of aerobic metabolism are widely recognized [3,4,6,21,27]. However, despite the great importance of anaerobic metabolism for many sports, few standardized evaluation tools or training protocols are firmly established.

Currently, the Wingate Anaerobic Test [2] is commonly used to determine anaerobic power. The Wingate Anaerobic Test measures peak power (P_{Power}), mean power (Me_{Power}), minimum power (Mi_{Power}) and fatigue index (FI) over 30 s of maximal effort on a cycle ergometer. The metabolic data produced by this test indicate that the Wingate Anaerobic Test requires a predominance of anaerobically derived energy from the subject [5]. Additionally, even if this test lacks specificity for other types of exercise, it may provide some insights regarding anaerobic parameters for athletes in general. In an attempt to apply the Wingate test to running exercises, Cheetham, et al. [8] modified the Wingate Anaerobic Test by performing a similar evaluation on a non-motorized treadmill using a tethered system composed of load cells. Importantly, it has been firmly established that high levels of glycolytic intermediaries, including adenosine triphosphate, glucose 1-phosphate, glucose 6-phosphate, fructose 6-phosphate, pyruvate and lactate were observed during the running exercise in the tethered system [7]. Additionally, the anaerobic index suggested by this test was validated in the laboratory [9], and the tethered ergometry was recently applied in the field for running [16] and in swimming tests [25]. Although tethered evaluation is considered useful for measuring force and metabolic parameters, its use is still restricted in sports that suffer from a lack of scientific information. For example, slalom kayakers routinely use tethered paddling in training sessions, but do not have standard evaluation protocols to measure force and physiological parameters using the tethered system.

The canoe slalom is a sport composed of descents in rivers and white waters, where the kayakers negotiate "gates" that can be found both with and against the current. During competitions, kayakers perform 2 runs, and the winner is defined by the time taken to complete the entire course [20]. Penalties of 2–50 s are incurred if the athlete touches or fails to negotiate any gate correctly [23]. Originating in 1932, until recently, few scientific studies had been performed to evaluate the physiological [1, 19, 26], psychological [17, 22, 28] or biomechanical parameters [13], as well as the variability in official races [23]. Requiring unique movements and, consequently, specific metabolic demand, lactic acid metabolism is predominant (29.9 %) compared to alactic (24.9 %) metabolism during simulated canoe slalom races and, when linked, shows predominance over aerobic metabolism (45.2 %) [29].

However, despite its importance, literature evaluating the force of paddling and physiological variables involved in anaerobic metabolism in canoe slalom remains scarce. This may be because of the difficulty in implementing protocols due to the peculiar characteristics of this sport. An all-out 30-sec test using a tethered canoe system (TCS) may be an alternative to analyze the force produced concomitantly with anaerobic metabolic characteristics. Additionally, if the results provided by the application of an all-out 30-sec test using the tethered canoe system have relationship to performance results, the use of this system can be implemented in training sessions aiming to improve force and anaerobic metabolic characteristics.

Thus, the aim of this study was to determine anaerobic parameters of slalom kayakers through a tethered all-out 30-sec test and investigate the relationship of these parameters with performance results in this sport.

Methods

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Participants

12 males, elite slalom kayakers (Brazilian national team, 18 ± 2 years, 68.1 ± 0.6 kg, 173.6 ± 0.6 cm, 10.3 ± 0.1 fat %) were evaluated. Athletes have been training and competing at the national and international levels for ± 5 years. Of the total sample, 58 % participated in the canoe slalom World Cup in 2013, and 75 % are classified in the canoe slalom world ranking according to the International Canoe Federation (ICF). Athletes and parents were informed about the risks of the experimental procedures, and both provided written, informed consent authorizing the athlete's participation in this study. All experiments were approved by the Ethics Committee and were conducted according to the ethical standards of International Journal of Sports Medicine [12].

Design

Prior to the evaluation sessions, athletes were asked to keep the same individual food/hydration habits and avoid hard physical activity, as well as alcohol and caffeine ingestion. For determination of anaerobic parameters from an all-out 30-sec test and performance results from a simulated race, each athlete participated in 2 evaluation sessions that took place at approximately the same time of the day (± 1 h) separated by 3 days:

1st session: An all-out test using a tethered canoe system to determine peak force (P_{Force}), mean force (Me_{Force}), minimum force (Mi_{Force}), fatigue index (FI) and impulse (IMP);

2nd session: A simulated race to obtain physiological parameters such as heart rate (HR) and blood lactate concentration ([Lac]), and performance results, including the total time and mean velocity.

All-out 30-sec test in tethered canoe system

The all-out 30-sec test was performed using a denominated tethered canoe system (TCS) constructed specifically for this purpose (▶ Fig. 1a). This system was initially described in a prototype model [18], which demonstrated high reproducibility (P_{Force} r = 0.87, CV = 6.6 %, P = 0.057; Me_{Force} r = 0.85, CV = 8.1 %, P = 0.108; peak [Lac] r = 0.95, CV = 8.9 mM, P = 0.315). The ergometer was composed of a load cell (CSL/ZL-MK, SP, Brazil) with 250 kgf capacity, using a strain gauge as the primary sensor from the electric application of Wheatstone bridges (1/2 Bridge). The dynamometer was fixed to a suction pad (Vonder, PR, Brazil), and its center was coupled to a metallic hook connected to an elastic cord (length–320 cm; external diameter–16.60 mm; internal diameter–4.00 mm; thickness–6.30 mm; Altaflex, SP, Brazil). This arrangement enables the researcher to measure the force performed by the kayakers, using their individual capabilities, to extend the elastic cord. Since the elastic cord eventually reaches its maximum length, each kayaker would present a different capability to maintain the elastic cord extended, or even retard its shortening. The force signal represents the kayaker effort to continuously surpass the resistance imposed by the elastic cord. The digital signal was converted with a module USB 6008 (National Instruments, TX, USA). During the test, signals were obtained at frequency of 1 000 Hz (totaling 30 000 Hz), then processed and filtered using LabView-Signal-Express 2.0 (National Instruments, TX, USA). The dynamometer (Crown Filizola, 20 kgf, SP, Brazil) was calibrated with the aid of a linear calibration curve (r ~ 0.99), obtained by the relationship between known weights (in a scale from 0 to 20 kgf) and its electrical potential values (mV). With respect to SI units, force was converted from kgf to N. Dynamometer calibration was performed in a vertical position without the elastic cord.

The test was performed in a 25 m outdoor swimming pool. Each slalom kayaker has used his own double-bladed paddle. However, the same boat (kayak model arrow, 355 cm length; 61 cm width, 16 kg mass) was used for every athlete. A keel was coupled to the rear of the boat (situated below the boat with an acrylic structure) to stabilize the ergometer. Athletes warmed

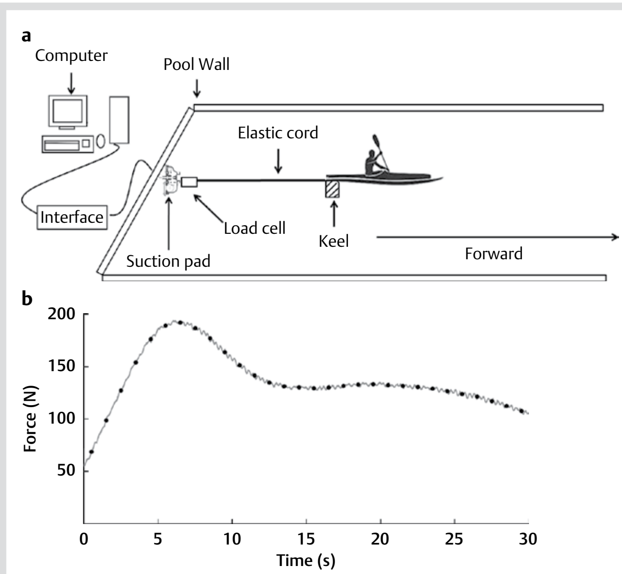

Fig. 1 **a** Tethered Canoe System (TCS) used in the all-out test. **b** Raw data at 1 000 Hz (grey) and the mean at each second (black) for the all-out test; the P_{force}, Me_{force}, and Mi_{force} of the all-out test are labeled.

up by paddling for 5 min at low intensity. At the end of each minute, the slalom kayakers were encouraged to perform 3 s of high intensity tethered paddling. After the warm up, the subjects remained in passive recovery for 5 min. The athletes were then instructed to paddle for 10 s at the low intensity paddling, and then perform the test at all-out intensity for 30 s after the signal (whistle) was sounded.

P_{Force} was defined as the highest force registered during the test. Me_{Force} was defined as the mean force of the all-out test. Mi_{Force} was defined as the lowest signal during the test (▶ **Fig. 1b**). IMP was calculated by the numerical integration of a trapezoidal method from the total area of the 30 000 Hz obtained from the test. The classical equation proposed by Bar-Or et al., [2] was used for FI: $FI = (P_{Force} - Mi_{Force}/P_{Force}) * 100$.

Simulated race

The simulated race was conducted on a white water course (Itaipu, PR, Brazil) where the athletes performed competitions and training sessions. Each slalom kayaker has used his own boat and double-bladed paddle during the simulated race. All boats and paddles complied with ICF regulations (i.e., model, length, width and mass). The warm-up consisted of low intensity paddling in a lake for 5 min. At the end of each minute, the slalom kayakers were encouraged to perform 3 s of high intensity free paddling. The course had 24 gates (18 with and 6 against the current) to be negotiated by the kayakers. The athletes were instructed to perform similarly to an official race; however, the penalties were not considered.

Time was recorded with a timer (Casio, HS-30W – N1). The distance and velocity were measured using a global positioning system (GPS-Polar, RS800, RJ, Brazil; precision = ±98 % either for distance as well as velocity) coupled just below the canoeist knee. HR was measured using a validated [10] heart rate monitor (Polar, RS800, RJ, Brazil; precision = ±99 %). Data were acquired at 1-s intervals. The HR peak (P_{HR}) was defined as the highest value during the simulated race. The mean HR (Me_{HR}) was defined as the mean of all HR measurements obtained during the race.

Blood sampling

Blood samples (25 µl) were collected from the earlobe with a heparinized capillary and were deposited into microtubes (*Eppendorf*–1.5 ml) containing 50 µl of 1 % sodium fluoride (NaF); the samples were collected while the participant was at rest and 2, 4, 6, 8 and 10-min intervals following the all-out test and simulated race, and [Lac] was measured. The samples were frozen at −20 °C before being homogenized and analyzed in a lactimeter (YSI – 2300-STAT-Plus™ Glucose & Lactate Analyzer – Yellow Springs).

Statistical analysis

Statistical analysis was carried out using a statistical software package (Statistic 7.0, Statsoft, OK, USA). Mean and standard deviation were calculated for all studied variables. Prior to the parametric analyses, homogeneity and normality were confirmed using the Levene and Shapiro-Wilk tests, respectively. A two-way ANOVA and a Scheffé post-hoc test were used to assess the interaction (time × all-out test/simulated race) of lactate concentration and multiple time points in the all-out test and simulated race. A Pearson product moment correlation was applied to the relationship between the results of the all-out test and simulated race. Confidence intervals were also calculated for relationships analysis (Pearson product moment correlation) and standard deviation with $\alpha = 0.05$ ($\sigma/\sqrt{n}$). In all cases, statistical significance was set at $P < 0.05$.

Results

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▶ **Table 1** shows the absolute (N) and relative ($N \cdot kg^{-1}$) values of P_{Force}, Me_{Force}, Mi_{Force}, FI and IMP obtained in the all-out test using the TCS. The mean time to attain P_{Force} was 6.4 ± 0.6 s (fifth second = 9 % of participants; sixth second = 41 % of participants; seventh second = 50 % of participants).

For the simulated race, the results evaluated as time of race, distance covered and mean velocity, as well as physiological indexes such as peak and mean heart rate, are shown in ▶ **Table 2**. There was no relationship between time of race and mean velocity (r = 0.38, $P = 0.212$, CI = −0.22–0.77).

▶ **Fig. 2** illustrates the significant and inverse correlations observed between the absolute and relative P_{Force}, Me_{Force}, and IMP values and the time in simulated race. Regarding the Mi_{Force} and FI, no relationship was visualized (A.Mi_{Force} × TR – r = −0.43, $P = 0.152$, CI = −0.19–0.81; R.Mi_{Force} × TR – r = −0.45, $P = 0.134$, CI = −0.17–0.81; FI × TR – r = −0.03, $P = 0.910$, CI = −0.55–0.59). Additionally, no relationship was visualized between mean velocity (MV) and the force results from the all-out test (range r = 0.24–0.36).

Table 1 Absolute (A) and relative (R) values for peak force (P_{Force}), mean force (Me_{Force}), minimum force (Mi_{Force}), FI and impulse (IMP) obtained in the all-out 30-sec test.

	A.P_{Force} (N)	R.P_{Force} ($N \cdot kg^{-1}$)	A.Me_{Force} (N)	R.Me_{Force} ($N \cdot kg^{-1}$)	A.Mi_{Force} (N)	R.Mi_{Force} ($N \cdot kg^{-1}$)	FI (%)	A.IMP ($N \cdot s$)	R.IMP ($N \cdot s \cdot kg^{-1}$)
Mean	170.29	2.50	121.12	1.78	86.30	1.27	49.06	3 634.73	53.46
SD	35.36	0.39	23.58	0.26	19.96	0.27	6.62	707.26	7.72
CI ($\alpha = 0.05$)#	(25.0–60.0)	(0.28–0.66)	(16.7–40.0)	(0.18–0.44)	(14.1–33.8)	(0.19–0.46)	(4.6–11.2)	(501.0–1 200.8)	(5.4–13.1)

#Upper and lower confidence limits of confidence interval for SD

	TR (s)	Distance (m)	MV (km/h^{-1})	P_{HR} (bpm)	Me_{HR} (bpm)
Mean	109.1	289.6	9.62	184	173
SD	15.0	42.8	1.21	8	14
CI ($\alpha = 0.05$)#	(10.6–25.4)	(30.3–72.6)	(0.86–2.05)	(5.67–13.5)	(9.9–23.7)

#Upper and lower confidence limits of confidence interval for SD

Table 2 Time of race (TR), distance, mean velocity (MV), peak heart rate (P_{HR}) and mean heart rate (Me_{HR}) obtained in a simulated race.

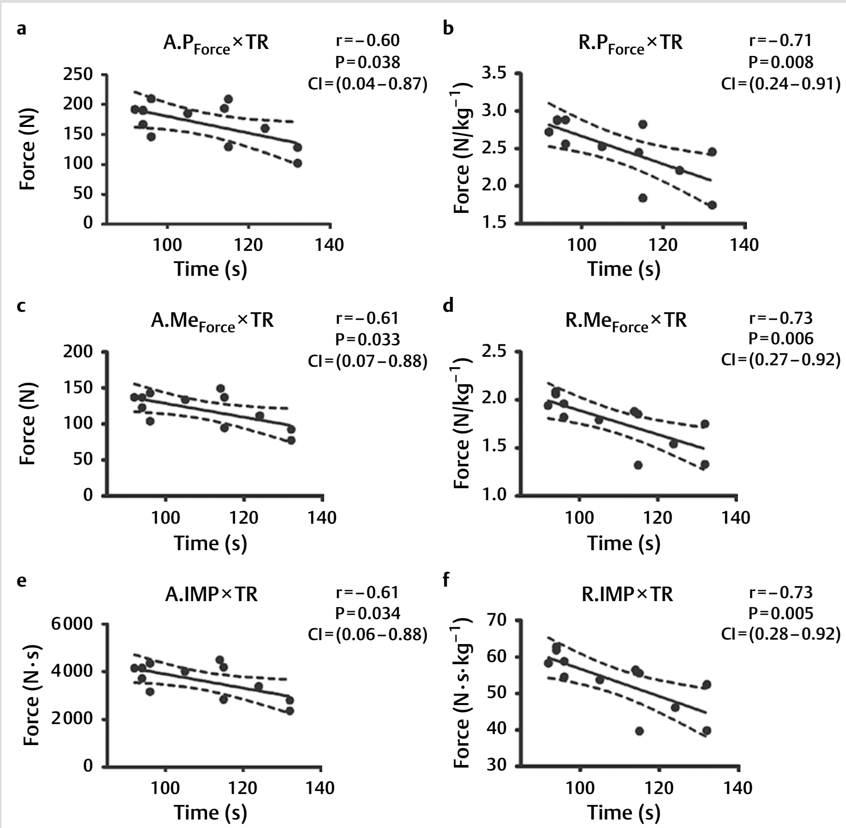

Fig. 2 Pearson product moment correlation (r) and confidence interval (CI) between the TR and the absolute and relative P_{Force}, Me_{Force}, and IMP values. A.P_{Force} = absolute peak force; R.P_{Force} = relative peak force; A.Me_{Force} = absolute mean force; R.Me_{Force} = relative mean force; A.IMP = absolute impulse; R.IMP = relative impulse; TR = time of race. $P<0.05$.

Regarding the comparison between [Lac] in the all-out test and simulated race, the two-way ANOVA (**Fig. 3**) analysis showed no interaction of time (at rest and at 2, 4, 6, 8 and 10-min intervals) and protocols (all-out and simulated race) ($P<0.365$). Peak [Lac] was similar for all-out and simulated race (8.07 ± 1.83 mM and 8.29 ± 2.43 mM, respectively).

Discussion

The main findings of the present study showed that the all-out 30-sec test using the TCS is a useful tool for determining anaerobic parameters of slalom kayakers. In addition, relevant relationships were observed between the results provided by the all-out 30-sec using the TCS and the performance results from the simulated race in canoe slalom.

The P_{Force} was inversely correlated with TR (**Fig. 2a, b**). Interestingly, in 2012 Olympic Games and 2013 World Championship of canoe slalom (K1-Men), the mean time between gates was 4.5 and 4.3 s, respectively (International Canoe Federation, 2013. In Internet: www.events.slalom.canoeicf.com/standings/standings-2013, 07/07/2014; Olympic.org, 2012. In Internet: www.olympic.org/canoe-kayak-slalom-k-1-kayak-single-men, 07/08/2014). In this study, 91 % of the athletes attained the P_{Force} between 6 and 7 s. Although there is a range of paddle techniques that a slalom kayaker uses during a race [14] and differences to negotiate a gate [15], it is possible to propose that the initial effort (first 6 s) of the all-out test is related to the efforts required to negotiate some gates, especially the downstream gates. While the former requires high force development to lead with the elastic cord resistance, the latter also requires high force development to lead with the water resistance caused by the opposing water flow. Although it is impossible at present, if we assume that the P_{Force} obtained in the all-out test is closely related to performance in the canoe slalom, tethered training sessions intended to improve the P_{Force} can thus improve performance in the sport. Future studies of the effects of tethered training on P_{Force} and performance results may answer this question.

Papoti, et al. [24] visualized that the Me_{Force} obtained during an all-out 30-sec in tethered swimming is related with the performance in swimming, assuming the Me_{Force} as the anaerobic fitness of the swimmers. In the present investigation, the Me_{Force} and IMP were inversely correlated with TR (**Fig. 2c–f**). During the all-out test using the TCS, higher levels of IMP and Me_{Force} were obtained by the kayakers that were capable to produce and sustain the force throughout the 30 s. The capacity to produce and sustain higher levels of force are extremely necessary for the slalom kayakers to negotiate the gates and travel around natural obstacles [20]. Therefore, the inverse correlations of Me_{Force}/IMP and TR may mean some similarity of the anaerobic capacity required in the all-out test and simulated race. Thus, Me_{Force} and IMP obtained in the all-out test may be accepted as anaerobic indexes of slalom kayakers.

In line with this, the metabolic results of the all-out test in the present study also showed relationship with the results of the simulated race. In regard of the [Lac], the two-way ANOVA did not show an interaction between time and protocol. Additionally, the time to peak [Lac] was similar in both tests (**Fig. 3**). Though scientific studies specifically addressing slalom canoe are lacking, Zamparo, et al. [29] have previously reported the analysis of a simulated race. The authors reported similar peaks [Lac] (8.10 ± 1.60 mM) after a simulated race when compared with the results after the all-out test and the simulated race in the present investigation (8.07 ± 1.83 and 8.29 ± 2.43 mM, respec-

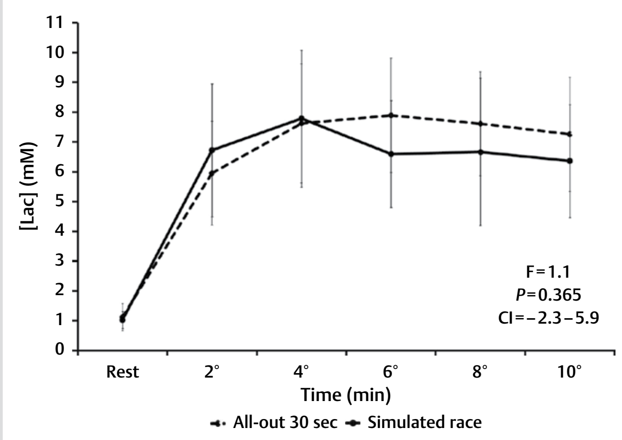

Fig. 3 Two-way ANOVA interaction analysis on blood lactate concentrations [Lac] at different time points (collected at rest and at 2, 4, 6, 8 and 10-min intervals) in the all-out test and simulated race. $P<0.05$.

tively). In that sense, the metabolic similarity visualized in the present study between the all-out test and simulated race does not seem to have happened by chance, suggesting that the bioenergetic supply in the all-out test was similar for the simulated race. Although the MV may be understood as a performance index of the kayakers during a simulated race, this variable did not show significant relationship with TR, which is the result considered to determine the champion. The standard deviation of distance performed by kayakers (42.8 m) was comprised of 15 % of the total distance in the simulated race (**Table 2**). This result may have contributed to the absence of relationship between MV and TR. However, the variation of 42.8 meters is normal in a race and occurred due to different strategies adopted by the kayakers [13, 20]. Additionally, taking into consideration the 24 gates travelled by the kayakers, the mean difference from gate to gate comprises only 1.78 meters. Furthermore, the MV did not show a relationship with force results from the all-out 30-sec test. As a result, we propose that the TR is the main performance index of kayakers during a simulated race.

One major challenge of the all-out test using the TCS is that the kayaker does not have significant displacement through the test. Indeed, during a canoe slalom race the kayaker performs many kinds of paddles [13–15] across natural obstacles [20]. Nevertheless, Hunter, et al. [14] state that during a canoe slalom race, 67–71 % of the paddles are propulsive stroke named as *forward stroke*. According to these authors, the *forward stroke* pulls straight though the water effecting a propulsion of 90 % on the boat with no significant change in direction. Despite the fact that TCS does not necessarily require significant displacement during the all-out test, it is relevant to state that all paddles performed by the slalom canoeist were the *forward stroke*.

Regarding the canoe slalom, until now no study has investigated the application of the tethered system in this sport. In this regard, it is necessary to use an ergometer that provides insights into paddling characteristics and provides parameters, as well as metabolic characteristic related to results from a performance task. The study that was closer to analyzing the force performed by the kayaker considering paddling characteristics was conducted by Fleming, et al. [11]. These authors aimed to investigate whether variables such as muscle activation, stroke force and kinematic data differ from on-water paddling and an on-kayak ergometer. Once significant differences were found between the variables investigated, the authors suggest that at least biomechanically, paddling with an on-kayak ergometer and in an on-water setting are not perfectly matched. Although the results of the present investigation do not suggest any biomechanical similarities between on-water and tethered paddling, it should be noted that the forces (P_{Force}, Me_{Force}), IMP and [Lac] were related to the performance in canoe slalom, indicating that the tethered, all-out 30-sec test can give insights about anaerobic parameters for slalom kayakers.

Despite differences between the TCS setting and a real canoe slalom race, this study is the first of its kind to propose an ergometer that takes into account an important technique of paddling (i. e., *forward stroke*) and enables acquisition of the force that the slalom kayakers perform during tests. During training sessions in rivers and white water, the relationship between the coach and the athlete is hampered by the fact that the coach analyzes the training from the riverbank. Using TCS, the coach can correct stroke technique easily and up close. Moreover, it is worth noting that not all kayakers have a specific location for their practice (i. e., training in river or white water is not always possible). Therefore, only using a simple tethered system and a swimming pool, specific training techniques can be applied independent of geographical location and climatic conditions. As a limitation, during the all-out test and the simulated race, the mean paddling frequency was not recorded. Future studies regarding these aspects may provide insight into how paddling frequency affects performance in the canoe slalom.

In conclusion, aiming to increase scientific information about the canoe slalom, the present study showed that the all-out 30-sec test using the TCS is a useful tool for determining anaerobic parameters for slalom kayakers. Additionally, relevant relationships were observed between the results provided by the all-out 30-sec test using the TCS with performance results from the simulated race in a canoe slalom.

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