International Journal of Performance Analysis in Sport

ISSN: 2474-8668 (Print) 1474-8185 (Online) Journal homepage: https://www.tandfonline.com/loi/rpan20

Physiological, psychological and biomechanical parameters applied in canoe slalom training: a review

Leonardo Henrique Dalcheco Messias, Ivan Gustavo Masselli dos Reis, Homero Gustavo Ferrari & Fúlvia de Barros Manchado-Gobatto

International Journal of Performance Analysis in Sport
2014, 14, 24-41.

Physiological, psychological and biomechanical parameters applied in canoe slalom training: a review

Leonardo Henrique Dalcheco Messias, Ivan Gustavo Masselli dos Reis, Homero Gustavo Ferrari and Fúlvia de Barros Manchado-Gobatto

Laboratory of Applied Sport Physiology, School of Applied Sciences, University of Campinas – UNICAMP. Pedro Zaccaria St. 1300, Santa Luíza, 13484-350 Limeira, SP, Brazil. +55 19 3201-6669

Abstract

Canoe slalom is an Olympic sport held in natural and artificial rivers, with peculiar characteristics as compared to other sports. This sport is divided into the subdisciplines of kayak single (K1), canoe single (C1) and canoe double (C2), which also have specific characteristics. As with many other Olympic sports still on the rise, which lack expressive media recognition, few scientific studies have investigated canoe slalom. This information gap minimises possible similarities between theory and practice and advances in the preparation of teams (i.e., coaches, physical trainers and athletes). It is well established that for athletic development, several areas of knowledge must be integrated and applied to the specific nature of the sport, optimising sports training and athletic performance. Accordingly, this review aims to bring together studies on the physiological, psychological and biomechanical parameters, sports strategies and periodisation training applied to canoe slalom, explaining the need for increased knowledge in each of these areas of the practice of this sport.

Keywords*- Canoe slalom, Training, Physiology, Psychology, Morphology, Biomechanics*

1. Introduction

Sports on the rise increasingly use scientific information to improve the performance of their athlete and, in most cases, to develop and receive recognition. However, this assessment does not transpire in the same way for less recognized sports, being characterised by a shortage of scientific studies.

Canoeing is featured among the Olympic sports that gradually elevate their media exposure but lack scientific studies. Canoeing consists of a range of different specificities and is has distinctive characteristics from other water sports that use boats. "Canoe" has several disciplines: i) Canoe Sprint, held in rivers or lakes with calm waters and limited boundaries; ii) Canoe Slalom, performed in white waters and rivers, over distances of approximately 300 meters, in which athletes must negotiate gates both downstream (with the current) and upstream (against the current); iii) Canoe Ocean Racing, held in marine waters aiming at going a predetermined distance in the shortest possible time; iv) Canoe Marathon, held in calm and turbulent waters without a course previously determined, in which athletes must overcome obstacles but not necessarily within the boat (disembarking from the boat and carrying it with their own hands is an alternative); v) Canoe Polo, which resembles water polo but is performed with kayaks and paddles; and vi) Canoe Freestyle, which uses waves and eddies in which athletes must perform technical moves without leaving the wave, thus accumulating points (Michael *et al.*, 2009; ICFa, 2013).

Considering the various Canoe branches, the acquisition of scientific information about the peculiarities of each discipline in this sport becomes even more difficult. Studies that investigate Canoe Sprint, although restricted, are still more frequent in the literature, possibly because it is a cyclic sport with races defined by fixed distances, which is closer to the severity needed when adopting scientific methods. When the searching for studies on Canoe slalom, specifically regarding approaches related to means and training methods of physiological evaluation, scientific deficiencies are even more pronounced.

Because it is held in rivers, with races characterised by displacement exercises both for and against the current, canoe slalom has several peculiarities and suffers interference from the environment where it is practiced and thus is not considered a "closed" sport (i.e., held in conditions of high control). In this sense, studies of slalom that are guided by scientific methods with traditional characteristics are hampered. This is one of the major reasons for the low number of scientific studies on canoe slalom. Therefore, there are very few reports in the literature about the metabolism and bioenergetics predominant in slalom (Zamparo *et al.*, 2006), variability of races (Nibali *et al.*, 2011), race strategies (Hunter *et al.*, 2008; Hunter, 2009), biomechanical analyses (Hunter *et al.*, 2007), psychological analyses (Males *et al.*, 1998; Moran and MacIntyre, 1998; White and Hardy, 1998; Macintyre *et al.*, 2002; Macintyre and Moran, 2007) and physiological analyses (Sidney and Shephard, 1973; Baker, 1982).

The purpose of this review is to encourage dialogue between those involved in practical and theoretical canoeing, with emphasis on studies of slalom, helping the rapprochement between science and coaches/technical committees of these sports, presenting the different scientific aspects of canoeing. Accordingly, the present review addresses different aspects of the sport and is divided into a brief historical section containing the profile characterisation studies involving canoe slalom, followed by examination of physiological, psychological, biomechanical, performance, race strategy and training aspects.

Scientific studies were searched for using the search engines EBSCO Host and NCBI PubMed and various combinations of words such as "*training*", "*tests*", "*physiological*", "*biomechanics*", "*canoe*", "*slalom*", "*white water*", "*canoeing*" and "*kayaking*". For the studies that emphasised the "white water" term, only the articles that clearly described the slalom discipline were included. Studies that did not relate psychological, biomechanical, performance, race strategies and training with canoe slalom were not included in this review. Only studies written in English as the primary language were used in this paper. Factors such as sample characteristics (level of training), the number of samples evaluated and the reproducibility of the assessments proposed in the mentioned studies were not considered limiting and did not determine their inclusion in this review.

2. Canoe Slalom

The first canoe slalom competition was held on September 11th, 1932, in Switzerland. Canoe slalom arose from an adaptation of "slalom skiing" held on snow, which could only be performed in winter. The adequacy of performance strategies adopted in other seasons resulted in the use of kayaks in rivers and white waters (ICFb, 2013). The first canoe slalom world championship occurred in 1949, in Geneva. It was later included in the Olympic Games in Munich in 1972 (Sidney and Shephard, 1973; Ridge *et al.*, 2007). In 1992, the slalom event returned to the Olympic Games in Barcelona and was held in La Seu d'Urgell, near the border with Andorra (ICFc, 2013). Since that point, slalom has become established as an Olympic sport.

In the slalom sport, several branches can be found with even greater specifications. The discipline K1 (kayak single) is carried out in boats whose minimum dimensions are 8 kg, 60 cm wide and 350 cm long, where the athlete, in a seated position, paddles with the aid of a double-bladed paddle. Similar to K1, the C1 (canoe single) discipline is held in boats that must have minimum proportions of 8 kg, 60 cm wide and 350 cm long; however, the canoeist uses a single-bladed paddle. The performances that adopt the canoe as a boat can also be performed by pairs, in a discipline called C2 in (canoe double), with two canoeists in the same boat (13 kg, 75 cm wide and 410 cm long), and the paddles used similar to those of C1 athletes (ICFd, 2013).

Despite different boats or stroke tools, the slalom competitions take place in similar environments, running on natural and artificial rivers. During competitions, performances are characterised by two runs, and the winner is defined by the time he/she completes the entire course, negotiating "gates" that can be found both with and against the current. To touch or fail to negotiate a gate invokes a penalty, resulting in an increase of 2 or 50 s, respectively, added to the final time of the run (Nibali *et al.*, 2011).

It is important to note that the official courses have closer to 90 seconds duration (Hunter, 2009), with random courses composing a range between 200 and 400 meters (ICFd, 2013). The latter are defined at the beginning of the competition without allowing athletes to test the course prior to the competition (Moran and MacIntyre, 1998). Although athletes could watch a 32 demonstration run at the course after 1997 (performed by several good paddlers), according to the International Canoe Federation, they cannot perform training in the course prior to their participation (Macintyre and Moran, 2007). In that sense, Nibali *et al.* (2011) stress that variability in performance for swimmers, runners, cyclists and flat water kayakers appears to be related to the maintenance of high-intensity exercise by the athletes. However, for canoe slalom, the athletes not only have to sustain high-intensity efforts but also have to negotiate gates and natural obstacles, brining in the variability of the performance attributed to intensity and technical ability.

3. Profile of studies on canoe slalom

Table 1 shows studies focused on physiological, psychological, biomechanical, performance, race strategy and training aspects of canoe slalom, published from 1973 to 2013. It is possible, by literature review, to observe a clear lack of scientific information involving slalom, as only twenty-one studies were found that directly considered the aspects of this sport that this review emphasises. Underscoring the need for knowledge in this area, only one study was found on physiological parameters and specific assessments capable of assisting in the development of training programs, as well as evaluative responses, after periodic slalom training. This can be considered a detrimental factor to the sport, given the recent placement of Banfi *et al.* (2012), noting the need for information about the volume and intensity of training essential for the growth and improvement of athletes' performance in any sport.

Table 1. Studies regarding physiological, psychological, biomechanical, performance, race strategy and training aspects of canoe slalom published in periodical journals from 1973 to 2013.

Author(s)	**Year of publication**	**Periodical**	**Canoeists (n)**	**Objective of the study**
Sidney and Shepard	1973	European Journal of Applied Physiology	12	To describe the structural and functional factors related to the features of success in canoe slalom competition
Baker	1982	British Journal of Sports Medicine	19	To analyse the blood lactate concentration after competition in a canoe slalom race
Vaccaro and Gray	1984	Research Quarterly for Exercise and Sport	13	To analyse the physiological characteristics in elite canoe slalom
Sklad *et al*	1994	Biology of Sport	10	To determine the morphological differences in elite rowers and canoe slalomists
Vest	1997	Kinesiologia Slovenica Scientific Journal on Sport	20	To characterise the influencing factors on competitive results in canoe slalom
White and Hardy	1998	The Sport Psychologist	3	To explore qualitatively how high-level canoe slalomists use images in competitions and training
Moran and Macintyre	1998	The Irish Journal of Psychology	12	To investigate the images of kinaesthetic processes in canoe slalomists

Males *et al*	1998	Journal of Applied Sport Psychology	9	To analyse qualitatively the metamotivational states during canoe slalom competition
Macintyre *et al*	2002	Perceptual and Motor Skills	31	To explore the controllability of imagination of elite athletes and the intermediate canoe slalom
Usaj	2002	Kinesiologia Slovenica Scientific Journal on Sport	7	To analyse the effects of different methods within distinct periodisation in canoe slalom
Beatie *et al*	2004	Journal of Sport and Exercise Psychology	81	To explore self-discrepancies in self-confidence in relation to performance and cognitive anxiety in canoe slalomists
Ong *et al*	2005	Sports Biomechanics	42	To characterise and differentiate the boat (kayak) of canoe slalomists
Zamparo *et al*	2006	International Journal of Sports Medicine	8	To investigate the metabolism prevalent in canoe slalom
Hunter *et al*	2007	Sports Biomechanics	4	To analyse canoe slalom races using kinematics and determine the reliability intra- and interobserver
Ridge *et al*	2007	European Journal of Sport Science	43	To characterise the specific morphological aspects of canoe slalomists
Macintyre and Moran	2007	Journal of Imagery Research in Sport and Physical Activity	12	To explore imagery experiences among elite canoe slalomists
Hunter *et al*	2008	Sports Biomechanics	30*	To kinematically analyse and assess the strategies used during a canoe slalom race
Hunter	2009	Sports Biomechanics	17	To study different courses chosen in simulated canoe slalom races by kinematic analysis
Nibali *et al*	2011	European Journal of Sport Science	151	To characterise the variability effects between canoe slalom races
Bílý *et al*	2011	Journal of Outdoor Activities	110	To find selected somatic factors of canoe slalomists and compare with previous measurements

Bílý *et al*	2012	European Journal of Sport Science	84	To analyse the effect of paddle blade adherence as well as the prevalence of the use of the stroke arm on the morphological aspects of canoe slalomists

* (n) characterised by number of runs in official races.

Notwithstanding the clear need, it is possible to identify a small quantitative growth in the number of scientific publications involving physiological, psychological, biomechanical, performance, race strategies and training and canoe slalom in recent years (Figure 1). According to the graphic representation, there was a 62.5% increase in the number of scientific publications indexed in 2001-2010 compared to the previous three decades.

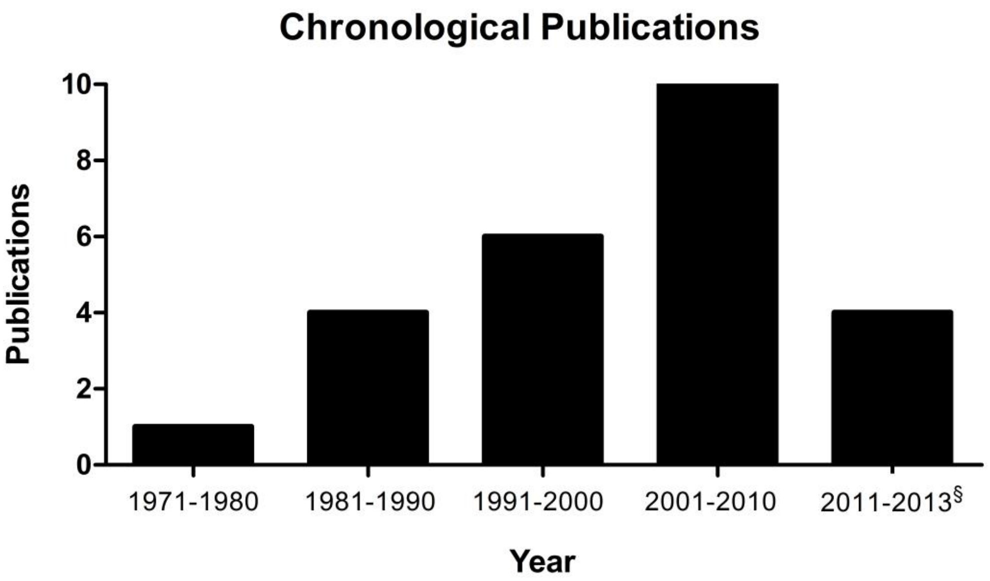

Figure 1. Distribution of publications regarding physiological, psychological, biomechanical, performance, race strategy and training aspects related to canoe slalom in the past five decades (period analysed: 1971 to 2013)
§ Reviewed until July 2013.

Regarding the percentage distribution among these studies of subjects related to slalom publications, it is possible to observe a predominance of physiological, anthropometric. biomechanical evaluations and race strategies (Figure 2). It is important to emphasise the lack of studies directly related to training, such as the means and methods of training and periodisation applied to the sport, as well as obtaining physiological data through evaluations of specific characteristics of the sport. Despite this lack in the literature, in the subsequent topics of this review, it will be possible to identify some aspects listed in an attempt to bring together the data from their studies into canoe practice, with emphasis on performance optimisation of canoeists.

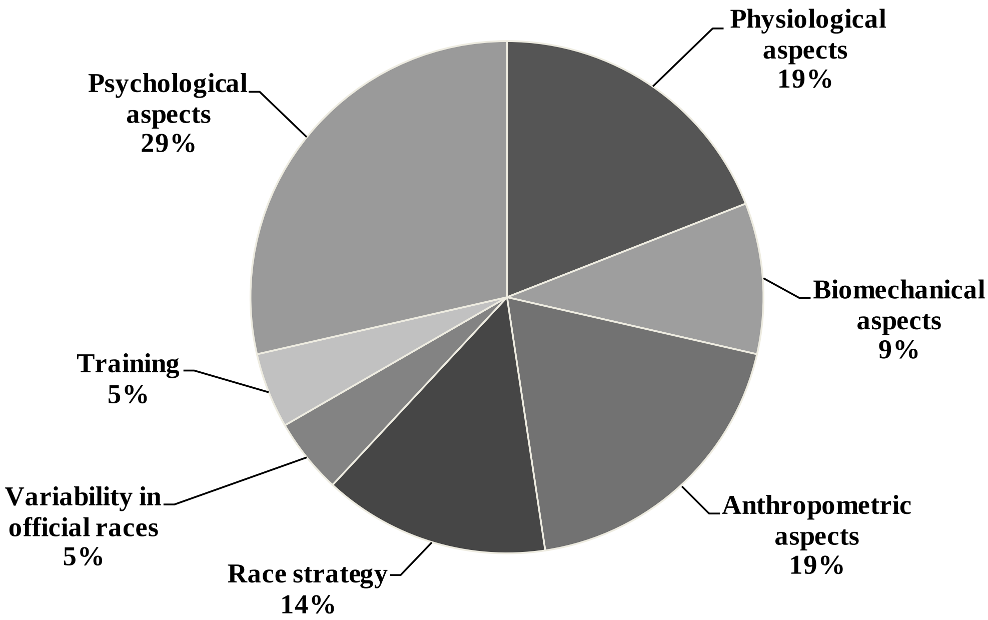

Figure 2. Percentage distribution of scientific articles indexed when considering the main topics investigated in the publications. The results are shown as a percentage of the 21 publications found on canoe slalom.

4. Physiological variables and energetic predominance in canoe slalom

Information on the predominance of energy systems, lactate concentration and maximal oxygen uptake in canoe sprint are commonly found in the literature (Zamparo *et al.*, 1999; van Someren *et al.*, 2000; Bishop *et al.*, 2002; van Someren and Oliver, 2002; Zamparo *et al.*, 2006; Michael, 2008), which is in contrast with canoe slalom. This difference is possibly related to differences in the characteristics of the races.

The pioneering study involving physiological analyses in canoe slalom was published by Sidney and Shephard. (1973) one year after its insertion as a demonstration sport in the Munich Games. The authors reported the physiological and functional data from approximately 10 male and 2 female aspirants to the Canadian national white water slalom team. However, the subjects in this pioneering study regarding physiological characteristics in canoe slalomists were evaluated outside of their place of competition and training. Thereafter, Baker. (1982) investigated the blood lactate concentrations in different slalom categories (K1, C1 and C2). The author found that, after the execution of the official race, male K1 athletes had a greater elevation of this metabolite (16.18±1.20 mM) compared to female K1 athletes (12.20±1.77 mM). Analyses revealed that male C1 and C2 competitors had blood lactate concentrations of 13.10±1.75 mM and 10.83±1.68 mM, respectively. Baker suggested that the participation of lactic anaerobic metabolism was important in races of different canoe slalom categories, despite the differences between slalom categories and athlete’s gender, due to the elevated blood lactate concentrations obtained in these conditions.

Still aiming to investigate the participation of aerobic and anaerobic metabolism (lactic and alactic) in providing energy during competition and training, Zamparo *et al.* (2006) studied race simulations of 300 meters for canoe slalom (K1). Using the equation proposed by Wilkie. (1980), the authors determined the predominance of energy systems in race simulation, as well as in a maximal test in flat water (300 meters all-out test), considering three variables: *Aer* (contribution of aerobic metabolism), *Anl* (contribution of lactic anaerobic metabolism) and *AnAl* (contribution of alactic anaerobic metabolism). According to the authors, using these values to quantify the contribution of metabolism and dividing by the duration of the exercise, it is possible to obtain the predominance of each type of metabolism during participation. The authors report that in the two evaluation sites (river and lake) and in both testing conditions (simulated race or stimulus of 300 m), the contribution of aerobic metabolism is between 45 and 47 %, with the lactic anaerobic metabolism responsible for 29.9 % in simulated races and 33.9 % in maximal tests. With respect to alactic metabolism, the authors present values close to 24.9 % and 19.0 % in simulated races and maximal tests, respectively.

The predominance of specific energy or metabolism systems in exercises is determined primarily by the intensity and duration of the effort. Even considering the short duration and high intensity of official slalom races (90 to 120 s), there is great interest in providing energy by aerobic metabolism, and training sessions with oxidative character are interesting tools implemented to improve the performance of slalom athletes (Zamparo *et al.*, 2006).

In contrast, other factors such as different categories and boats used are elements that can interfere with both biomechanical and physiological variables, such as energy demand. Pendergast *et al.* (1989) emphasised that differences related to boat, paddle and canoeist body size can generate different energy expenditures. Studying a heterogeneous sample (elite and inexperienced athletes slalom athletes), the authors note that athletes who do not have a developed technique should run trainings to improve this aspect because the technique is significant for reducing energy expenditure and improving efficiency mechanics. Moreover, according to these authors, elite athletes must turn their attention to training with an emphasis on increased muscle mass, especially in the upper limbs, thus improving their metabolic power.

5. Morphological profile

The characterisation of morphological profiles has become, over the years, a relevant tool in the identification and pursuit of great athletes around the world (Norton and Olds, 2001), especially in detecting potential talent in individual sports.

In this sense, analysing the morphological particularities of canoeists, Freeman *et al.* (1987) look for similarities between canoeist profiles of canoe sprint and slalom disciplines, characterising them as mesomorphic individuals. Expanding the comparison of somatotypes to other sports, Table 2 exposes anthropometric and morphological parameters of various sports performed in boats. Interpreting the data shown, it is possible to highlight the similarity in somatotype patterns of canoe sprint and canoe slalomists with other sports presented. However, despite being similar, the differentiation and identification of specific morphological profiles in various sports is necessary.

Supporting this idea, Sklad *et al.* (1994) initially reported differences ($P < 0.05$) in anthropometric characteristics (weight and height) between rowers and slalom kayakers. Thereafter, Ackland *et al.* (2003) evaluated Olympian athletes (canoe sprint, Sydney, 2000) and reported that their sample was characterised as homogeneous in relation to anthropometric and somatotype variables. However, even though marked differences were not observed when compared to general population characteristics, canoe sprint athletes show peculiarities such as lean bodies, large circumferences of the upper limbs, and narrow hips. Similarly, Vedat. (2012) also observed similar results for the Turkish national canoe team. In the study of Alves *et al.* (2012), the somatotype was not given; however, there were similarities regarding height (cm), weight (kg) and fat percentage (%) when canoe polo athletes were compared with canoe sprint and slalom athletes. Studying a large sample of female paddlers, Battista *et al.* (2007) found an endomorph somatotype predominance, thus indicating differences in anthropometric characteristics for the canoe slalom, sprint and polo.

Anthropometric variables of canoe slalomists were also investigated. Male canoe slalom athletes from the USA were studied, where the mesomorphic profile of athletes was predominant (Vaccaro and Gray, 1984). In addition, Ridge *et al.* (2007) note that male canoe slalomists have a high brachial index (ratio between lengths of forearm and arm) that is 1.9 % higher compared to reference values of the population (76.7 % for slalomist athletes and 74.8 % for reference values) (Norton and Olds, 2001). As this factor is primarily affected by genetic variables than training adaptations, it highlights that this index may be an indicator for identifying potential talent.

6. Psychological aspects

In regards to the relationship between physical and sporting performance aspects, some attention has been given in the literature to studies relating psychology to performance. However, even though it is evident that reduced performance can be related to psychological factors, minimum training sessions are implemented for the development of psychological skills of these athletes (Carr, 2006).

Psychological skills play an extremely important role in performance during the training of slalom athletes and, particularly, during races. In this way,(Macintyre and Moran, 2007) emphasise that psychological traits are important for canoe slalom for two reasons: 1) the canoe slalom is a cognitively demanding activity, requiring the planning and sequencing of complex routes under time constraints; and 2) canoe slalomists regularly use imagery both in competition and training. Moreover, Moran and MacIntyre. (1998) stress that in competitions, athletes must plan their route mentally from the bank of the river in question. Thus, specific psychological skills, such as "controllability of imagery", can be determinants for a better race performance. The controllability of imagery can be conceptualised as the ability to predict tasks before they happen, playing a role in the transmission of specific skills obtained through mental imagery of performance improvement of these skills during the actual event (Macintyre *et al.*, 2002).

Macintyre *et al.* (2002) applied the Mental Rotation Test (Vandenberg and Kuse, 1978) in 31 slalom athletes after 3 or 4 weeks of the Canoe World Championship in Augsburg (1992-1993). The test consisted of a questionnaire with questions directed toward psychological and cognitive issues; the final test score had a minimum of 0 and maximum of 40 points. The main findings were significant correlations ($r = 0.42$; $P < 0.05$) between the placement the canoeists achieved at the world championships and the score obtained on the Mental Rotation Test.

More recently, Macintyre and Moran. (2007) implemented an interview guide comprising sections with questions about imagery, athletes meta-imagery knowledge and experiences in 12 elite canoe slalomists. The authors aimed to analyse qualitatively how imagery can be used in canoe slalom situations. The athletes reported that they used imagery as part of their performance routine. Additionally, they also indicated that imagery was used to generate creative solutions to the problems of planning their route down the slalom course. Moreover, prior to participating in competitions, the athletes visualised other competitors in their route and imagined themselves doing the course.

Based on the literature, it is possible to suggest that canoe slalomists are subject to great cognitive challenges during races, and psychological skills are fundamental to better performance in competitions. Thus, the team involved with training the slalom athletes should not be limited to professionals who are only able to apply physical and tactical training but should also include sports psychologists. In summary, training directed toward the development of psychological skills is indispensable because mental abilities can be a determining factor in the performance of athletes during canoe slalom races.

7. Biomechanical analyses applied to performance

Biomechanical analyses are commonly used for the study and implementation of technical aspects in different sports, which are directly linked to better performance. Given that stroke technique is one of the determining factors in the classification of elite athletes (Hunter, 2009), analysis of biomechanical stroke characteristics appears to be an important tool in the development slalom athletes.

In slalom, a simple stroke begins at the starts of the capture phase (where the paddle goes into the water) on one side of the kayak and ends at the start of the capture on the other side and includes the period during which the paddle is submerged (propulsion phase) as well as the phase when the paddle is out of water and the recovery phase (where the canoeist prepares for the next stroke) (Michael *et al.*, 2009). Double strokes have all the same phases as the simple stroke, except that two sequential strokes are performed on the same side (McDonnell *et al.*, 2012). Although the stroke technique is the determining factor in canoeist performance and focus of canoeing biomechanics studies, other factors such as aerodynamics and hydrodynamics of the boat (Michael *et al.*, 2009), as well as the type of paddle blade (Sumner *et al.*, 2003), have specific relevance in achieving a better race performance.

According to Michael *et al.* (2009) the drag force (D_f), in the context of both the hydrodynamics and aerodynamics, can be defined as the force that acts opposite to the velocity vector of the kayak, resulting in slowdown when the kayak is submerged into the water. However, according to the authors, in the case of the canoe, the boat hydrodynamic variable has a greater influence on the loss of kayak speed than aerodynamic aspects. In addition, hydrodynamic D_f is composed of three drag variables: a) friction or drag surface between the boat hull and the water; b) the pressure or drag force created when water is separated to allow passage of the kayak; c) the drag caused by the wave, which is a result of acceleration of water produced away from the boat.

Sumner *et al.* (2003) report that, in opposition to the D_f on the boat, the propulsion efficiency of the stroke can be maximised by another D_f produced by the paddle blade, which aims to shift the boat and competes with the D_f of the boat. Analysing three types of blades (*Conventional, Norwegian, Turbo*), the authors report that, regardless of the type of blade used, D_f does not show difference. On the other hand, aspects such as blade return to the beginning of the stroke, the blade entrance into and exit from the water and the interaction between the blade and the water surface are factors that differ according to the type of blade used and thus may be an aid for canoeist performance.

When canoeing is performed in standing water, the above aspects are adequate to describe canoe sprint races. However, due to the characteristics of slalom race environments, aspects related to the types of blade are attenuated. Nevertheless, the effects related to the stroke type and boat used is heightened. Performed in natural and artificial rivers, the slalom races have obstacles (e.g., rocks and waterfalls) (Shephard, 1987), and during the race, changes in biomechanical variables are necessary for the athlete to complete the course.

Thus, Hunter *et al.* (2007) analysed in detail the biomechanic particularities of different strokes in canoe slalom and designated two classifications: pure strokes and multi-strokes. Pure strokes are strokes of one predominant phase. Among these types, the authors name them as *Forward* (propulsive stroke, carries boat forward with no significant change in direction), *C* (propulsive stroke moving the blade in a C-shaped path, turns the boat while propelling forward), *Draw* (blade facing inwards, parallel to boat, significantly changes the direction), *Sweep* (blade facing outwards, causes significant change in direction but not much propulsion), *Reverse Sweep* (reverse *Sweep* movement), *Reverse* (reverse stroke, causes a significant change in direction without slowing the boat), *Brace* (support stroke used for stability), *Punt* (stroke in contact with solid surfaces, usually used for turning), *Side Draw* (blade facing inwards, parallel to the boat in line with the body of the paddler, does not propel the boat forward or change direction, but moves sideways) and *Steering* strokes (strokes that define the direction of the boat). Moreover, the authors define that multi-strokes are classified as combinations of pure strokes, which include *Draw-Forward*, *Reverse Sweep-Forward*, *Forward-Reverse Sweep*, *Draw-Draw*, *Reverse Sweep-Draw*, *Draw-Sweep* and *Forward-Sweep*. Through these analyses, Hunter *et al.* (2008) aimed to quantify the influence of the stroke technique in different groups of canoeists (female C1, male C1 and K1) in the performance of official canoe slalom races. The authors reported that, for the group composed of female K1 canoeists, longer race durations were reported (108.5±2.6 s) compared to C1 males (100.8±2.2 s) and K1 athletes (97.9±1.3 s).

Table 2. Anthropometrical and morphological variables of sports performed in boats.

Study	Sport	Subdiscipline	Gender	Athletes (n)	Age (years)	Height (cm)	Body mass (kg)	Fat percentage (%)	Somatotype Predominance
Sklad et al, 1994	Canoe slalom*	K1	M	10	19.1 ± 2.2	178.3 ± 7.3	73.7 ± 5.9	10.3 ± 2.6	#
Ridge *et al*., 2007	Canoe slalom*	K1	M	12	27.8 ± 3.9	177.0 ± 0.0	71.7 ± 4.8	#	Mesomorphic
			F	12	25.3 ± 4.8	168.0 ± 0.0	59.0 ± 4.5	#	Mesomorphic
		C1	M	19	28.2 ± 5.9	177.0 ± 0.0	73.1 ± 6.5	#	Mesomorphic
Bílý *et al*., 2012	Canoe slalom*	K1	M	29	24.0 ± 4.7	176.8 ± 6.0	74.0 ± 6.7	10.0 ± 2.7	#
			F	23	24.0 ± 6.6	166.1 ± 5.7	59.5 ± 4.9	17.0 ± 4.6	#
		C1	M	17	25.2 ± 5.2	181.6 ± 6.4	77.4 ± 7.5	10.1 ± 3.5	#
		C1 bowmen	M	7	22.7 ± 5.4	175.4 ± 5.6	73.7 ± 4.4	11.6 ± 2.6	#
		C1 stern men	M	8	23.4 ± 3.5	175.9 ± 3.6	74.5 ± 8.4	11.8 ± 4.9	#
Ackland *et al*., 2003	Canoe Sprint*	K2, K4 e C2[§]	M	50	24.8 ± 3.0	184.3 ± 5.8	85.2 ± 6.2	#	Mesomorphic
			F	20	26.4 ± 5.1	170.4 ± 6.3	67.7 ± 5.7	#	Mesomorphic
Vedat, 2012	Canoe Sprint*	#	M	10	#	176.2 ± 5.5	74.5 ± 10.7	#	Mesomorphic
Alves *et al*., 2012	Canoe Polo	#	M	10	26.7 ± 4.1	177.1 ± 6.5	76.8 ± 9.0	12.3 ± 4.0	#
Battista *et al*., 2007	Paddle*	#	F	90	20.2 ± 1.3	173.0 ± 0.0	74.6 ± 8.5	22.4 ± 2.5	Endomorph

Data shown as the means ± standard deviation. M-Male; F-Female; [§]Data presented encompassing all sports; [#]Information not specified in the study; *Olympic discipline.

According to Hunter *et al.* (2008), the longer duration for female athletes may be linked to physical differences of this group compared to males. However, no differences were detected between the durations of the C1 and K1 males; only the number of strokes was significantly lower (C1=80+; K1=100+) ($P< 0.05$). Thus, the authors suggest that although C1 canoeists use paddles that include only one blade, and thus have limitations compared to the paddles used in K1 canoeists, the stroke technique of C1 canoeists is more effective compared to K1 canoeists. Though it is suggested that canoeists improve their performance through training aimed at improving physical abilities, technical training should be implemented for athlete development

.

8. Strategies and variability in canoe slalom races

Commonly, canoe slalom races consist of two runs, the first (semi-final) being used to classify athletes for the second (final). However, the courses in official races are not similar across competitions. In addition, the final time of the athlete is adjusted in slalom races if the canoeist touches any of the gates or fails to negotiate a gate. Additionally, Vest. (1997) emphasises that the identification of competitive capability in athletes is hampered by components such as non-standard wild-water conditions, different gate placements and various constructions of artificial slalom courses. Moreover, these factors make it difficult to analyse the variability of performance in this sport (Nibali *et al.*, 2011).

Based on these observations, Nibali *et al.* (2011) emphasised that, for sports such as swimming, running and cycling, the variability in performance appears to be linked to the athlete's ability to sustain high-intensity exercise. In other words, the variability is directly related to the duration required for the athlete to complete the race. On the other hand, canoe slalom is a sport that requires a large technical development of the athlete. Because they need to sustain high-intensity exercise while negotiating gates and natural obstacles, the variability in slalom performance is linked not only to the athlete’s performance at high intensities but also to their technical capabilities.

Races in canoe sprint are characterised by a linear course (i.e., the canoeist paddles in a fixed direction throughout the race). Regarding strategies for performing in this type of a race (*pacing strategy*), coaches and canoe athletes generally agree that the best strategy is to begin a race with maximal effort (*fast start*) and then transition to a steady pace (Bishop *et al.,* 2002). However, slalom races are nonlinear, and each course is distinct. Consequently, various strategies can be chosen depending on the course.

In support of this idea, Hunter *et al.* (2008) investigated the different strategies used by canoeists (C1, C2 and K1) for thirty runs in official races. The authors report that, regardless of the sport, the strategy used to negotiate gates and navigate the course is the same (i.e., in general, throughout the race, athletes have used similar techniques to negotiate all the gates). However, the use of different strokes techniques, such as *spin* (situation where the canoeist turns to the gate at an angle greater than 180 °) and *pivot* (situation where the canoeist turns to the gate at an angle less than 180 °) in specific locations, such as gates placed in locations where the current is flowing upstream (upstream gates), can differentiate the final performance of the athlete.

In an attempt to extend these findings, Hunter. (2009) aimed to determine how the strategy chosen by canoeists to negotiate upstream gates influences the final race duration. In a simulated race with six gates (four with and two against the current), 17 canoeists (11 - K1; 6 - C1) repeated the course six times according to their respective strategies. Similar to considerations already presented (Hunter *et al.*, 2008), the authors report that regardless of the sport, the strategy used to negotiate upstream gates is the same. However, using kinematic analysis, Hunter explains that the canoeists who showed better performance in the simulated race used techniques that included a passage closer to the canoeist head and the negotiated gate.

In summary, the strategy chosen to go through the course is a determining factor for improved performance in slalom races. However, canoeists should not be limited to considering evidence only from slalom races of their respective discipline but instead should pay attention to all disciplines, which present great similarity in terms of race strategies and techniques used (Hunter, 2009).

9. Training periodisation

Throughout this review, several aspects involving physiological, psychological, biomechanical and morphological parameters were addressed, and studies were analysed that aimed to equip slalom participants, including athletes, coaches, and trainers, to enhance the sports training of slalomists. However, despite timely attempts, there is a clear lack of studies that assess periodisation and periodic evaluations in canoe (Ušaj, 2002; Garcia-Pallares *et al.*, 2010).

Periodisation in sport was the subject of a review of the literature presented by Issurin. (2008). In this study, the author stresses that training periodisation is one of the more training theory-oriented branches, and its application is essential in obtaining a better athletic performance. Nevertheless, this strategy is not well investigated in canoeing.

Recently, Garcia-Pallares *et al.* (2010) investigated the physiological and performance effects using a traditional periodisation (TP = 22 weeks) and block periodisation (BP = 12 weeks) applied to elite athletes (n = 10) of canoe sprint. According to the authors, the most pronounced differences between traditional and block periodisation is in the total volume of training implemented and the percentage of this volume aimed at improving physiological parameters such as ventilatory threshold 2 (VT2) and peak oxygen consumption (VO_2 peak). Conducting periodic evaluations within each periodisation, the authors found that similar gains in these parameters were obtained at the end of each periodisation, observing a VT2 increase of 9.9 % for TP and 8.0 % for BP and a VO_2 peak increase of 11.0 % for TP and 8.1 % for BP. Based on these results, the authors suggest that block periodisation seems to be more effective than traditional periodisation for canoe sprint, considering that the gains obtained were similar to traditional periodisation but over a shorter duration of time (12 weeks).

Only one study was found in the literature that evaluated the effects of periodisation applied to canoe slalomists. Ušaj. (2002) aimed to examine whether the traditional periodisation (40 weeks) would be effective in modifying physiological parameters such as anaerobic threshold as well as enhancing related variables to performance into two groups: Olympic athletes (n=3) and non-Olympic (n=4). Applying an incremental test, the athletes were subjected to five maximum efforts equivalent to 600 meters, with intervals of one minute between efforts for the extraction of blood and blood lactate analysis. The anaerobic threshold was classically determined by a method proposed by

Kindermann *et al.* (1979) and by fixed blood lactate concentration (Sjodin and Jacobs, 1981). Performance data were presented as the total time for completion of the EIGHT test (Ušaj, 2002), where the athletes performed a course on a lake consisting of eight "gates". According to Usaj, unexpectedly, neither Olympic athletes nor non-Olympic athletes showed any significant differences in the physiological parameters analysed after 40 weeks. However, increased performance (i.e., lower test duration in the lake) was displayed at the end of periodisation for both groups. The author assigns no modifications in physiological variables at the training level of each group, speculating that the athletes could be at their biological limit and that improvement in this aspect would be very difficult to attain.

10. Final considerations

Commonly, studies published in the scientific community mistakenly include canoe slalom alongside other disciplines that include canoes. However, despite being performed with a boat and paddles, the present review indicates that slalom has peculiar aspects, including the race features, which should preclude its comparison and/or association with other canoe disciplines.

We speculate that the limited number of scientific studies focused on canoe slalom is also a reflection of the characteristics of the sport, which hinder the application of scientific methods to evaluate the practice of the sport. Nevertheless, in spite of the lack of scientific studies, the number of studies in the literature focused on canoe slalom has increased in recent decades, with emphasis on designs related to investigations of physiological, psychological, biomechanical, and morphological aspects and the race strategies of canoe slalomists.

To improve the progress of performance in this sport, we believe that a combination of all the factors discussed in this review, as well as the adoption of specific assessment methods for canoe slalom, should be considered when drafting and prescribing regimens for training. In this respect, scientific attention to slalom, with specific proposals addressed to aspects related to training and athletic performance, certainly aids in the understanding of this Olympic sport.

11. Acknowledgments

We would like to thank the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP – Proc. 2012/06355-2 and 2009/08535-5), Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq - Proc. 472277/2011-1), Fundo de Apoio ao Ensino, à Pesquisa e à Extensão (FAEPEX – Proc. 756/13), and Funcamp (Proc. 1403) for financial support.

12. References

Ackland, T. R., Ong, K. B., Kerr, D. A., and Ridge, B. (2003), Morphological characteristics of Olympic sprint canoe and kayak paddlers. **Journal of Science and Medicine in Sport**,6,285-294

Alves, C. R., Pasqua, L., Artioli, G. G., Roschel, H., Solis, M., Tobias, G., Gualano, B. (2012), Anthropometric, physiological, performance, and nutritional profile of the Brazil National Canoe Polo Team. **Journal of Sports Science**,30,305-311

Baker, S. J. (1982), Post competition lactate levels in canoe slalomists. **British Journal of Sports Medicine**,16,2

Banfi, G., Colombini, A., Lombardi, G., and Lubkowska, A. (2012), Metabolic markers in sports medicine. **Advanced Clinical Chemistry**,56,1-54

Battista, R. A., Pivarnik, J. M., Dummer, G. M., Sauer, N., and Malina, R. M. (2007), Comparisons of physical characteristics and performances among female collegiate rowers. **Journal of Sports Science**,25,651-657

Beattie, S., Hardy, L., and Woodman, T. (2004), Precompetition Self-Confidence: The Role of the Self. **Journal of Sport and Exercise Psychology** 26,427-441

Bílý, M., Balas, J., Martin, A. J., Cichrane, D., Coufalova, K., and Suss, V. (2012), Effect of paddle grip on segmental fluid distribuiton in elite slalom paddlers. **European Journal of Sport Sience**,1,1-6

Bílý, M., Suss, V., and Buchtel, M. (2011), Selected somatic factors of white water canoeists. **Journal of Outdoor Activities** 5,30-42

Bishop, D., Bonetti, D., and Dawson, B. (2002), The influence of pacing strategy on VO2 and supramaximal kayak performance. **Medicine Science Sports Exercise**,34,1041-1047

Carr, C. M. (2006), Sport psychology: psychologic issues and applications. **Physical Medicine and Rehabilitation Clinics of North America**,17,519-535

Freeman, P. L., Chennells, E. R., and Briggs, C. A. (1987). Specificity in performance:Determination of the antropometric and physiological characteristics of canoeists. **Applied Sports Research Program**.

Garcia-Pallares, J., Garcia-Fernandez, M., Sanchez-Medina, L., and Izquierdo, M. (2010), Performance changes in world-class kayakers following two different training periodization models. **European Journal Applied Physiology**,110,99-107

Hunter, A. (2009), Canoe slalom boat trajectory while negotiating an upstream gate. **Sports Biomechanics**,8,105-113

Hunter, A., Cochrane, J., and Sachlikidis, A. (2007), Canoe slalom--competition analysis reliability. **Sports Biomechanics**,6,155-170

Hunter, A., Cochrane, J., and Sachlikidis, A. (2008), Canoe slalom competition analysis. **Sports Biomechanics**,7,24-37

ICFa. (2013). International Canoe Federation, from http://canoeicf.com/icf/Aboutoursport.html

ICFb. (2013). International Canoe Federation, from http://canoeicf.com/icf/Aboutoursport/Canoe-Slalom/More-on-Canoe-Slalom.html /

ICFc. (2013). International Canoe Federation, from http://laseudurgell2013.worldcup.events.slalom.canoeicf.com/en/parc-ol%C3%ADmpic-del-segre-la-seu-durgell/20-years-olympic-slalom

ICFd. (2013). International Canoe Federation, from http://www.canoeicf.com/icf/Aboutoursport/Canoe-Slalom/Rules-and-education/main/0/text_files/file/ICF%20Canoe%20Slalom%20Competition%20Rules%202013.pdf

Issurin, V. (2008), Block periodization versus traditional training theory: a review. **Journal of Sports Medicine and Physical Fitness**,48,65-75

Kindermann, W., Simon, G., and Keul, J. (1979), The significance of the aerobic-anaerobic transition for the determination of work load intensities during

endurance training. **European Journal of Applied Physiology and Occupational Physiology**,42,25-34
Macintyre, T., Moran, A., and Jennings, D. J. (2002), Is controllability of imagery related to canoe-slalom performance? **Perceptual and Motor Skills**,94,1245-1250
Macintyre, T. E., and Moran, A. P. (2007), A qualitative investigation of imagery use and meta-imagery processes among elite Canoe-Slalom competitors. **Journal of Imagery Research in Sport and Physical Activity**,2,1-25
Males, J. R., Kerr, J. H., and Gerkovich, M. M. (1998), Metamotivational states during canoe slalom competition: A qualitative analysis using reversal theory. **Journal of Applied Sport Psychology**,10,185-200
McDonnell, L. K., Hume, P. A., and Nolte, V. (2012), An observational model for biomechanical assessment of sprint kayaking technique. **Sports Biomechanics**,11,507-523
Michael, J. S. (2008), The metabolic demands of kayaking: A review. **Journal of Sports Science and Medicine**,7,1-7
Michael, J. S., Smith, R., and Rooney, K. B. (2009), Determinants of kayak paddling performance. **Sports Biomechanics**,8,167-179
Moran, A., and MacIntyre, T. (1998), 'There's more to an image than meets the eye': A qualitative study of kinaesthetic imagery among elite canoe-slalomists. **The Irish Journal of Psychology**,19,406-423
Nibali, M., Hopkins, W. G., and Drinkwater, E. (2011), Variability and predictability of elite competitive salom-kayak performance. **European Journal of Sport Science**,11,125-130
Norton, K., and Olds, T. (2001), Morphological evolution of athletes over the 20th century: causes and consequences. **Sports Medicine**,31,763-783
Ong, K. B., Ackland, T. R., Hume, P. A., Ridge, B., Broad, E., and Kerr, D. A. (2005), Equipment set-up among Olympic sprint and slalom kayak paddlers. **Sports Biomechanics**,4,47-58
Pendergast, D. R., Bushnell, D., Wilson, D. W., and Cerretelli, P. (1989), Energetics of kayaking. **European Journal of Applied Physiology and Occupational Physiology**,59,342-350
Ridge, B. R., Broad, E., Kerr, D. A., and Ackland, T. R. (2007), Morphological characteristics of Olympic slalom canoe and kayak paddlers. **European Journal of Sport Science**,7,107-113
Shephard, R. J. (1987), Science and medicine of canoeing and kayaking. **Sports Medicine**,4,19-33
Sidney, K., and Shephard, R. J. (1973), Physiological characteristics and performance of the White-Water paddler. **European Journal of Applied Physiology**,32,55-70
Sjodin, B., and Jacobs, I. (1981), Onset of blood lactate accumulation and marathon running performance. **International Journal Sports Medicine**,2,23-26
Sklad, B., Krawczyk, B., and Majle , B. (1994), Body build profiles of male and female rowers and kayakers. **Biology of Sport**,11,249-256
Sumner, D., Sprigings, E. J., and Bugg, J. D. (2003), Fluid forces on kayak paddle blades of different design. **Sports Engineering**,6,11-20
Ušaj, A. (2002), Kinetics of basic endurance and basic speed endurance characteristics throughout one olympic season in white water slalom kayak. **Kinesiologia Slovenica**,8,30-37
Vaccaro, P., and Gray, P. R. (1984), Physiological Characteristics of World Class White-Water Slalom Paddlers. **Reaseach Quartely for Exercise and Sport**,55,206-210

van Someren, K. A., and Oliver, J. E. (2002), The efficacy of ergometry determined heart rates for flatwater kayak training. **International Journal of Sports Medicine**,23,28-32

van Someren, K. A., Phillips, G. R. W., and Palmer, G. S. (2000), Comparison of Physiological Responses to OpenWater Kayaking and Kayak Ergometry. **International Journal of Sports Medicine**,21,200-204

Vandenberg, S. G., and Kuse, A. R. (1978), Mental rotations, a group test of three-dimensional spatial visualization. **Percept Motors Skills**,47,599-604

Vedat, A. (2012), Somatotypes of male whitewater canoe athletes of the Turkish National Canoe Team. **Educational Research and Reviews**,7,526-531

Vest, A. L. (1997), Correlation of the actual and the substitute competitive result in kayak slalom. **Kinesiologia Slovenica**,1,13-17

White, A., and Hardy, L. (1998), An In-Depth analysis of the uses of imagery by high-level canoe slalomists and artistic gymnasts. **The Sport Psychologist**,12,387-403

Wilkie, D. R. (1980). Equations describing power imput by humans as a function of duration of exercise. In: Ceretelli P, Whipp BJ (eds).Exercise Bioenergetics and Gas Exchange. Amsterdam, Elsevier

Zamparo, P., Capelli, C., and Guerrini, G. (1999), Energetics of kayaking at submaximal and maximal speeds. **European Journal of Applied Physiology and Occupational Physiology**,80,542-548

Zamparo, P., Tomadini, S., Didone, F., Grazzina, F., Rejc, E., and Capelli, C. (2006), Bioenergetics of a slalom kayak (k1) competition. **International Journal of Sports Medicine**,27,546-552