

STROKE PARAMETER ANALYSIS PERFORMING A COMPETITION DISTANCE (200 M) ON WATER

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Abstract. *Canoe sprint is a water sport (under natural conditions, it takes place on water); therefore, for the most part, research is carried out under laboratory conditions, when the load is performed on various special exercise machines (ergometers) that try to simulate natural conditions as closely as possible since doing research in natural conditions is very challenging. However, technological development and recently available specific devices allow to go forward and overcome these challenges. The aim of the research is to provide information on stroke parameters for a 200 m distance with maximum effort in natural conditions of the sport – on water, provided by the only device currently available on the market that measures the power and force applied to the stroke, and result comparison with similar research done by other authors. Dynamometry was used as the primary method to obtain indicators on power and force applied to the paddle, using a specialized device – canoe sprint power meter (One Giant Leap, Nelson, New Zealand). The average force value to the brace in a 200 m distance between all 87 braces was found to be 456.2 ± 8.7 N.*

Keywords: *canoe sprint, force measurements, force of the stroke, power of the stroke, stroke analysis.*

Introduction

The main goal of a paddler during a competition is to cover the distance in the shortest time possible. Authors Kendal & Sanders (1992) found that the average speed of the kayak fluctuates during the stroke. Research on both canoe sprint and paddling have concluded that the speed of the boat increases during a brace due to the applied forces acting on the paddle, while water resistance slows down the speed of the boat between the braces (Mann & Kearney, 1980; Jackson, 1995; Baudouin & Hawkins, 2002). Thus, the characteristics of the brace and changes in speed are important valuables in predicting the time needed to cover the distance. The performance of a paddler can be improved in two ways:

- by increasing the forward driving force – the efficiency of the brace and/or the force applied to the paddle should be increased;
- by decreasing the total resistance acting on the boat during the stroke – considering the standards and technical regulations used in boat

production, resistance can be reduced by eliminating accelerations and rotations along and around all axes of its movement and by optimizing the athlete's power-to-weight ratio (Michael, Smith, & Rooney 2009).

Several researches have looked at the forces exerted by kayakers (of various training levels) under different conditions during a brace on water; however, there are only a few such studies as research is complicated by the specifics of canoe sprint. In general, there are two main forces that move the boat forward in canoe sprint (Mann & Kearney, 1980) – the first is the one that the athlete applies to the paddle, and the second – the one that the athlete applies to the foot rest (the spot against which the athlete supports himself/herself with his/her feet).

There are studies that reflect different values of the stroke force for different subjects and under different conditions (Aitken & Neal, 1992; Baker, 1998; Sperlich & Baker, 2002; Sturm et al., 2010; Brown et al., 2010; Gomes et al., 2015; Nilsson & Rosdahl, 2016; Hogan et al., 2019; Bonaiuto et al., 2020; Kong et al., 2020), but in general there is no specific data on stroke parameters (force and power values) in a competition distance. With the development of technology, various wearable receivers for biomechanical assessment of human movements have become available in sports. Inertia, force and electromyographic receivers are the most widely used in the field of sport (Taborri et al., 2020).

In canoe sprint, one of the wishes of coaches, athletes, and other specialists (including researchers) is to obtain information about the perfect stroke (the force-time curve). The obtained data would help to optimize the training process in a competition distance.

Currently, various devices have been used in research on stroke parameters in canoe sprint, most of which are not yet commercially available (Gomes et al., 2011; Sturm et al., 2010; Nilsson & Rodhal, 2016; Bonaiuto et al., 2020). Nonetheless, a commercially available device has been used in recent research (Hogan et al., 2019; Kong et al., 2020).

The opportunity to perform force measurements on water with the use of dynamometry and to carry out a full-fledged analysis of stroke parameters for a high-performing athlete (paddler), as well as to integrate the use of such a device (kayak power meter (One Giant Leap, Nelson, New Zealand)) for the optimization of the training process is the aim of this case study.

Literature Review

The types of biomechanical measurements in canoe sprint fall into three basic types: competition analysis, kinematic analysis, and force measurements on water (Sperlich & Baker, 2002). The third of the types is the one discussed in the study; moreover, it is also the most complicated one as it should be taken into account that, according to the authors Aitken & Neal (1992) and Stothart et al.

(1986), the devices that perform these measurements must meet a list of requirements:

- the device must be waterproof;
- the device must be light, < 3% of the total weight of the paddler and the boat, i.e., 2-3 kg;
- the device must be portable so that it can be used in different boat classes;
- there must be a robust signal energy transducer for the device to operate under variable temperature and humidity conditions;
- the length, weight, balance and blade area of the paddle must not change;
- the paddler's usual technique must not change;
- the device must have high signal and data recording capacity for at least 5 min;
- the device must have high data reliability and repeatability analysis with real-time reflection;
- the device must be able to acquire data from up to 4 paddlers at the same time, so that it could also analyse team boats (twos and fours).

The most important stroke parameters that can be obtained by using these devices are as follows:

- stroke frequency or pace (the number of strokes performed per minute);
- brace length (the distance from the water contact of a paddle blade until its removal from water);
- brace duration (the time from the water contact of a paddle blade until its removal from water);
- stroke length (the distance travelled from the start of a brace with one hand to the start of the next brace with the other hand);
- stroke duration (the time from the beginning of a brace with one hand to the start of the next brace with the other hand);
- air phase time (the part of the stroke time in which the paddle blade is out of the water);
- brace length (the distance travelled by the boat only during the brace phase);
- stroke force variables (the maximum achieved force, average force, force ratio, rate/frequency of force increase, impulse and impulse frequency);
- stroke power variables (the maximum power achieved/peak power in a stroke, average power, power ratio and work performed).

A more thorough analysis of stroke parameters would be possible along with the development of measuring devices. Until now, a large part of the equipment used for on-water measurements has been experimental and of limited availability (not commercially distributed). Most of the stroke parameters in canoe sprint could only be obtained by performing measurements under laboratory conditions, i.e., on various ergometers. However, it is clearly visible that the on-water

measurements (see Table 1), in which the force of the stroke (the force applied to the paddle) was recorded, were done at the end of the 20th century. Moreover, the authors mentioned in the table sometimes refer to even older measurements – from the 70s of the 20th century. It can be seen that at the beginning of the century, the researcher Baker has spoken about these indicators several times (Baker, 1998; Sperlich & Baker, 2002), but then a 10-year period followed, during which silence can be observed on this topic in sports science. In the last decade, researchers have become more active again and several measuring devices have been created, with the help of which the stroke force parameters have been determined, mainly – the force applied to the paddle. Still, there are also studies that have examined the force applied to the foot rest.

Table 1 The highest values of the stroke force and power recorded in research (authors' summary)

Boat Class	Research Place	Maximum Force, (N)		Maximum Power, (W)		Authors
		Men	Women	Men	Women	
K1	On water	213.5	-	-	-	Aitken & Neal, (1992)
K1	On water	~220.0	-	-	-	Mononen & Viitasalo, (1995)
K2	On water	~180.0	-	-	-	Mononen et al., (1994)
K1	On water	525.0	-	-	-	Baker, (1998)*
K1	On water	375.0	290.0	-	-	Baker (1998); Sperlich & Baker (2002)
-	Laboratory	120.0	-	-	-	Sturm et al., (2010)
K1	On water	354.4		-	-	Brown et al., (2010)
K1	On water	274.0	153.0	-	-	Gomes et al., 2015
-	Laboratory	-	-	610.0	359.0	Bjerkefors et al., (2018)
-	On water	-	-	-	373.0	Hogan et al., (2019)
K1	On water	324.1	152.8	-	-	Bonaiuto et al., (2020)
K2	On water	344.3	-	924.8	-	Kong et al., (2020)
-	Laboratory	600.2	-	-	-	Petrovic et al., (2020)

*A claim that it should equal this value (it is not clear if this is an obtained measurement).

The column of the table “Maximum Force” reflects the force (N) values presented in research. The research by author Baker (1998) stands out from the rest, as it states that the values of the maximum force applied to the paddle by Australian national-level male paddlers were 375N, but when discussing high-performing paddlers (participants of international championships), he states that at the start of a 1000 m distance they should show a force applied to the paddle of 525N. On average, it should be 400N over the distance. However, specific graphs with exact units of measurement have not been displayed. If these values are true, then it contradicts Gomes et al. (2015) who also examined high-performing

paddlers (participants of international championships), who took on a 200 m distance in competition mode. For these athletes, the values of the maximum force applied to the paddle were only 274N. Nonetheless, similar values were reported by Bonaiuto et al. (2020) and Kong et al. (2020), although the measurements of the latter were taken while paddling in the K2 boat class. The highest recorded force in one stroke was recorded in a study by Petrovic et al. (2020). Still, in this study, the force applied to the paddle was determined on a specific ergometer – a one-sided sliding ergometer, on which simulations of the kayaking movement can be performed with each side of the body (the right and the left stroke, respectively).

Overall, no similar trend can be observed, and the differences in the obtained measurements are quite large. The measurements of the maximum distance covered by high-performing athletes have not yet been published, and there are various attempts to perform individual sections at respective speeds or stroke frequencies. It is clearly necessary to measure the actual distances covered in order to be able to determine the correlation and differences of stroke parameters depending on the planned competition distance and to further adjust it to the training process.

Methodology

In order to solve the research task, it was necessary to obtain the stroke parameters of a high-performing paddler during a 200 m distance in natural conditions – a field experiment had to be carried out. The experiment was conducted in a competition distance, at the end of the competition period. Within the framework of the experiment, the athlete covered a 200 m distance at maximum effort in a competition distance; the following methods were used to obtain data: heart rate measurements (for obtaining HR recovery indicators); blood biochemical analysis (for obtaining lactate recovery indicators); dynamometry (for obtaining indicators of the power and force applied to the paddle, using a specialized device – a kayak power meter (*One Giant Leap, Nelson, New Zealand/ <https://onegiantleap.co.nz>*)).

Heart Rate Measurements. The study used a Garmin heart rate monitor (model: Forerunner 935) together with a heart rate belt (model: HRM-Tri™ monitor) for data acquisition. The belt was placed around the athlete's chest, and an adapter was attached in the middle of it, which recorded the heart rate and transmitted it telemetrically to the heart rate monitor. The heart rate monitor was placed on the boat, wrapped around a special watch holder, placed in easy sight of the athlete so that he could see the information reflected on it.

Blood Biochemical Analysis (Lactate Measurement During a Load). In order to assess the special load of the sport under natural conditions on water, a biochemical analysis of blood was performed, as the lactate value was measured

before the load, immediately after the load and during the first 30 minutes of recovery. Lactate measurement was performed with the portable test strip analyser Accutrend® Plus. Based on the scientific literature on portable lactate devices in sport, it is one of the most commercially available (Baldari et al., 2009; Tanner, Fuller & Ross, 2010). It is a device capable of determining glucose, total cholesterol, triglyceride and lactate values in capillary blood and plasma by using special test strips (Baldari et al., 2009).

Dynamometry (On-Water Force Measurements). A special device – a kayak power meter (*One Giant Leap, Nelson, New Zealand*) – was used to measure the force and power of a stroke. Currently, it is the only freely available device on the market, with the help of which it is possible to obtain data on the force and power of a stroke. The device is an adjustable shaft of a canoe paddle, which, like all paddle shafts, is made from a composite material – carbon fibre. The only difference is that this shaft is about 100 g heavier than the shafts of conventional paddle manufacturers. In assembled form (together with the blades), its mass is slightly over 1000 g; in a study conducted in Singapore in 2020, the mass difference of an assembled paddle (using this equipment) compared to a standard assembled paddle was 12% (1010 g to 901 g) (Kong, 2020). In our case, the difference is ± 3 g. This specialized shaft is heavier because it is equipped with receivers (voltage meters and gyroscopes). The device validity ranges from 0.12% to 1.4% (Macdermid & Fink, 2017). To prepare the device for work, one must use an online application with a *Bluetooth* connection, the operation of which is ensured through the Adaptive Network Technology (ANT+™).

Data recording is done using a Windows desktop application or a paired compatible ANT+™ device, which is running in bike mode (as power display is required). The device we used is already of the second generation, therefore data reflection is possible in two ways. First, by using a paired compatible smart device, for example, a sports watch, as it is possible to keep track of one's power output, as well as the heart rate and speed during the workout. After the workout, these various parameter graphs are available in the Garminconnect application.

Secondly, the device is capable of operating in high-speed data mode (HSD). In this mode, instantaneous stroke force and power values are recorded every 0.01 seconds at a frequency of 100 Hz (hertz). The device can operate in the HSD mode for approximately 12 minutes; the data are recorded on the device (in the paddle shaft) and then the data can be downloaded via Windows desktop application, using an ANT+™ USB transmitter.

Research results

The power meter recorded the covered competition distance at a frequency of 50 hertz (Hz); each value (for upper and lower arm) of the power (W) and applied force (N) was recorded every 0.01 s. The device stored the file in its

internal memory, and it was then possible to analyse the data using an internet connection by accessing the manufacturer's data reflection application. Furthermore, the data were downloaded into the *Microsoft Excel* application format. A total of 27834 cells were filled with the data as the device was operated in the high-speed data recording mode for approximately five minutes and recorded all of the subject's force and power values applied to the strokes every 0.005 s. Then data filtering was performed, and only the data (3814 cells) reflecting the power and force values during a competitive distance (200 m) on water were extracted. Data comparison was conducted in the MS Excel application and the online application, as it was important to mark the end and the beginning of the strokes, as well as to separate the brace phases in order to further record and analyse the average values of these indicators. Moreover, the stroke and brace durations were recorded and summarized. These actions were performed for each of the 87 strokes performed by the athlete in the 200 m distance on water. The power meter recorded six different values in high-speed data mode every 0.01 s: the upper arm force applied to the paddle shaft (left stroke), the lower arm force applied to the paddle shaft (left stroke), the upper arm force applied to the paddle shaft (right stroke), the lower arm force applied to the paddle shaft (right stroke), power (left stroke), power (right stroke) (see Figure 1). Accordingly, during the execution of each stroke (right or left), there were changes in the indicators of the relevant active side, for instance, when the athlete performed a left stroke, there were changes (an increase) in the values of upper and lower arm forces of the left stroke and in the power values of the left stroke.

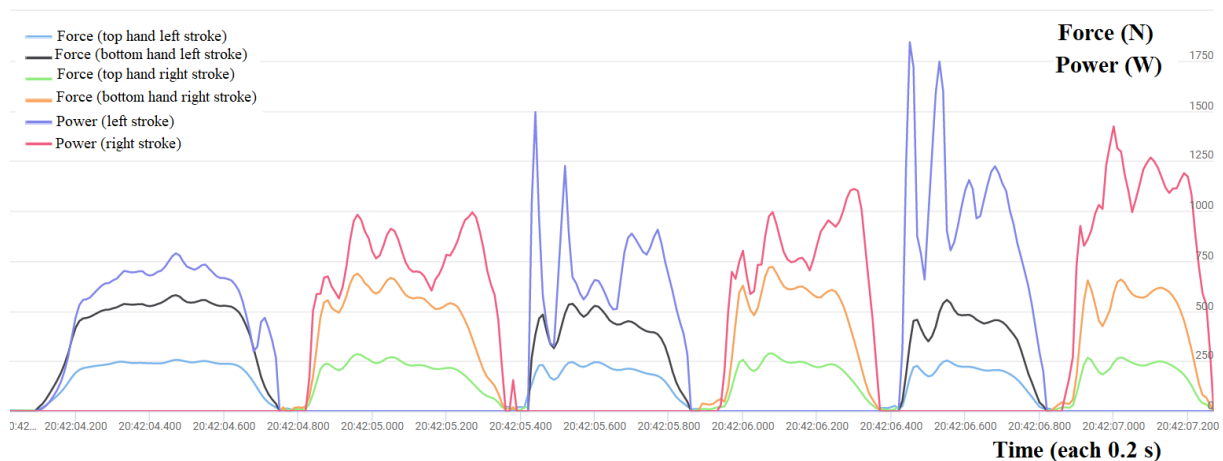


Figure 1 The ratio of the stroke power and force values per unit of time, graphical representation (the first six strokes of the 200 m distance on water) (created by the authors)

The above-mentioned parameters (upper arm force, lower arm force and power of the stroke) are displayed in the application with curves of various colours. In this case, the red curve represents the power values (W) in the right stroke, the orange curve represents the lower arm force in the right stroke (N), and the green curve represents the upper arm force in the right stroke (N). The blue

curve represents the power values (W) in the left stroke, the black curve represents the lower arm force in the left stroke (N), and the light blue curve represents the upper arm force in the left stroke (N). It is possible to read instantaneous values (in every 0.2 s) for both force and power on each curve. It can be seen that, when comparing the actions of both arms, the lower arm applies the greatest force to the paddle during the stroke (comparatively – orange versus green and black versus light blue curves), and these values differ by more than two times during some moments of the stroke.

The figure shows the first six strokes; the athlete started the competition distance from the spot (the speed of the boat at the start of the movement was 0 km/h), so in the first four braces there was a small difference between the applied lower arm force and the stroke power, but as the boat gradually approaches the competition speed, the difference increases.

In the third and fifth brace, two “peaks” of rapid power increase were observed, which is partially explained by the measurement frequency of the device, the above-mentioned 50 Hz (value recording every 0.01 s), as well as by the subject’s manner of performing the left stroke, which is influenced, first of all, by the technical performance with an aggressive execution of the brace hook phase, and, secondly, – by the fact that the athlete holds the paddle in the left grip. In general, two types of grips can be observed in the world – left and right. The type of grip refers to which arm holds the shaft of the paddle and turns it with the wrist to place the opposite blade of the paddle in the water at the appropriate angle. This also explains the flatter increase in power and force for the athlete’s right-hand strokes throughout the distance.

All strokes performed by the athlete and the values of applied force and power shown in them were summarized, and the average values were calculated in each stroke and brace, as well as the average values were calculated in every 0.01 s. The values of stroke and brace duration (s) were summarized; then a third value was calculated from these two values – the duration of the unsupported phase of the stroke (s). Table 2 summarizes the values of stroke and brace durations. Since paddling in canoe sprint takes place with both the right and the left side, the average stroke durations for both the right and the left stroke were compared; the average stroke duration for the right side is 0.43 s, and 0.45 s for the left side, respectively. According to Student’s T-Test for paired samples $t < t_{\alpha, v}$, the difference is not significant.

Table 2 Stroke duration values (s) (created by the authors)

	Stroke duration	Brace duration	Unsupported phase duration
Average in phase	0.44	0.34	0.10
Percentage wise (%):	1	0.78	0.22
Total:	38.1	29.74	8.36

The table 2 shows the average durations (s) of the stroke phases and in percentages – the average stroke duration; covering a 200 m distance on water, it is 0.44 s, which is divided into two parts: first, in the brace phase with a duration of 0.34 s, and second, in the unsupported phase with a duration of 0.1 s. Overall, 78% of the time spent in the distance (29.74 s) the paddle was in the brace phase, while 22% of the time spent in the distance the paddle spent in the unsupported phase (8.36 s).

By summing up all the average stroke values and the average values every 0.01 s, an average brace graph was created with the athlete covering a 200 m distance on water (see Figure 2).

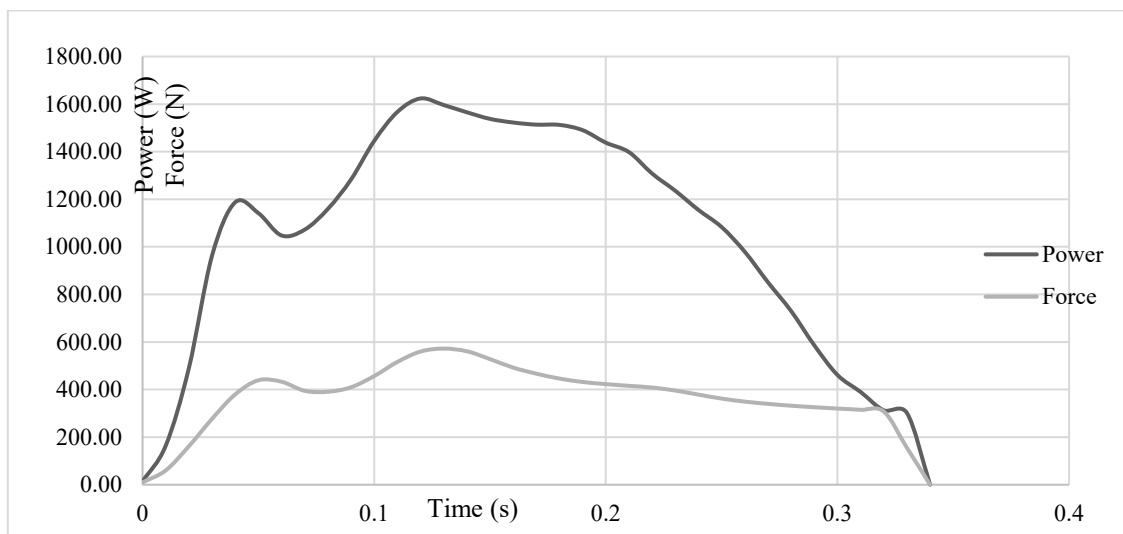


Figure 2 Average brace power and force graph for a 200 m distance on water (created by the authors)

The average force value for a brace in the 200 m distance between all 87 braces was 456.2 ± 8.7 N. The average value of the strongest brace was 655.1 N (in the 2nd brace), and the average lowest value of a brace was 257.5 N (in the 87th brace), while the average brace duration was 0.34 s. Logically, it would seem that the first stroke should have the highest value of the force applied to the paddle; however, starting from the spot is a specific condition, and inertia appears in the second brace, which creates a greater force applied to the paddle. On the other hand, the lowest value being in the last brace can be explained by the fact that the brace was 0.04 s longer than the average and the subject performed it partially, as the finish was already reached during the brace.

The average power value for a brace in a 200 m distance between all 87 braces was 1071.5 ± 22.8 W. The average value of the strongest brace was 1407.2 W (in the 14th brace), and the average lowest value of a brace was 546 W (in the 1st brace), while the average brace duration was 0.34 s. The 14th brace could also be related to reaching the maximum speed, as it is the 7th second (the time spent in the distance at the end of a brace is 6.46 s); however, according to the

Garminconnect application, the maximum movement speed in the speed graph appears around 10 s, but in practice it had been observed that sports watches display the speed with a delay, since the athlete himself mentioned in his training diary that he can reach the maximum speed already in the 8th second.

Small differences were also observed between the power values between the two sides of paddling – the average value of brace power for the left side was 1055.6 W in contrast to the 1087.7 W of the right side. Nonetheless, according to the T-Test for paired samples $t < t_{\alpha, v}$, the difference is not significant.

As for heart rate and lactate measurements, - the maximum registered heart rate value after performing 200 m distance was 183 bpm (beats per minute), the maximum registered lactate value was 13 mmol/l (millimoles per litre), however those measurements were made for overall characterizing of the physical load and for recovery data for athlete's coach. As aim of the study was to obtain, analyse and compare the stroke parameter data of high-class athlete to other researches, the heart rate and lactate were not analysed wider.

One of the initially set goals was a graphical representation of the “perfect brace” in a 200 m distance. In order to depict and analyse it, 20 consecutive braces were selected out of the 87 braces performed in a 200 m distance. The 23rd-42nd brace was analysed. These braces were selected because, according to the GPS data reflected by the sports watch Garmin, at this moment the highest movement speed is on average 21.66 ± 0.13 km/h. Looking at the time spent in the distance, these strokes were performed from 9.64 s to 17.84 s, which is consistent with the athlete being in the 50th-100th metre of the distance in real life, which is related to achieving the maximum speed.

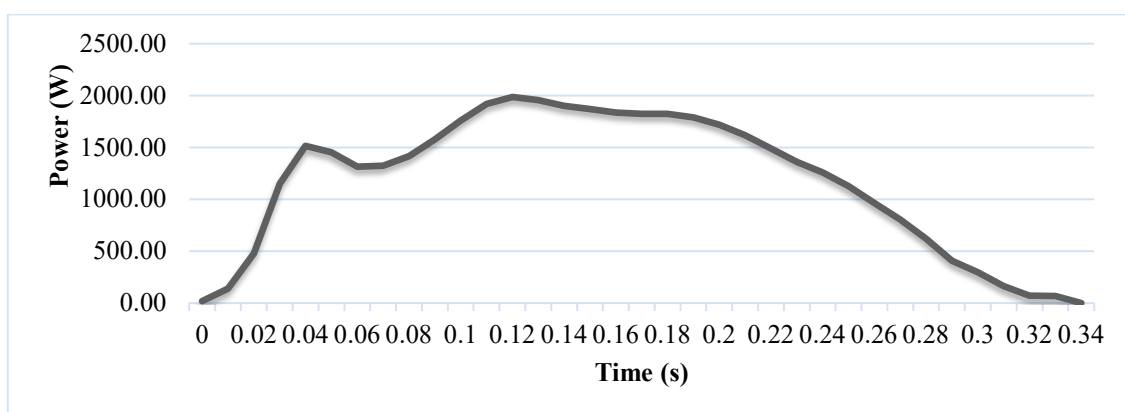


Figure 3 Average brace graph at maximum movement speed ($\bar{X}=21.66$ km/h) in a 200 m distance (created by the authors)

Conclusions and discussion

After looking at all 20 braces performed during a 200 m distance at the maximum movement speed and carrying out descriptive statistics and univariate analysis of variance, it was found that the highest instantaneous power value of

2526 W was detected in the 29th brace. It should be noted that the instantaneous power values did not exceed the 2000 W mark in only three braces (31st, 33rd and 34th brace). Analysis of variance showed a p value of 0.98; $p > 0.05$ so the differences between the braces are not considered significant.

The average stroke values were calculated for every 0.01 s, thus obtaining the average time-to-power ratio (graph) for a brace in a 200 m distance at an average speed of 21.66 km/h (see Figure 3).

The average power value for the 20 considered braces when paddling at maximum speed in a 200 m distance was 1171.9 W; however, it is lower than the value recorded in a single separate stroke. This can be explained by the fact that all the considered 20 strokes were not of the same duration; the duration of each stroke was different, therefore the average values also changed. The two highest average values of these strokes were detected in the 26th and 27th brace (1389.1 and 1357.6 W, respectively), and these braces also had the shortest brace durations of 0.29 s, which is 0.05 s less than the average brace duration.

Comparing the recorded force and power values in the author's study with the values recorded in literature, it was concluded that the highest correspondence was with the statement by author Baker (1998) that the average power of a stroke for high-performing paddlers can exceed 580 N, and that the force of a brace on average for men in a 1000 m distance can be as much as 525 N (in the first 20 seconds of the start), which is 53.5 kg when converted into force kilograms. As the distance continues, this value decreases and on average stays within the limits of 400 N. In our case, the average force value of a stroke in a 200 m distance was sometimes > 600 N. A certain idea was also given by V. Kong (2020) who, together with his team, conducted a numerically large study for canoe sprint with $n=79$, in which they looked at the differences in how the characteristics of athletes' strokes changed when paddling in a two-person boat class and changing positions – sitting as the first and sitting as the second number. This study also used a device purchased for the purposes of the author's research; however, the idea of author Kong to look at the teams of the two-person boat class is inspiring and in a short period of time someone should come up with a new research, if not in the context of such a large sample, then in the analysis of high-performing two-person boat teams.

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