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DEVELOPMENT AND VALIDATION OF PHYSICAL EFFORT GAUGING SYSTEM IN SURF TRAINING EQUIPMENT-A PILOT STUDY

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Abstract. *One of the application fields of Mechanical / Mechatronic Engineering is the development of technologies to performance sports. Nowadays, there are modalities with an equipment's gap to practice and training. Maybe one of the biggest examples is surfing. This sport is having a quick development, reaching status of Olympic sport and being practice by thousands of people around the world. However, for the sport development, there is a need of new methods and specific equipment. Currently, the athletes are submitted to an adapted routine, usually searching for devices dedicated to other sports. This situation does not provide the ideal conditions to the practices and limits the athletes' potential, once the evaluation of results and training techniques are directly linked to their performance, and, being able to measure and evaluate development is indispensable for their evolution. Linked to that, Brazil today has expressive names in this modality. The country has World champions of professional surfing, world record holders of big waves, between others respected surfers. Also, Santa Catarina has a lot of places to practice of the sport being a traditional cradle of athletes. Furthermore, the scientific institutions of the state have tradition in the development of technology. So, the Federal Institute of Santa Catarina (IFSC) work together with de Surf Evolution Enterprise developed a specific equipment for surfing training. This development was supported by Sinapse da Inovação Program and developed a prototype that was validated and it is in currently production. The prototype was used to develop a new functionality as system to evaluate the effort. The ergometer is the main equipment, used in medicine too, to assess anaerobic and aerobic thresholds. Using evaluation protocols and an ergometer you can train and evaluate an athlete specifically for the sport. This work presents the equipment development and the insertion of a system for effort evaluation performed on the surf training device. The results generated show that it is possible to create new specific ways of evaluating surfing and that the equipment needs adaptations to generate better results.*

Keywords: *surf simulator, ergometer, performance evaluation*

1. INTRODUCTION AND STATE OF THE ART

Surfing is a sport that has been gaining practitioners around the world. Estimate made in 2020 indicates that the number of surfers in the world is around 35 million (Lima, 2020). Brazil alone is near of 3 million, moving approximately R$ 7 billion in clothes, boards and accessories (Surftotal, 2019 and Carvalho, 2019).

Many people have started their practice due to contact with nature and by the plastic movements of the activity beyond it be complete as physical exercise. This is because it involves the use of both upper and lower limbs, in addition to demanding the aerobic part of the practitioner. Lowdon apud Mendez-Villanueva and Bishop (2005) "has described the surfing process as follows: first of all, the surfboard is paddled out with the surfer in the prone position in order to reach the take-off area. Once there and when a suitable wave approaches, some powerful strokes are needed to give the board enough speed to be gathered up by the swell. When the wave has been caught, it is necessary to quickly stand up and to perform maneuvers on the wave's wall until the wave breaks on the beach".

So, Mendez-Villanueva and Bishop describe the Surfing as "an activity characterized by intermittent exercise bouts of varying intensities and durations involving different body parts and numerous recovery periods". Canozzi et al (2015) point out that it is "a predominantly moderate activity interspersed with periods of high intensity".

Another relevant feature is that there is a wide range of movements that generate different types of energy expenditure, concentrating efforts on different parts of the body by practitioners (Figure 1).
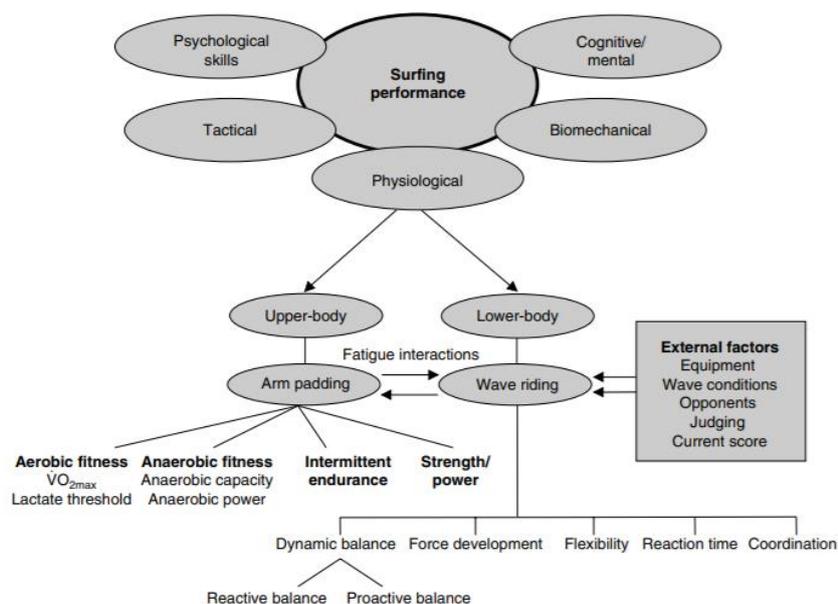
Figure 1: Schematic diagram of the physiological aspects relevant to surfing performance (Mendez-Villanueva and Bishop, 2005)

In addition, another factor that has been contributing to increase the number of surfers is its introduction as an Olympic sport in December 2017, by the International Olympic Committee (COI) in agreement with the International Surfing Association (ISA) and the league World Surfing Championship (WSL) (its debut in the Olympics is scheduled for the year 2021 in Tokyo). This inclusion, added to new ways of transmission technology of championships, generated a greater exposure and accessibility to the general public.

In Brazil, the increase in the number of surfers also due, in the last years, to the prominence of athletes in several championships. The Brazilian surfers has been wining with world titles in the junior category, in the access division to the world circuit and in the main division of professional surfing circuit. Furthermore, several national athletes have been well on the world circuit. This group of competitors has been called the "Brazilian Storm". In other surfing modalities the Brazilian surfers are reaching great results. One example is at modality of big wave surfing in which Brazilian surfers are holders of the records of the Biggest Waves Ever Surfed for both males and females (Globo esporte, 2018 and Guinness World Records, 2020).

The development of maneuvers with greater plasticity, called "progressive maneuvers" by sports practitioners, also contributes to a greater diffusion of the sport (Peirão and Santos, 2012). These maneuvers help to increase competitiveness and demand more and more from athletes who, in turn, invest in new training techniques because these also involve a wide range of physical movements and efforts.

Due to this variety of situations in modality practice, there is a complexity in the elaboration of a training routine and effort evaluation for its practice. Works such as Canozzi et al (2015), Borgonovo-Santos et al (2021), Meir et al (1991), Loveless and Minahan (2010), among others, try to develop models for evaluating efforts in surfing. These models mostly follow the effort analysis model based on the O2 deficit, gas analysis and the presence of lactate in the blood of athletes and indicate that a good part of the effort expended in the practice of sport is in the rowing movement. This question is relevant especially in terms of competition surfing, where the rule assumes that, at certain times, the surfer who gets to the outside first has priority in choosing the waves.

It is important to highlight that the authors point out that there is a considerable energy expenditure during the period in which the athlete performs maneuvers on the wave. This implies that when adding the effort performed in the rowing step, there is an effect of loss of yield due to the rowing. Thus, one of the points that training for high performance athletes seeks is physical improvement for the execution of the rowing movement.

Therefore, several studies carried out use these tests to assess and improve paddling. Godoy (2017) presents a physiological and biomechanical evaluation model of recreational surfers. In this work, the author points out as a measure the rowing on a surfboard in a pool and with a crawl swimming. This evaluation tends to be quite faithful to what happens in reality, however they end up requiring a large structure for its execution. The procedure adopted by Canozzi et al (2015) and Borgonovo-Santos et al (2021) is very similar.

Another possibility of performing tests would be through ergometers. McArdle and Katch (2004) define ergometer as an exercise apparatus that quantifies and normalizes physical exercise in terms of work and/or power. The ergometer is a

device used in the sports field to assess the athlete's effort during physical exercise. Today, there are ergometer models for specific sports, but there is no specific model for surfing.

With the use of ergometers, it is also possible to use another exercise analysis model with good acceptance known as the Wingate method or Wingate Anaerobic Test (Barfield et al, 2002 apud Cavazzotto et al, 2014). This test aims to assess the athlete's anaerobic power when subjected to a certain load for a stipulated time of 30 seconds. According to Cavazzotto (2014), the parameters evaluated by this test are the Peak Anaerobic Power, Average Power and Athlete Fatigue Index. Due to its application in specific equipment, this model ends up being simpler to apply (Bar Or, 1987 apud Cavazzotto, 2014).

Thus, considering all aspects related to the need of technique improvement that involves surfing training as a modality, the absence of specific equipment for training and the increasing demand from practitioners, whether competitive or just recreational, the company Surf Evolution created, in partnership with IFSC, a movement simulator for surfing for functional training and teaching in gyms. The device simulates the lateral oscillation movement of the board, the paddling movement with the arms and the movement of piercing the wave with the board, which are movements that require effort from the practitioner.

This project ended up generating a functional prototype that provides movements and efforts very similar to those that occur in water. However, it was found the possibility of improving it by adding an effort analysis functionality. Therefore, a measuring system was adapted to the prototype developed to work as an ergometer for the upper limbs. This system consists of a device for measuring the displacement of the paddling, thus enabling the measurement of the work and power performed by the practitioner.

Thus, the objective of this work is to present the development of this device as well as a proposal for its validation, which used the Wingate method as a reference.

2. PROTOTIPE DEVELOPMENT

For the development of this work, the prototype of the equipment for surfing training was used as a basis. This prototype is described below, as well as the adaptations made to it.

2.1 Surf Training Equipment

The equipment used as the basis for this project (shown in Figure 1), developed in a partnership between the IFSC and Surf Evolution, enables training, learning the sport and physical conditioning by simulating the movements of the board in the water. The movement of the row is simulated through a system of cables and pulleys and the water resistance is simulated by a spring that resists the pulling of the cable (Figure 2). The system is composed of a steel cable connected on one side to a grip handle and a Pilates spring on the other to provide paddling resistance, thus simulating the resistance of water in surfing.

Figure 2 - Surf Evolution Equipment (Source: Surf Evolution, 2019).

To determine the spring constant, it was necessary to carry out tests with the springs. By Hooke's law, to determine the elastic constant of springs, it is necessary to know the applied force and the deformation that this causes. For this, calibrated masses of 7.25 kg, 8.00 kg, and masses of 1.00 kg were used to increase the weight, in addition to a caliper to measure the deformation. The test was performed with 5 Pilates springs to select the pair with similar elastic constant,

first the springs were measured without load. After the springs were hung from one end of the crane, the weight was hung from the other end, after the spring had stabilized, and the deformation was measured and the deformation values noted in table 1.

Table 1 – Spring deformation in the test performed

		Deformation (mm)								
	mass (Kgf)	0,00	7,25	8	9	10	11	12	13	14
Spring	1	443,4	631,0	661,6	716,0	757,8	790,8	841,6	882,5	924,7
	2	444,2	677,8	711,2	759,3	795,3	837,3	883,0	925,7	962,9
	3	451,7	696,5	730,0	780,2	816,0	855,7	904,9	943,3	989,9
	4	453,3	683,0	720,0	770,1	814,5	848,0	897,3	936,4	979,8
	5	470,0	491,3	505,6	513,9	532,0	537,7	554,2	560,7	575,2

Source: elaborated by the author.

To generate the values of the elastic constants, the values of the sizes of the unloaded springs were disregarded, as it was analyzed that the springs did not present a linear behavior in the initial range of deformation since there are factors such as the form of construction, the fixation hooks and a load inherent to the shape of the spring in the rest position. The deformation force results generated the elastic constants in table 2:

Table 2 – Spring elastic constant.

Spring	1	2	3	4	5
K (N/m)	227,12	233,35	229,50	229,45	836,99

Source: elaborated by the author.

Springs 3 and 4 were selected for the equipment due to their similar coefficient, thus the effort in each arm would be the same during the stroke movement. The springs replaced the ones used in the equipment, which showed wear.

2.2 Implementation of an encoder to measure cable distance

The KY-040 encoder was coupled to the pulley with a fabricated bracket (Figure 3):
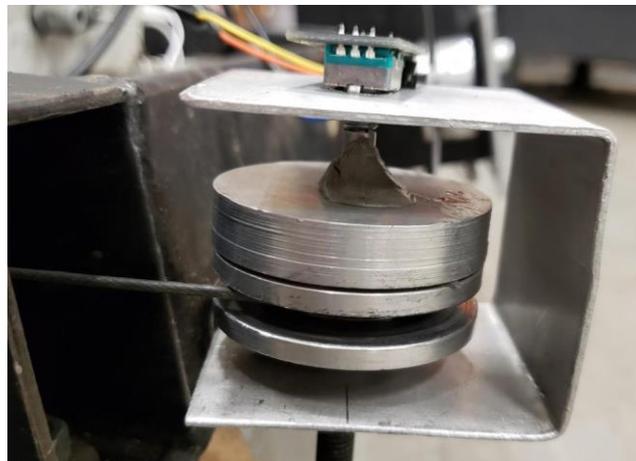

Figure 3 - Encoder positioned (Source: elaborated by the author).

To measure the deformation of the springs, it is possible to measure the displacement of the cable during rowing. For this purpose, encoders coupled to the pulleys of the system were used, the encoder thus measuring the revolutions of the pulley.

The encoder used has a resolution of 20 pulses per revolution, this means 1 pulse every 18°, to determine the arc length per pulse (Eq. 1):

$$l = \alpha \pi R / 180 = 18 \pi 15 / 180 = 4,71 mm \tag{1}$$

Where l is the arc length (mm), α is the arc length opening angle (°) R is the radius (mm) and π value is 3,1416

Therefore, for the pulley used, the encoder has a resolution of 4.71 mm per pulse. Arduino acquires the pulses and calculates the cable movement.

A test was carried out to assess the accuracy of the encoder, moving the cable 0.10 m at a time and the values calculated by Arduino were noted in table 3:

Table 3 - Encoder Calibration Result

X real	0,100	0,200	0,300	0,400	0,500
X calculated	0,098	0,196	0,294	0,392	0,490

(Source: elaborated by the author).

The system had a systematic error of 2% due to low encoder resolution and conversion rounding, an encoder with a higher resolution could improve these results. The error in this case has been corrected mathematically by the program.

2.3 Software development for Wingate tests

The Wingate test is done by paddling as many times in 30 seconds, because of its ease of implementation and interpretation of the results it was chosen. To implement the program (Figure 4), the stroke movement distance was captured for 30 seconds, and the spring preload could be adjusted in advance. The test starts with the user's first stroke and data is captured during runtime. The encoder position is measured every 0.3s, the value is converted to distance traveled by the cable and the results are sent to an Excel spreadsheet through Arduino Excel, the values are placed in column B.
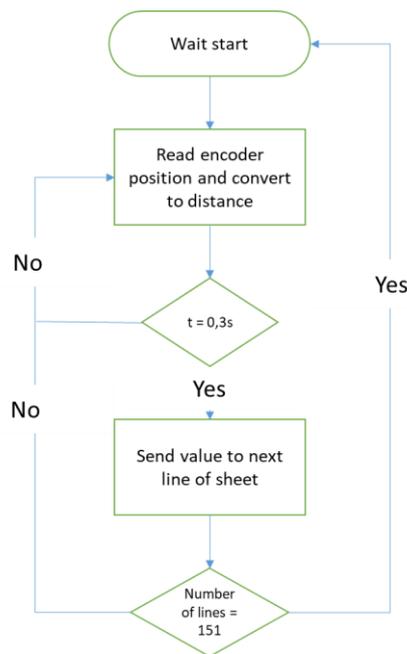

Figure 4 - Wingate Routine (Source: elaborated by the author).

2.4 Data processing

Data from each test were analyzed in the spreadsheet where the potency is calculated. For the Wingate test, the maximum and average power is calculated by the total work of the rows (Figure 5).

t(s)	Dist/Stroke (m)	Maximum power (W)	Medium power (W)	Fatigue Index
0,3	0,06			
0,6	0,36	69,3	59,5	9%
0,9	0,44			
1,2	0,64			
1,5	0,83			
1,8	0,91			
2,1	1,04			
2,4	0,68			
2,7	0,56			
3	0,3			
3,3	0,19			
3,6	0,49			
3,9	0,8			
4,2	0,92			
4,5	1,02			
4,8	0,81			
5,1	0,59			

Figure 5 - Results sheet (Source: elaborated by the author).

The graph generated by distance over time shows the cycle of strokes done during the test and indicates the distance of a complete stroke.
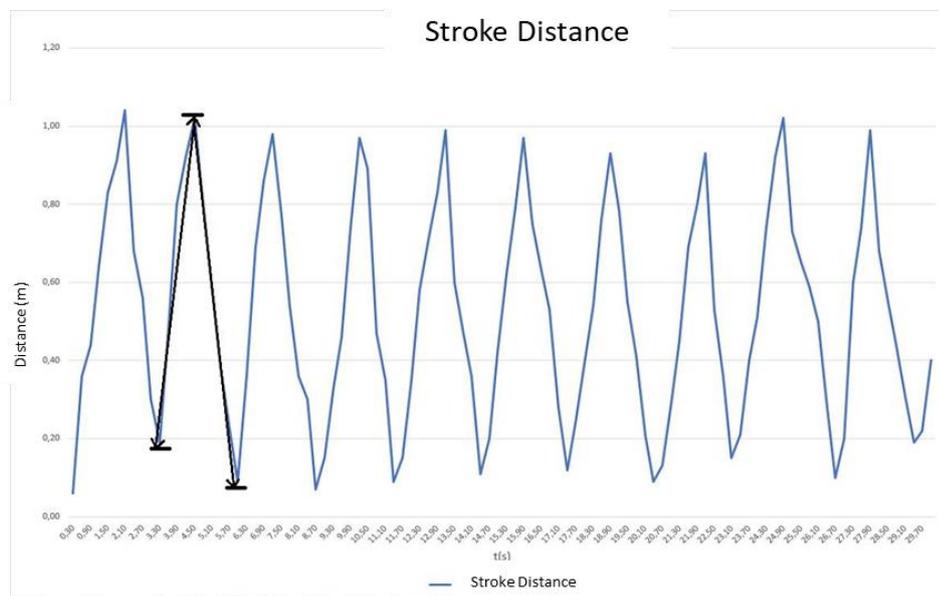

Figure 6 - Graph of stroke distance over time (Source: elaborated by the author).

The maximum power given in the first 5 seconds of the test, and the average power is the power generated during the test can be calculated by Equations (2) and (3):

$$P = F.d/t \tag{2}$$

Where, P is the power (W), F is the Force (N), d is the cable distance traveled (m) and t is the time interval(s)

$$F = (K.\Delta x/2) + Fp \tag{3}$$

Where, F is the Force (N), Fp is the Preload force (N), K is the Spring constant (N.m) and Δx is the Spring deformation (m).

In other ergometer models the resistance force is fixed, but for the surf simulator the spring presents a variable force during movement, so to determine the calculated force in the time interval the initial preload is added for each calculated force value, after the mean of these values was taken for the measured time interval.

The distance covered was found by adding the largest values of the stroke distance and subtracting the smallest values, using the Excel equation (figure 7):

```
=(MAIOR(B3:B102;1)+MAIOR(B3:B102;2)+MAIOR(B3:B102;3)+MAIOR(B3:B102;4)+MAIOR(B3:B102;5)+MAIOR(B3:B102;6)+
MAIOR(B3:B102;7)+MAIOR(B3:B102;8)+MAIOR(B3:B102;9)-MENOR(B3:B102;1)+MENOR(B3:B102;2)+MENOR(B3:B102;3)+
MENOR(B3:B102;4)+MENOR(B3:B102;5)+MENOR(B3:B102;6)+MENOR(B3:B102;7)+MENOR(B3:B102;8)+MENOR(B3:B102;9))
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Figure 7 – Equation to find the stroke distance (Source: elaborated by the author).

3. RESULTS

Five Wingate tests were performed at intervals of 5 minutes with 1 individual. The results were saved to the spreadsheet and then analyzed.

The powers generated through the calculation of work and execution time and calculated in table 4:

Table 4 - Test results

	Maximum Power (W)	Medium Power (W)	Fatigue Index
Test 1	69,3	59,5	9%
Test 2	48,9	36,3	6%
Test 3	47,3	38,3	12%
Test 4	40,2	25,3	29%
Test 5	40,7	24,5	20%

(Source: elaborated by the author).

The behavior of the results shows that at each test performed, the maximum and average power decrease and the heart rate increases, demonstrating that the effort increased. The result is as expected and the equipment is capable of generating an external load and evaluating the internal load.

Other results analyzed were the total rowing distance (Table 5), where the distance peaked and then dropped drastically. The number of strokes (Table 6), the stroke length (Table 7), and the time between strokes (Table 8) also decreased with each test.

Table 5 - Total stroke distance

	Test 1	Test 2	Test 3	Test 4	Test 5
Distance (m)	15,25	15,25	16,36	11,89	11,77

(Source: elaborated by the author.)

Table 6 - Total number of strokes

	Test 1	Test 2	Test 3	Test 4	Test 5
Number of Strokes	18	18	17	17	16

(Source: elaborated by the author.)

Table 7 - Stroke range in the test

Test 1	Test 2	Test 3	Test 4	Test 5
Stroke range(m)				
0,98	0,92	0,87	0,80	0,80
0,93	0,88	0,89	0,78	0,82
0,91	0,82	0,89	0,77	0,82
0,88	0,88	0,88	0,76	0,83
0,88	0,87	0,87	0,78	0,75
0,85	0,87	0,89	0,78	0,76
0,84	0,81	0,86	0,74	0,74
0,80	0,86	0,87	0,71	0,64
0,92	0,88	0,82	0,65	
0,80	0,76			

(Source: elaborated by the author).

Table 8 - Stroke time in the test

Test 1	Test 2	Test 3	Test 4	Test 5
Time (s)				
3,30	3,30	3,60	3,60	3,90
2,40	2,70	3,30	3,30	3,30
2,40	2,70	3,30	3,30	3,30
2,40	2,70	3,30	3,00	3,00
2,70	3,00	2,70	3,30	3,00
2,70	3,00	3,00	3,90	3,30
2,70	3,00	3,00	3,30	3,90
2,40	3,00	2,70	3,00	3,30
3,30	3,00	3,30	3,30	
2,40	2,70			

(Source: elaborated by the author).

4. DISCUSSIONS AND CONCLUSIONS

The objective of the present work was to build a model of an equipment that could measure the performed effort in a pre-existing surfing training equipment. This apparatus was built with Wingate anaerobic test as a reference for the

measurement. This test seeks to measure three effort variables that are the maximum or peak power, the average power and the fatigue index. From the tests carried out with the device adapted to the equipment, it could be seen that the spring mechanism does not have the standard configuration for the performance of the Wingate test, as it does not have a fixed load. A spring is a device whose force changes as a function of deformation. However, the characteristic of effort performed in surfing is similar to spring. Thus, it is worth reflecting on how to apply the method to this specific case, an issue to be discussed with professionals in the field of physical education.

Regarding the developed device, it performed the planned measurements satisfactorily, that is, it allowed the measurement of the cable displacement from the encoder and, with this added to the spring constant, it was able to calculate the force and work performed by the practitioner. Because these quantities are time-varying, it was necessary to raise their curves throughout the test execution time. From the curves it was possible to measure the maximum power, average power and fatigue index of the practitioner.

Another relevant issue is that the system as a whole is quite simple from the point of view of mechanical and electro-electronic construction, with the programming part being responsible for processing and making data available to the user. This is something that appears as a pending issue due to the need to create an interface that is compatible with the one provided by the company's commercial equipment. Thus, this is a work that must be carried out in conjunction with it.

Still, it is worth noting that a more adequate adjustment of the springs used is necessary. Those chosen from the constant definition test ended up presenting a very high load configuration, which may result in the impossibility of regulating the test for people with less strength, such as beginner athletes, for example.

Also, it is recommended, in the case of using an encoder, to use an encoder with higher resolution for more accurate data acquisition. Based on the proposed improvements, it is believed that one can contribute to the study of effort evaluation methods by dealing with the problem of evaluating the results obtained by the equipment in order to think of an effort analysis more linked to what surfers actually face. The model can also be validated against the O2 deficit (VO2) or exhaust gas analysis methods.

So, the meaning scientific contribution of this work is to present a new and more realistic method to evaluate the physical effort to practice the paddle during the surfing training. This method can be used to other sports like swimming. Considering the evolution of the number of practitioners of the sport, the development of exercise routines to amateur athletes can be improved too.

Thus, it is concluded that the work developed met the initial requirements raised with the team of the physical effort laboratory at the Federal University of Santa Catarina and has great potential to add new functionality to the product.

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