Development of Biomedical Dynamometer for Measurement of Grip Strength in Mice Modeled with Cerebral Palsy

Eduardo Ferreira Horbach
Engineering College, Federal University of Mato Grosso do Sul; eduardoferreirahorbach@hotmail.com

Josivaldo Godoy da Silva
Post-graduate Saúde Centro-Oeste, Federal University of Mato Grosso do Sul; josivaldo.silva@ufms.br
https://orcid.org/0000-0003-0663-2087

Daniela Araújo de Almeida
Post-graduate Saúde Centro-Oeste, Federal University of Mato Grosso do Sul; dani-3103@hotmail.com

Iandara Schettert Silva
Post-graduate Saúde Centro-Oeste, Federal University of Mato Grosso do Sul; ian.da.ra@hotmail.com
https://orcid.org/0000-0001-9431-098X

Abstract

This research aimed to develop a biomedical dynamometer capable of measuring the grip strength of the forepaws of laboratory mices to verify the posterior phase, the effect of modeled cerebral palsy in the animal. The equipment was developed using a stainless steel blade, two double strain gages, a signal conditioning circuit that was connected to a software for acquisition, processing and plotting of graphs and tables in Excel. The metal blade has a length of 18.5 cm, a width of 1.5 cm and a thickness of 2 mm and a double strain gage model pa-09-125ha-350-l8 from Excel Sensors (Brazil), was glued to each face. The two double strain gages were connected in a Wheatstone bridge, which produces an analog response due to mechanical deformation of the blade, with force applied by the mice. This response was submitted to a signal conditioning circuit developed with Arduino that modulated the input wave, generated 10000 times amplification and performed filtering 4th order using Butterworth filter. Finally, a software developed in Labview 2019 of National Instruments (USA) was used for acquisition, processing and plotting of graphs and tables in Excel of the measurements performed. In the next step, the dynamometer was calibrated for sequential loading of masses of 0, 15.48 g, 31.53 g, 46.88 g to 62.47 g and also for sequential unloading of the same masses. For this, the masses were hung on a nylon string that was attached to the free end of the metal sheet. The final test was to measure the response time of the dynamometer with a stopwatch, when hanging a mass of 62.47 g on the nylon thread that was cut abruptly with scissors. Some of the main results of the calibration were as follows: 15.48 g generated 3.70 V, 31.53 g generated 7.48 V and 62.47 g gene rated 14.80 V and the response time was 0.3 s. These answers show that the dynamometer can be used to measure the grip strength of mice and can be modified for use in humans.

Keywords: biomedical dynamometer; cerebral palsy; mice; humans; sensitive.

1. Introduction

One of the objectives of neuroengineering is to study the effects of cerebral palsy (CP) on the nervous system in order to develop solutions that benefit and minimize the effects on people (MEDTRONIC, ?; INSTITUTO SANTOS DUMONT, ?).

The study of the CP can occur through the measurement initially of the effects in physical force of animals (mouse) and humans. However, this requires equipment that measures objectively, has sensitivity and can be purchased (MEDTRONIC, ?).

The importance of using a biomedical dynamometer to measure mouse force is that it is not an invasive and does not harms the animal or human. Furthermore, the complexity of the system means in vivo assays of muscular force in the animal is essential in the evaluation of its present condition and the effects of any treatments (DEACON, 2013).

Smith et al. (1995) developed a mechanic dynamometer to measure the force and resistance of muscles in the forelimbs of mice. The equipment explores a mice tendency to grab a horizontal metal bar while suspended by its tail. The dynamometer can be used to examine two parameters; the first one is the upward force, which the mice is able to exert against the horizontal bar.

Successive measurements of an animal's muscle strength were made under identical conditions. The constancy and reproducibility of the measuring procedure created a statistically useful level of accuracy in force measurement. The second parameter that the apparatus measured was the duration of the exertion of the force. Here, measurements also exhibited a useful level of accuracy, reproducibility, and precision. Apparatus measures the combined neuromuscular activity of the mice to maintain attachment to the horizontal bar.

The first disadvantage of this equipment is that it does not transform the animal's mechanical effort into graphs and numbers that are easily interpreted by health professionals. The second disadvantage is that the results can only be generated locally, close to the animal and cannot be sent remotely through a communication network and analyzed by a distant computer. The third disadvantage is that the equipment has parts that move and wear out, favoring the appearance of wrong measurements if used repeatedly.

Deacon (2013) uses a system to test the force of the mice devised the inverted screen test published it in 1964. It is a test of muscle force using all four limbs. Most normal mice easily score maximum force on this task. The test described in this article provide a finer measure of muscular force.

There are also several strain gauge-based pieces of apparatus available commercially that will provide more graded data than the inverted screen test, but their cost may put them beyond the reach of many laboratories which do not specialize in force testing. Hence in 2000 a cheap and simple apparatus was devised by the author. It consists of a series of chain links of increasing length, attached to a "fur collector" a ball of fine wire mesh sold for preventing lime scale build up in hard water areas. An accidental observation revealed that mice could grip these very tightly, so they proved ideal as a grip point for a weight-lifting apparatus.

A common fault with commercial force meters is that the bar or other grip feature is not thin enough for mice to exert a maximum grip. As a general rule, the thinner the wire or bar, the better a mice can grip with its small claws. This is a pure test of force, although as for any test motivational factors it could potentially play a role. The use of scale collectors, however, seems to minimize motivational problems as the motivation appears to be very high for most normal young adult mice (DEACON, 2013).

The disadvantages of this purely mechanical method in addition to those already mentioned above include measurement inaccuracies, use of masses that have not varied continuously**.** In addition, the system requires the animal to be upside down, causing inconvenience and difficulties for the mouse, in addition to this system not having any form of communication with a computer.

Aiming to circumvent the limitations found in the aforementioned meters and to measure the strength of the rat with CP, continuously and digitally through a computer, a biomedical mechatronic dynamometer with strain gages was developed to be used in laboratory.

The new dynamometer presented important advantages due to the fact that it does not have moving parts, can transmit information remotely over the internet and has software that generates graphics and analyzes the physical efforts of the animals and show high precision. The following text presents the characteristics of this new dynamometer that was tested.

2. Methodology

Mechatronic biomedical dynamometer was developed in the ENGEBIO laboratory (Biomedical Engineering and Assistive Technology) of the Midwest Health of Graduate Program of the College of Medicine of the Federal University of Mato Grosso do Sul – UFMS, Brazil.

The equipment was designed to measure in a range of 0 to 1 N, being composed of a stainless steel blade that has length of 18.5 cm, width of 1.5 cm and thickness of 2 mm to which it was glued on each face, a double strain gage (model pa-09-125ha -350-l8) from Excel Sensors company of Brazil, one signal conditioning circuit developed with Arduino and a software developed with Labview 2019 (National Instruments company - USA) for data analysis, graphical plotting and table.

2.1. Construction of the metal blade

The first region has a length of 2 cm and where a 0.5 mm recess was made on each face to increase the deformation of the metal and also to glue a double strain gage. The second region is 13.5 cm long, 1 mm thick, and contains a hole at the end to introduce a nylon wire used for rats to apply force. The third region has a length of 3 cm and is used to fix the metal blade to the iron support. This iron support has a height of 26 cm, to adjust the position of the metal blade and inclination. Figure 01 shows the layout of the metal blade containing the strain gages.

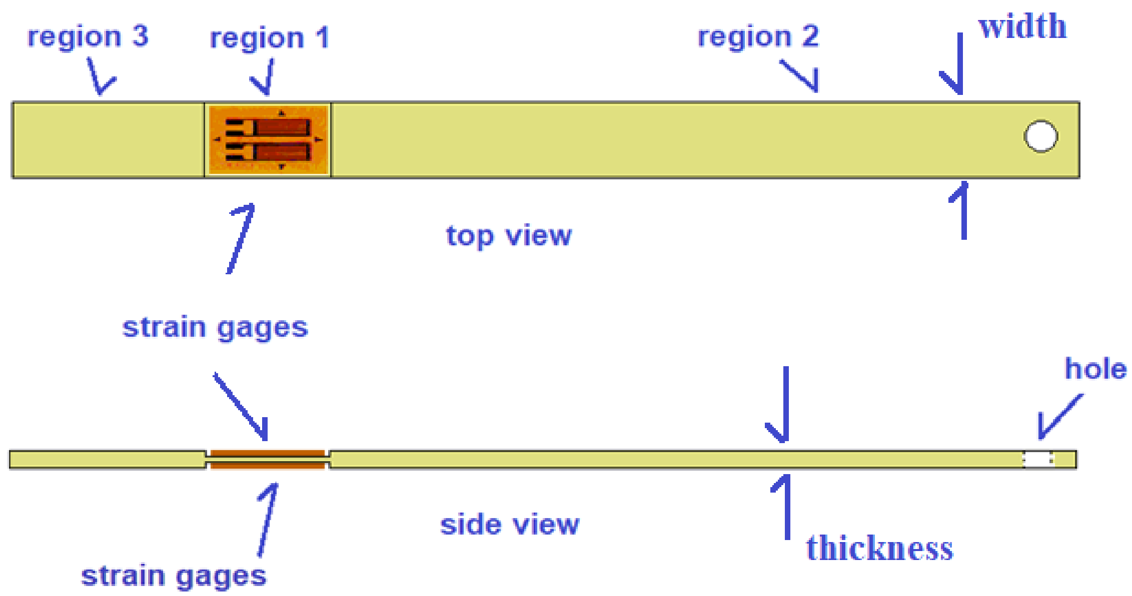

Figure 01. Stainless steel blade.
Source: autors (2021).

2.2. *Construction of the complete mechanical structure*

The two double gages were connected in a Wheatstone bridge, in order to stabilize the response with temperature. Through the nylon thread, the mice apply vertical physical force upwards or downwards, and the torque that forms the thin region 1 depends exclusively on the intensity applied force. Figure 02 shows the complete mechanical structure while Figure 03 shows the photo of the developed mechanical structure.

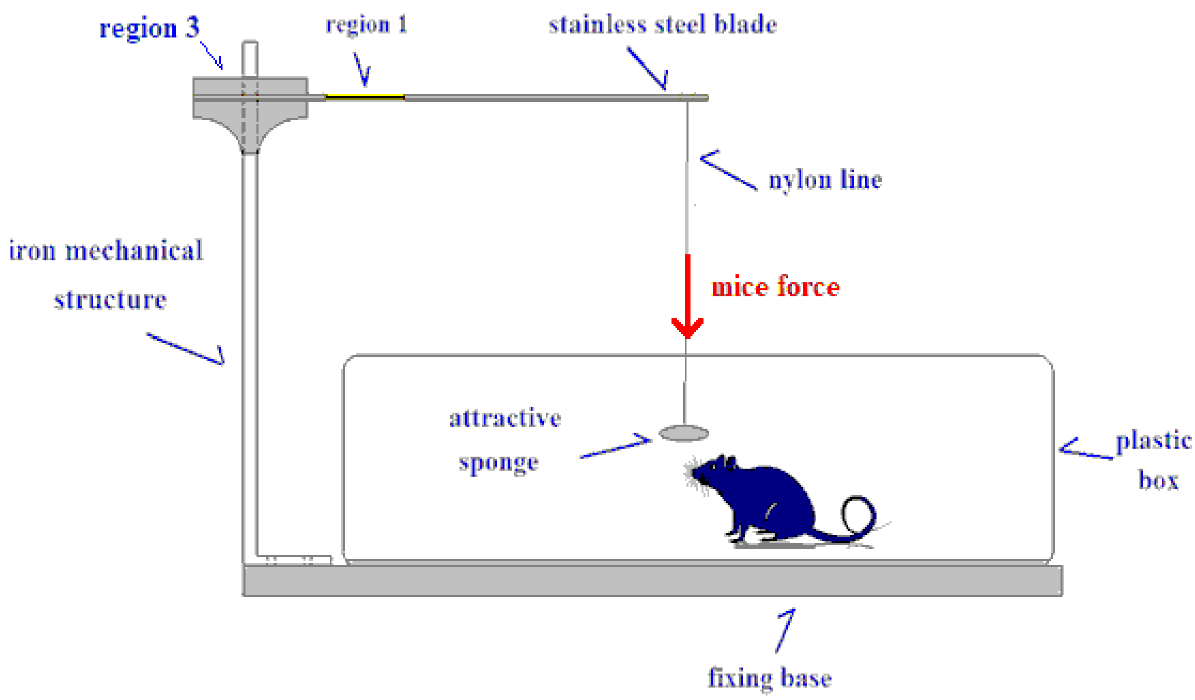

Figure 02. Layout of complete mechanical structure.
Source: autors (2021).

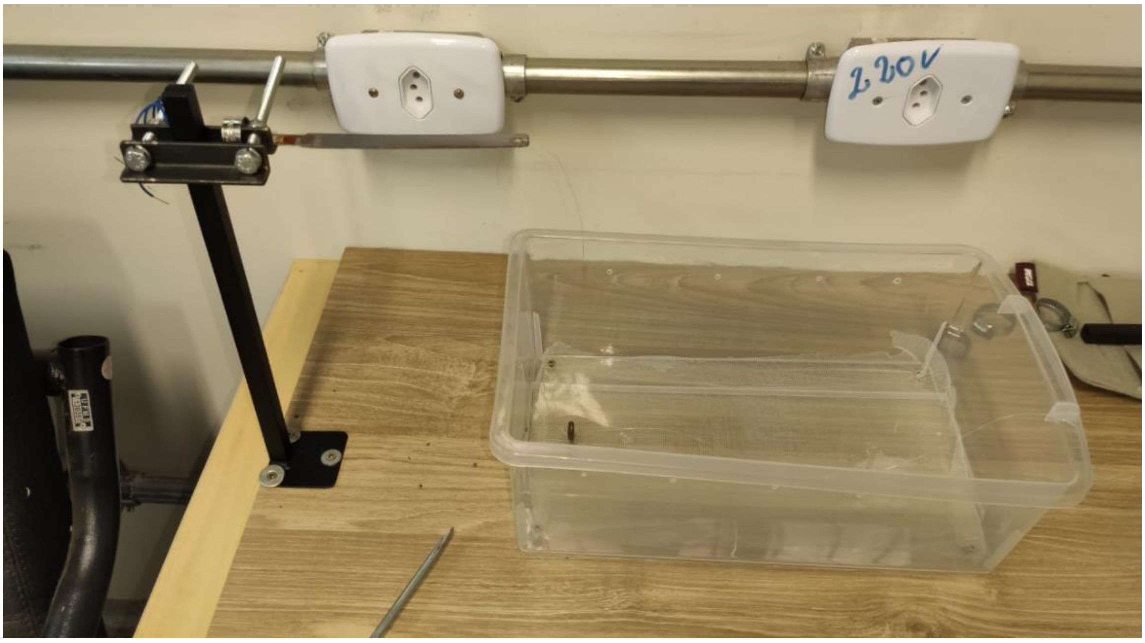

Figure 03. Developed mechanical structure.
Source: autors (2021).

The plastic box is 30 cm long, 19 cm heigh and 12 cm wide. It serves to confine the mouse's action and the sponge is to draw attention to holding and pulling. The correction base is made of wood to fix the plastic box and the iron support. Figure 04 shows a developed mechanical structure containing strain gages glued to the metal sheet and connected to the signal conditioning circuit.

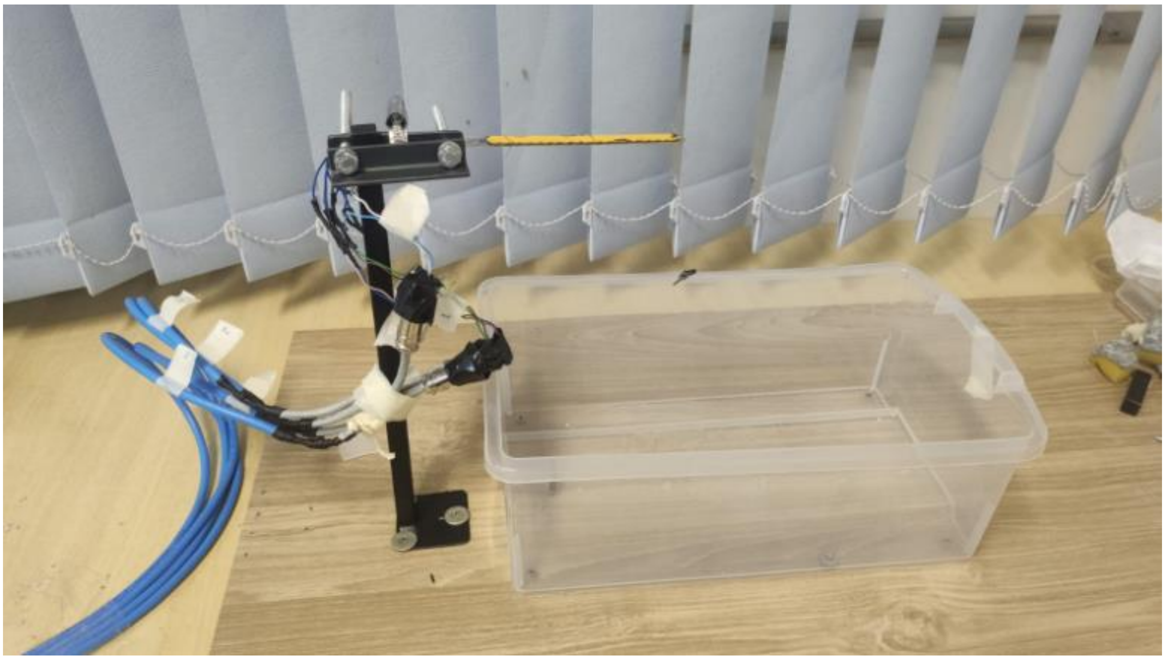

Figure 04. Strain gages connected to the signal conditioning circuit.
Source: autors (2021).

2.3. ***Construction of the signal conditioning circuit***

The response of the Wheatstone bridge with strain gage is connected to the signal conditioning circuit developed with Arduino to be processed (amplitude modulation, 10,000 gain amplification and 4th order filtering with Butterworth filter). Figure 05 shows the external photo of the signal conditioning circuit.

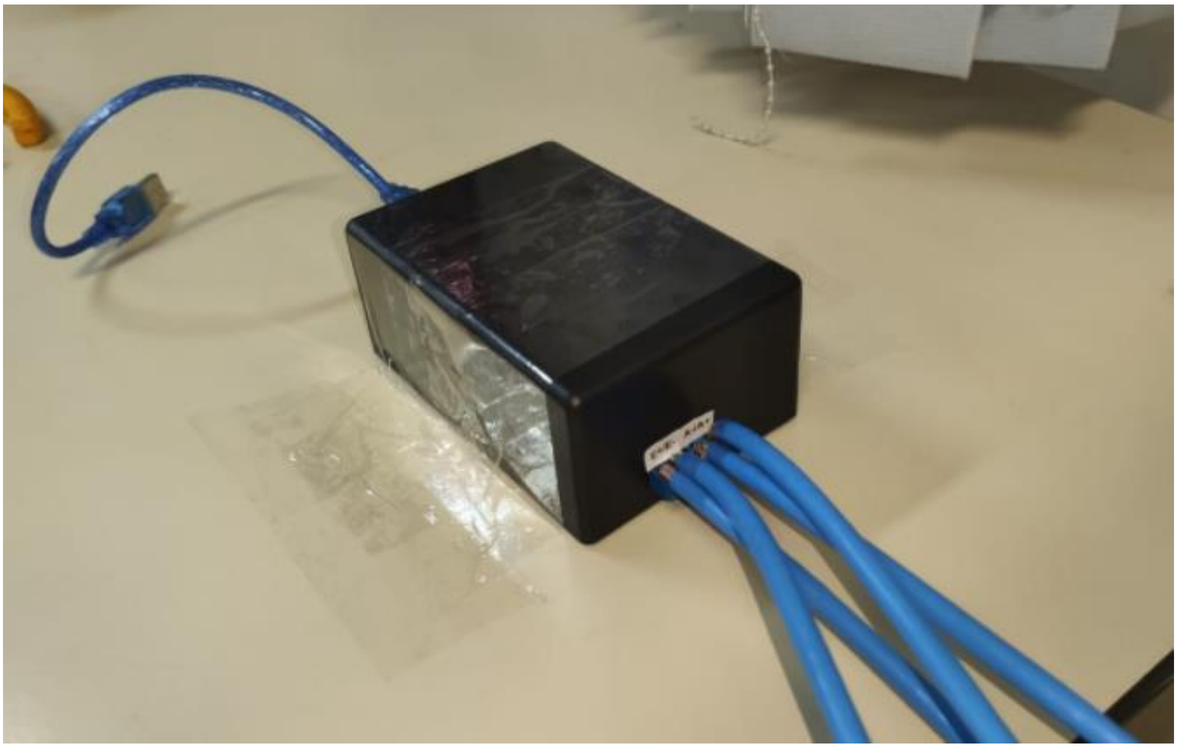

Figure 05. Signal conditioning circuit.
Source: autors (2021).

2.4. ***Force measurement system layout***

The signal conditioning circuit response was coupled to a data acquisition board and the information sent to the computer containing software for digital information processing. This Labview 2019 software makes the numerical tabulation of the information and plots graphs referring to the forces that the mice performs. Figure 06 shows the layout of the complete measurement system.

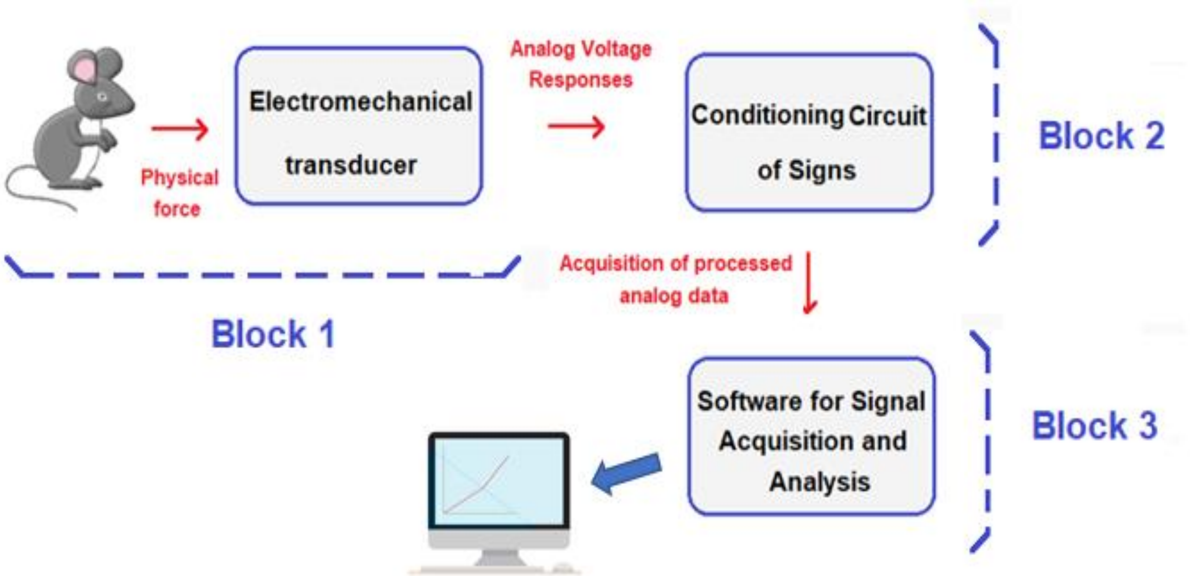

Figure 06. layout of the measurement system.
Source: autors (2021).

Block 1: Initially the mice applied varying forces to the nylon thread that is attached to the end of the metal blade. Then, the Wheatstone bridge with strain gauges glued to the sheet metal produced a proportional electrical response is very small, on the order of 0.2 mV to 1.0 mV.
Block 2: The electrical response produced on the Wheatstone bridge was submitted to the input of the conditioning circuit. The signal conditioning circuit, amplified 10000 times the voltage, filtered out low frequency electromagnetic noises and modulated the amplitude of the Wheatstone bridge response. The fourth order filter, Butterworth, was developed in the circuit.
Block 3: The analog information generated by the signal conditioning circuit was digitized and acquired be processed by software installed in the notebook Acer (model intel Core^{TM} i5-7200U 2.5 GHz).

2.5. *Calibration*

In this phase, the calibration of the dynamometer was carried out to know its behavior within the opera ting limit in the range of 0 to 1 N , were used known four masses. Initially, each mass was hung (loading) on the nylon thread to deform the metal blade and the read was carried out through the notebook. The masses were sequentially added to the nylon yarn in sequence: 0, 15.48 g, 30.96 g, 46.44 g, 61.92 g. The loading was repeated three times and the results are shown in Table 1.
The next phase consisted of sequentially removing each mass (unloading) hanging on the nylon thread until it returned to zero, in order to verify the presence of hysteresis. The procedure of loading the masses onto the nylon thread and subsequently unloading it was repeated two more times. The unloading was repeated three times and the results are shown in Table 2.

2.6. *Obtaining the sensitivity*

The next step was to verify the response of the dynamometer and sensitivity in loading and unloading, using masses much smaller than 0, 2.78 g, 5.57 g, 8.37 g, 11.09 g, 13.81 g, 16.47 g, 19.17 g. The loading was repeated three times and the results are shown in Table 3 and the unloading was repeated three times and the results are shown in Table 4.

2.7. *Obtaining the response time*

To find out the response time of the dynamometer, weights totaling 62,37 g were hung on the nylon wire to deformer the metallic blade. In the next phase, the wire was cut using scissors to recuperation of blade and the dynamometer response time was recorded using a timer.

3. Results

Tables 01, 02, 03 and 04 show measured quantities (mass and voltage) and also mathematical calculations (average and standard deviation).
M: Mass (g) measurements.

V_1, V_2, V_3: Voltage 1, 2, 3 (V) measurements.

A: Average (V) of measurements.

$$A = \frac{\Sigma V_i}{n} \tag{01}$$

V_i: voltage measurement.

i: measurement number

n: total number of measurements of sample.

S: Standard deviation (V) of sample.

$$S = \sqrt{\frac{\Sigma(V_i - A)^2}{n-1}} \tag{02}$$

3.1. *Calibration*

Table 01 shows results of three mass loadings on the stainless steel blade through the nylon wire.

Table 01. Dynamometer response.

	M	V_1	V_2	V_3	A	S
1	0.00	0.00	0.00	0.00	0.00	0.00
2	15.48	3.70	3.67	3.71	3.69	0.02
3	31.53	7.48	7.46	7.49	7.48	0.03
4	46.88	11.12	11.11	11.13	11.12	0,01
5	62.37	14.80	14.79	14.82	14.80	0.07

Figure 07 shows the behavior of the dynamometer with continuous mass loading.

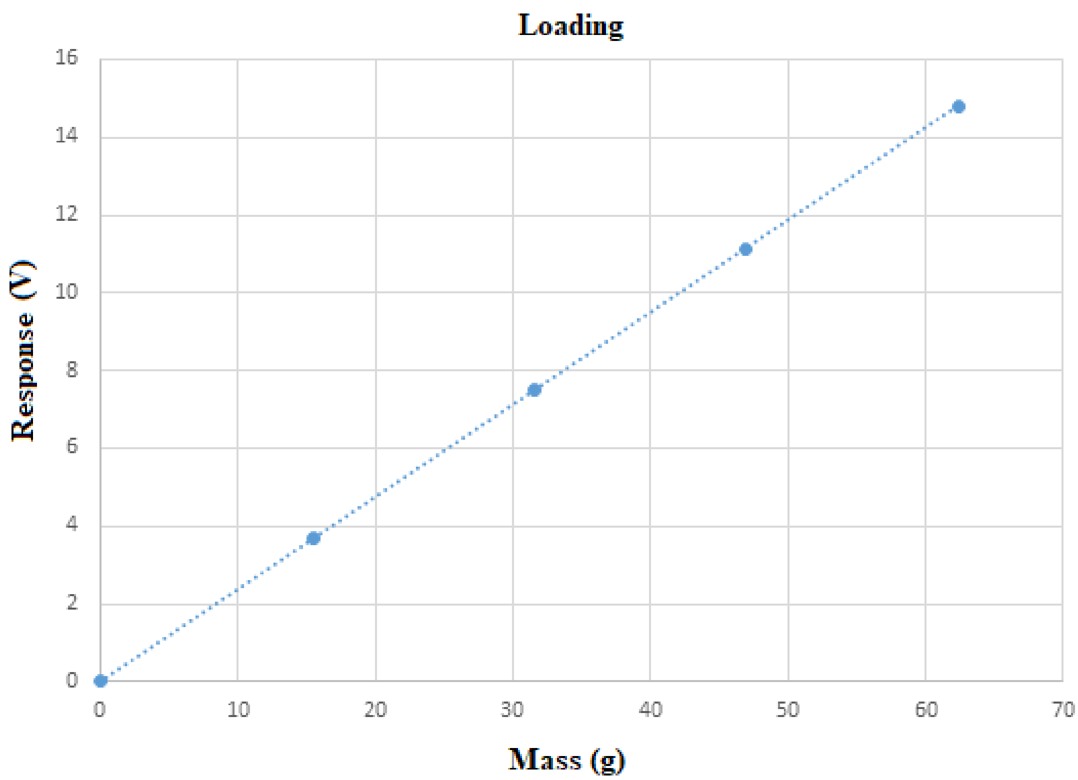

Figure 07. Dynamometer response (loading).

Source: Authors (2021).

Table 02 shows results of three mass unloadings on the stainless steel blade through the nylon wire.

Table 2. Dynamometer response.

	M	V_1	V_2	V_3	A	S
1	62.37	14.81	14.79	14.82	14.81	0.02
2	46.88	11.12	11.10	11.13	11.12	0.02
3	31.53	7.48	7.45	7.49	7.47	0.02
4	15.58	3.70	3.67	3.71	3.69	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00

Figure 08 shows the behavior of the dynamometer with continuous mass unloading.

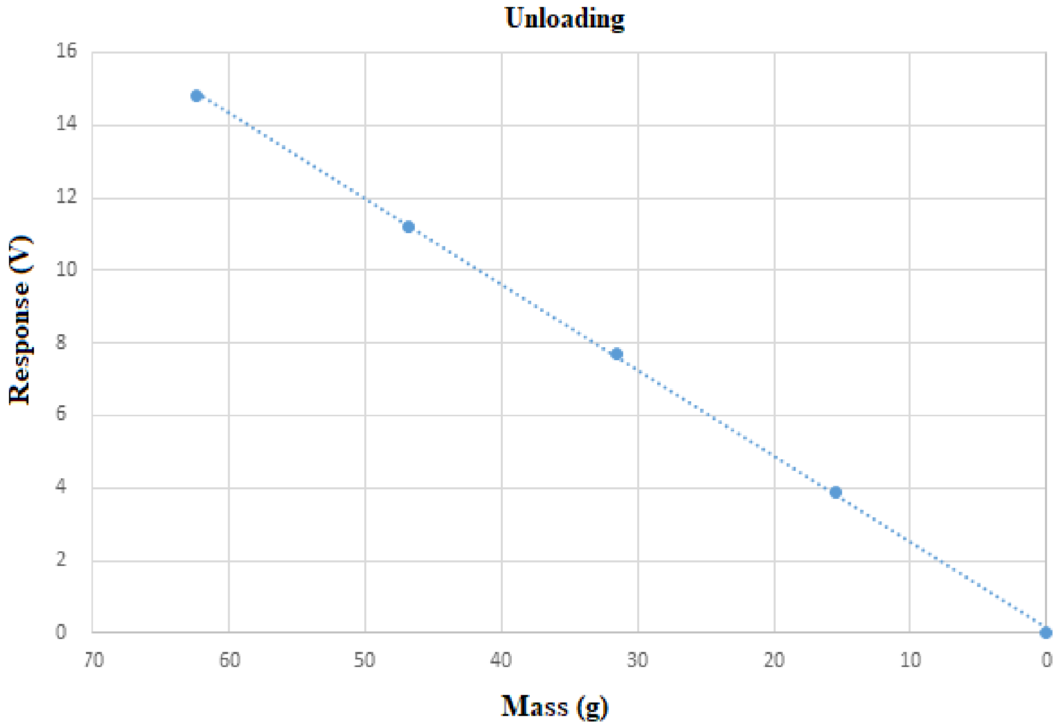

Figure 08. Dynamometer response (unloading).

Source: Authors (2021).

3.2. *Obtaining sensitivity*

Table 03 shows three results of small load masses.

Table 3. Dynamometer response.

	M	V_1	V_2	V_3	A	S
1	0.00	0.00	0.00	0.00	0.00	0.00
2	2.78	0.70	0.74	0.68	0.71	0.03
3	5.57	1.32	1.34	1.28	1.31	0.03
4	8.37	1.99	2.01	1.97	1.99	0.02
5	11.09	2.80	2.82	2.78	2.80	0.02
6	13.81	3.30	3.31	3.28	3.30	0.02
7	16.47	3.90	3.92	3.88	3.90	0.02
8	19.17	4.50	4.52	4.48	4.50	0.02

Figure 09 shows the behavior of the dynamometer with continuous mass loading.

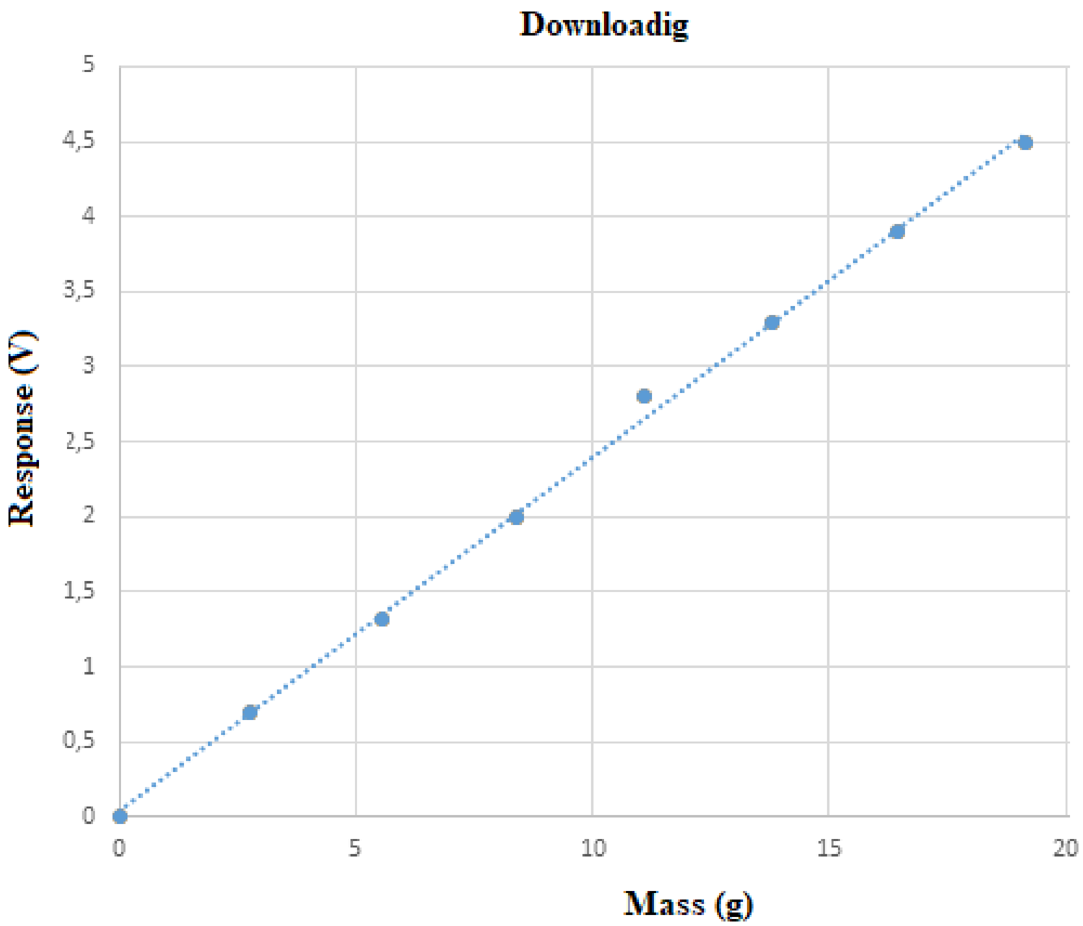

Figure 09. Dynamometer response (dowloading).
Source: Authors (2021).

Table 04 shows three results of small load masses.

Table 4. Dynamometer response.

	M	V_1	V_2	V_3	A	S
1	19.17	4.51	4.53	4.46	4.50	0.04
2	16.47	3.92	3.90	3.88	3.90	0.02
3	11.09	3.28	3.33	3.30	3.30	0.03
4	8.37	1.97	2.01	2.00	1.99	0.02
5	5.57	1.32	1.34	1.28	1.31	0.03
6	2.78	0.70	0.74	0.68	0.71	0.03
7	0.00	0.00	0.00	0.00	0.00	0.00

Figure 10 shows
the behavior of the dynamometer with continuous mass unloading.

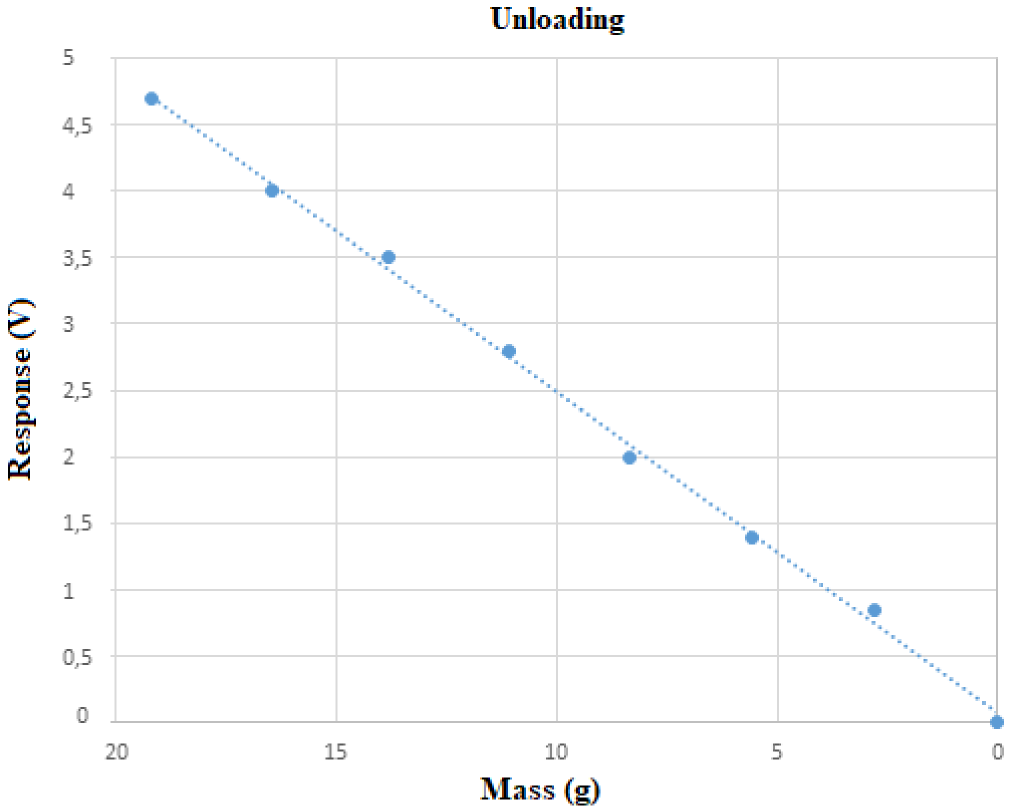

Figure 10. Dynamometer response (unloading).
Source: Authors (2021).

3.3. *Obtaining the response time*

The response time obtained for the dynamometer was 0.3 s.

4. Conclusion

The results presented indicate that the developed dynamometer can be used to measure the grip force applied by the rat's forepaws therefore, the problem presented in relation to the existence of a biomedical dynamometer capable of continuously measuring the animal's strength, processing analog information and assessing the animal's capacity was met. The measuring equipment showed excellent sensitivity as shown in the result of 2.70 g and 0.71 V in addition to good linearity. The equipment presented may also have applications for humans and in several researches.

5. Acknowledgement

The authors are grateful to CNPq for the scientific initiation scholarship granted and to the Federal University of Mato Grosso do Sul for its consent to the use of the ENGEBIO laboratory at FAMED.

6. References

MEDTRONIC (?). Sobre Paralisia Cerebral. Disponível em: https://www.medtronic.com/br-pt/your-health/conditions/cerebral-palsy.html.

INSTITUTO SANTOS DUMONT (?). Programa de Pós-Graduação em Neuroengenharia Disponível em: http://www.institutosantosdumont.org.br/pos-graduacao-neuroengenharia.

Deacon, R. M. J. (2013). Measuring the Strength of Mice. Journal of Visualized Experiments, pp. 1 a 4.

Smith, j. p, Hicks, p. s., Ortiz, l. r., Martinez, m. j., Mandler, R. N. (1995). Quantitative measurement of muscle strength in the mouse. Journal of Neuroscience Methods, pp. 15-19.