ERGO1
Physical Evaluation and Training for Wheelchair Users

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Abstract: According to the literature, there's a lack of methods, procedures and equipments for proper physical assessment. Physical tests applied to persons with disabilities are questionable due to their lack of adaptation to the motor gesture executed in these equipments, which are not the same executed in real wheelchair propulsion. Within this, was designed and built at the Habilitation/Rehabilitation Center in Paralympic Sports/UFU the second version of a wheelchair ergometer prototype that allows physical evaluation, being faithful to the specificity of movements. The equipment has several electronic systems controlled by computer such as electromagnetic resistance system, load cell, torquemeter, dedicated circuits and acquisition system. Preliminary results indicate that the evolution became more practical for the evaluator and comfortable for the user. The addition of flywheels and new calibration method proved its efficiency by improving the signal acquired. New evaluation procedures for physical capacity look promising.

1 INTRODUCTION

Physical activity, especially when directed to sports, is one of the ways to promote social integration at the same time that leads to health improvement, fighting sedentary lifestyle and avoiding future complications related to inactive life styles.

Wheelchair users represent a part of the population that, due to its mobility reduction, suffer from problems like cardiac complications, obesity, diabetes, shoulder and wrist injuries, among others. Frequently some of these problems result from activities developed in their daily life, such as seat transfer that makes the shoulder go through overcharges for which they are not prepared.

With regards to the generation of opportunities for disabled persons, one can highlight a great need for methods and processes for the evaluation of their physical capacities, mainly in sports and especially in high performance sport. However, Brazil has shown great potential in this particular area. For example, since the Olympics in Atlanta-1996 until London-2012, Brazil left the 37º place with two gold medals to the 7º place with 21 gold medals. In the Parapan American Games of 2011 at Guadalajara, Brazil reached first place with 81 gold medals. According to this, Brazilian Paralympic Committee (CPB) started in the last year partnerships with academic teachers across the country to create the Brazilian Paralympic Academy, searching to establish the missing link between knowledge production and its application. The first Specialized Training Centre in Adapted Physical Education and Parasports (CEFEP) was created in the School of Physical Education at the Federal University of Uberlândia.

Also based on this need, the Mechanical Projects Laboratory from the Federal University of Uberlândia created in 2007 a first prototype for a wheelchair ergometer. During its test phase, several structural and operational modifications were identified. So, at the new Habilitation/Rehabilitation Center in Paralympic Sports (NH/RESP), a new version was designed and built. This paper will focus on the differences between these prototypes showing the advances made in this second version, its preliminary results and some new features planned for a third version.

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2 PHYSICAL CONDITIONING OF WHEELCHAIR USERS

A low level of physical capacity is associated with high risk of cardiovascular complications (Hjeltnes and Jansen, 1990; Yekutiel, 1989) and may contribute for reduction in life quality. This reduction in physical capacity and, consequently, in life quality, may lead to secondary conditions as obesity, gastrointestinal problems, respiratory complications, joint pain and others (Steele, 2004) – coronary diseases are also highly related to physical inactivity, high fat diet, smoking and stress (Margonato, 2008). According to Margonato (2008), people with spinal cord injury are also more exposed to premature death due to cardiovascular accident.

Shimada et al. (1998) described wheelchair propulsion as the repetitive simultaneous bilateral movement of upper extremities. Through training, it's possible to enhance the efficiency of the propulsion force although, simultaneously, the real mechanical efficiency decreases. From a mechanical viewpoint, application of a non-effective force might be ineffective, but in a physiological viewpoint might be the optimal solution for upper extremities injuries (Lin et al., 2009). One of the fundamental aspects for wheelchair propulsion analysis is the definition of the motor gesture made. The propulsion cycle is described in two phases: impulse and recovery (fig. 1). Impulse phase is the period since the hand contacts the rims applying force to maintain or increase speed of the wheelchair. Recovery phase is the period between two consecutive impulse phases when the arms are retracted to prepare for the next impulse (Kwarciak et al. 2009). This propulsion cycle can also be executed in two different ways: one called synchronous, where both hands propel the rims at the same time, and one called asynchronous where the hands work alternate to propel the wheelchair (Goose-Tolfrey et al., 2003).

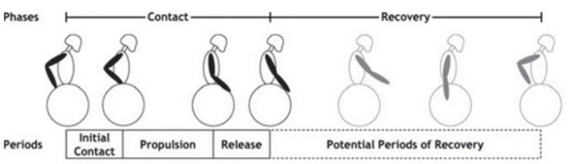

Figure 1: Definition of wheelchair propulsion cycle. Source: Kwarciak et al., (2009).

According to Boninger et al. (2002), wheelchair users receive few or none instruction about how to propel their wheelchairs or how to best adjust it to avoid injuries. Bjerkefors et al. (2006) affirms that it's essential for this population to maintain an adequate function for the shoulder's muscles and that it's important to consider an activity capable to stimulate muscular growth without symptoms of pain and excessive use.

Regarding available exercising equipments, both for rehabilitation and physical evaluation, literature indicates that the first ergometers aroused around 1950, whereas its first technological evolution regarding load control and information processing came up only in 1954 with the first cycloergometer produced in large scale developed by Astrand (Sousa, 2007). This kind of ergometer was often employed in studies that aimed to quantify forces and obtain physiological responses (Harman et al., 1987). After, arm ergometers arrived. This type can be used in the initial stages of rehabilitation programs and in subsequent phases to enhance muscular resistance (Andrews et al., 1998). Its use is also possible by persons with spinal cord injury, hemiplegia and for cardiac rehabilitation (Dicarlo, 1983; Nilsson et al., 1975). Although these apparels might be used by wheelchairs users along an adequate exercise program, they don't represent the real motor gesture made by this population in its wheelchairs.

Gordon et al. (2004) studied the different types of resistance generation for ergometers. The most common type, brakes made with belts, shows to be flawed because of the dependence of dynamic friction coefficient. It is recommended that ergometry exams make use of computer controlled interface and that its systems should be electronic or electromagnetic, allowing standardization of techniques, better control for load variation and monitoring signals (Guimarães et al., 2003). Haisma et al. (2006) mentions that it is important to have an adequate monitoring of exercises and trainings to verify changes in physical capacity, indicating if the training or rehabilitation program in question is effective.

3 ERG-CR09: FIRST PROTOTYPE

The first prototype developed was built in two modules, one for propulsion and one for electromagnetic resistance (fig. 2). This electromagnetic system has a generator for self-powering and an electromagnetic brake. The whole system was controlled by computer through an application made with LabVIEW. For physical evaluation, Wingate test was used.

Figure 2: ERG-CR09.

During the tests, it was possible to follow user's power and energy. These data, after the test end, were used to calculate fatigue index. Figures 3 and 4 shows a test result to exemplify the characteristics of the response obtained by the software.

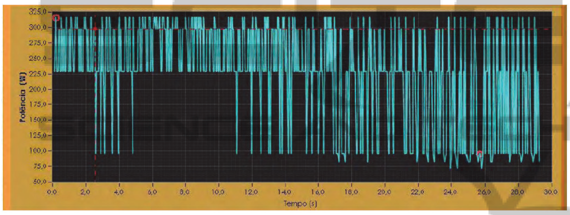

Figure 3: Absolute Power result where x axle is time (s) and y axle is power (W). Source: Salgado (2009).

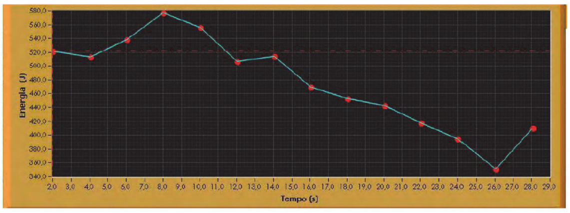

Figure 4: Absolute Energy result for the same test. X axle represents time (s) and y axle represents energy (J). Source: Salgado (2009).

As seen in these graphics, one cannot tell by looking to the power curve when the user started to lose its physical capacity nor in how much time that happened. This information can only be seen at the energy graph but this curve was only plotted after the test.

Although this prototype was designed to be comfortable and easily accessible to the user, several modifications were identified during its tests. Positioning of the user needed more adjustments, dimensions were too big, signal was good but may be improved, software interface may become more friendly and many other aspects. In light of that, the new prototype was designed in the search to fill the gaps left by the previous one.

4 ERGO1

The second version of the wheelchair ergometer prototype seeks to fill the gaps left by the first one. Major modifications were made in some areas, making it easier for the users and evaluators to work with it.

4.1 Structure

The new structure was designed to reduce previous dimensions. This was achieved changing the configuration to combine both previous modules into one. Material used was also changed to make this version lighter, allowing its transport to become easier.

According to the literature studied, in order to improve comfort and also performance of the users, it's necessary for the ergometer to have structural adjustments such as seat height, positioning related to the wheels and many more (Boninger et al., 2000; Sasaki et al., 2007; Sasaki et al., 2010).

To assess this structural project, a numerical simulation using finite elements modelling tested it with a maximum value chosen according to a load cell linked to the structure. Maximum stress value of this simulation was 19 MPa, which is much smaller than the yield stress of the materials used (250 MPa).

4.2 Signal Improvement

One of the characteristics of the previous prototype that led to the kind of signal seen on Figure 3 was the result of braking torque during the test. The pulsating brake and light rims caused the system to completely stop each time the brake acted, even at the its lowest level. This behaviour deviates the ergometer from real operation of the wheelchair on the ground.

Aiming to solve this, two inertial flywheels were designed and added to the ergometer. Due to size of these flywheels, the first pair of rims were excluded making the most external part of these flywheels act like rims.

The effect of this modification will be seen in the sessions ahead about the calibration process and test results.

4.3 Weight Acquisition

The load cell addition was made to the seat because the test protocols need the user's weight to calculate the level of resistance to be applied.

This feature has its own electronic circuit for signal conditioning and it's fully integrated to the software that controls the ergometer, so all calculations are made automatically.

After this modification, the beginning of test protocol became easier for the evaluator – since he only needs to press one button to obtain the necessary information – and for the user – who doesn't need to go through a secondary equipment to evaluate its weight.

4.4 Electromagnetic Resistance System

This part of the equipment remains almost the same as the previous project, having gone through minor modifications that are mainly structural to fit the new composition.

This system is responsible for generating the resistant torque and is controlled by computer through a dedicated electronic circuit, allowing to choose the brake level desired. The brake is based on the Foucault principle (García, 2005).

4.5 Torquemeter

The electromagnetic brake generates resistance levels triggered by respective voltage levels. Each voltage level is responsible for promoting a resistant torque range and receives an amplification through transmission pulleys. To evaluate the power exerted by the user in the equipment in accordance with the effort being employed, a torquemeter was developed. The equipment in question was mounted in the ergometer.

Static calibration of this system was made by locking the main transmission pulley and applying a known load through standardized masses in a support attached to the closest flywheel.

Due to limitations of the acquisition system, real time acquisition of torque signal couldn't be made making it necessary to adjust a dynamic torque curve in terms of angular speed. This way the torque developed by the user along the test can be achieved, allowing the calculation of power and energy spent by the user during the test.

Experimental setup for this calibration was made using a frequency inverter to control an induction motor that is attached to the main axle of the ergometer. The procedure consisted in acquiring a torque curve for angular speeds from 10 to 70 RPM with steps of 10 RPM.

More recently, this calibration was remade due to changes in the project. Now the torquemeter is a modular equipment that can be removed from the system at any time (Fig. 4). Also, calibration procedure now starts at 15 RPM and goes until 95 RPM since it was noticed that some users can achieve higher speeds than previously predicted.

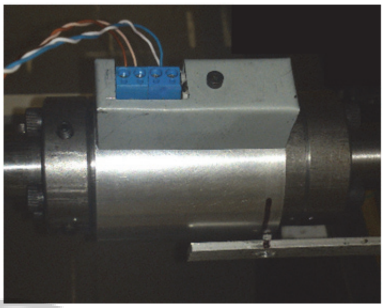

Figure 5: Torquemeter used in ERGO1 prototype.

4.6 Software Developed in LabVIEW Platform

To the execution of physical evaluation tests that include controlling the electromagnetic resistance system, acquiring user's weight and giving responses such as power levels, fatigue index and energy parameters, an application using LabVIEW platform was designed to perform the interface with the user and to execute all control and acquisition necessary to the system. This language was chosen due to its easiness not only to implement a friendly interface, but also for acquisition and signal manipulation.

This interface aims to be friendly and easy to use, allowing the tests to be executed by any person without previous knowledge of the application.

4.7 Test Protocols

Two protocols that stand out to assess the fitness and training are the Wingate and incremental. The first was developed in 1970s in Israel and lasts for 30 seconds in which the user being tested must overcome a resistance level doing maximum possible effort. Due to this characteristic, this protocol aims to assess physical conditioning through anaerobic performance of the person (Bar-Or, 1987; Franchini, 2002).

In the other hand, incremental protocols seek to evaluate physical conditioning through aerobic performance. Normally, the user has to maintain a certain pace while the resistance is incremented at determined time intervals. Test ends when the user is no longer able to keep pace. Because of that, each training or evaluation program sets its levels and increment intervals.

To evaluate test results, parameters as absolute and relative power, absolute and relative average equivalent energy and fatigue index are used, in addition to torque curves and angular speed.

For the purpose of this paper, only Wingate protocol was used. Three males and three females with average age of 30 years were assessed. None of them is an athlete. They are all able-bodied and have performed the protocol at the first resistance level.

5 RESULTS

5.1 Test Protocols

Data from volunteers evaluated are shown in Table 1. Figure 5 shows a user ready to begin the test. Tables 2 and 3 shows the result in terms of power, energy, fatigue and heart rate for each individual. Figures 6-11 shows the graphics for absolute power.

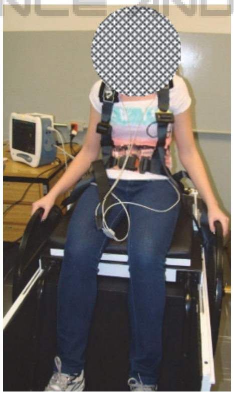

Figure 6: User ready for the test.

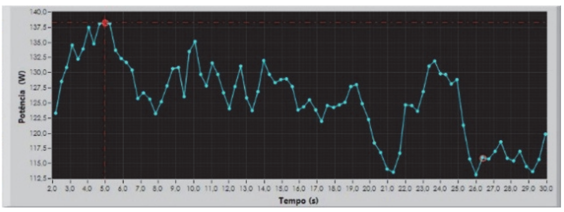

Figure 7: Absolute power for volunteer 1.

Figure 8: Absolute power for volunteer 2.

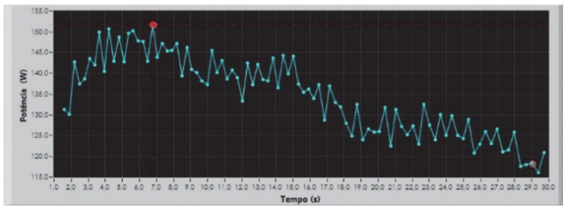

Figure 9: Absolute power for volunteer 3.

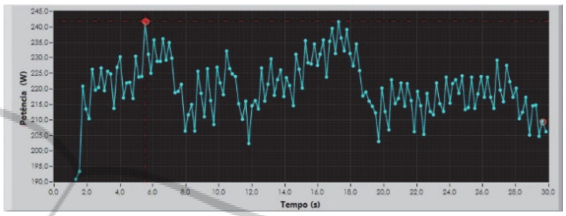

Figure 10: Absolute power for volunteer 4.

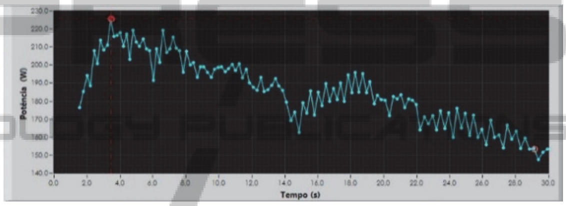

Figure 11: Absolute power for volunteer 5.

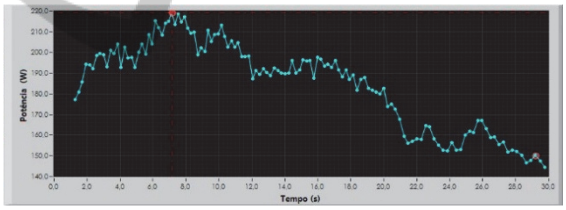

Figure 12: Absolute power for volunteer 6.

In all power curves from Fig. 6-11 there's a behaviour tendency in which the power first reaches a maximum value and then diminishes until the end of the test, reaching a minimum value. This behaviour cannot be clearly seen for subjects 1, 2 and 4.

The latter had problems with seat fixation, causing its performance and data acquisition to be impaired, leading to the curve observed. Subjects 1 and 2 seems to not have done the maximum effort required for Wingate protocol, which could explain why their power output could still rise at the end of the test.

Another characteristic observed in these results is the general value of power output. According to literature (Baker et al., 2011) they should be higher, meaning that the system responsible for torque acquisition must be reanalysed.

Despite these problems, comparing recent results

Table 1: Volunteers data for Wingate protocol.

Volunteer	Gender	Age (years)	Weight (kg)
1	F	24	45
2	F	25	63
3	F	32	63
4	M	45	88
5	M	27	80
6	M	28	85

Table 2: Results in terms of power and energy for the Wingate protocol.

Volunteer	Absolute Power (W)		Relative Power (W/kg)		Average Equivalent Energy (J)		Relative Average Equivalent Energy (J/kg)	
	Max	Min	Max	Min	Max	Min	Max	Min
1	138,30	113,09	3,07	2,58	249,36	164,41	5,54	3,65
2	146,58	114,91	2,33	1,91	255,89	203,75	4,06	3,23
3	151,86	116,14	2,41	1,88	253,76	204,48	4,02	3,24
4	241,79	203,06	2,75	2,38	426,89	368,35	4,85	4,18
5	225,84	147,69	2,82	1,92	388,92	244,01	4,86	3,05
6	219,30	144,70	2,58	1,77	386,88	250,75	4,55	2,95

Table 3: Fatigue index for the Wingate protocol.

Volunteer	Fatigue Level (%)	Max Heart Rate (BPM)	Blood Pressure (mmHg)	
			Initial	Final
1	34,06	171	115 x 76	112 x 68
2	21,60	178	113 x 75	114 x 67
3	23,52	149	113 x 69	125 x 71
4	16,01	131	130 x 92	129 x 79
5	37,25	153	104 x 22	135 x 74
6	35,19	182	170 x 87	134 x 85

with results from the first prototype (Fig. 3 and 4), one can see that now signal has improved. The addition of flywheels in each propulsion rim with the new torquemeter and calibration process made it possible to identify performance levels while the test is happening. This was only possible in the first prototype after test completion when energy was calculated.

Regarding heart rate, all subjects presented similar behaviour. Subjects 3, 4 and 5 showed lower maximum value because they have the habit of regularly exercising.

5.2 Physical Capacity Curve

During the analysis of test results, a new way to evaluate physical conditioning was proposed. This new analysis is based on the calculation of average equivalent energy and fatigue index, resulting in the calculation of how much physical capacity the person showed during the exercise.

For this analysis to be performed, the point of maximum energy developed by the user became its point of 100% of physical capacity. From this point, every drop of energy level was considered a loss of physical capacity. In case the energy level returned to a higher value than the previous point, it was considered that the physical capacity remained the same, i.e. equal to the last calculated value. At the end of calculations, plots of the physical capacity for the test were generated. Points used in these plots

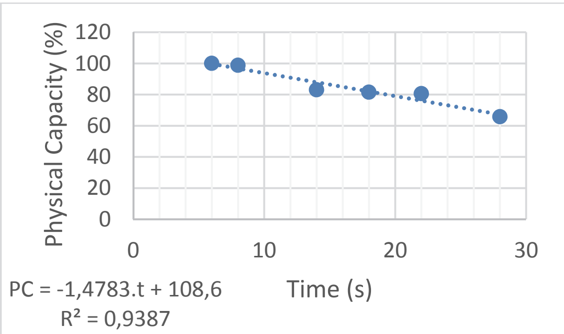

Figure 13: Curve of physical capacity for volunteer 3.

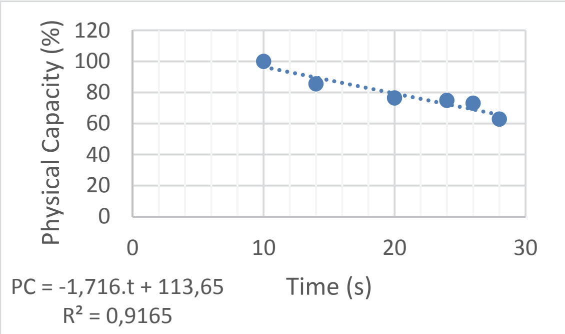

Figure 14: Curve of physical capacity for volunteer 5.

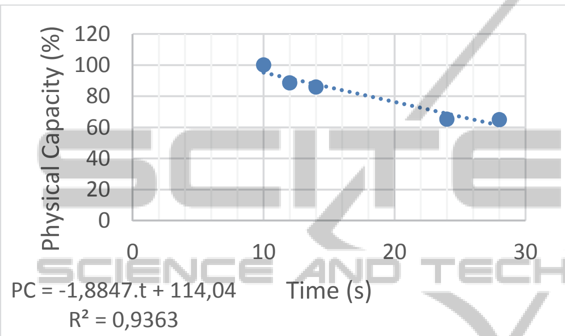

Figure 15: Curve of physical capacity for volunteer 6.

are the ones that show the moments of drop in performance. Figure 12-14 presents the graphs for subjects 3, 5 and 6.

The adjustment curves translated in equations shown in the figures calculate physical capacity drop rate in time for each subject. Concerning training and rehabilitation of physical conditioning, this curve becomes interesting, making it possible to visualize the fatigue evolution of each person analysed.

5.3 Ergonomics

Subjects from the previous prototype, ERG-CR09, answered some questions about ergonomics. Results are seen in Fig. 15. Two major criticisms made by those volunteers were about backrest position, which was a single fixed position, and seat belt – more accurately, lack of it.

Although in this version users were not asked about ergonomics because no subject with injury has participated, structural modifications applied came from those reports of ERG-CR09's volunteers. Doing so, one believes that ERGO1 severely improved its condition with regards to user's comfort and safety.

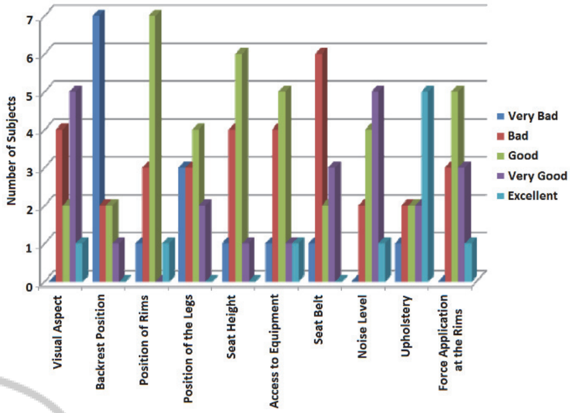

Figure 16: Evaluation of ERG-CR09 prototype. Source: Novais (2010).

6 CONCLUSIONS

The new wheelchair ergometer prototype has reduced dimensions and weight compared to the previous one, and the propulsion and electromagnetic resistance modules were mounted on the same structure. This prototype allows the user to position himself more comfortably with respect to the motor gesture, by adding ergonomic adjustments for the seat and backrest. Seat belt can now provide support to the torso. Beginning the test also became more practical since the user's weight is automatically captured.

Inertial flywheels added fulfilled their role, softening the acquired signal and preventing the braking force of causing interruption of the movement as it used to happen in the first prototype.

The tests performed showed a behaviour tendency for the new method proposed for determining the physical capacity, despite the low number of tests performed. This trend should be confirmed by performing tests with a larger number of volunteers.

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