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Research and Development of an Electronic Footrest: Prototype Tested with the Disabled

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Abstract

This study investigated and developed a prototype, with an emphasis on the ergonomic and inclusive design, aimed primarily at wheelchair users, called Electronic Foot Support. The objective of the prototype is to reduce the problems of the sedentary wheelchair user, and the health problems that may be created. The experimental research consisted of the 14 participants (n = 14) wheelchair users, to verify if the involuntary movements induced by the prototype, would result in a decrease of edema of the feet. Participants used the equipment for 50 minutes, and in 2 (two) of them the water volume remained the same in only one limb, the remainder showed decreased edema. With this study it was possible to confirm the contributions of ergonomic design in the reduction of problems for the product user, and to improve the quality of life for people with physical disabilities.

Keywords: Ergonomic Design; Inclusive Design; Wheelchair; Handicapped; Electronic Foot Support

Introduction

Limitations are inherent in the human condition. Throughout life, most people will have some permanent or temporary disability, especially in old age, a time when limitations appear and the functionality of the body goes through difficulties. Deficiency affects not only the person who suffers injury, but also the family of the disabled, who must take care of and attend to their special, needs [1].

The number of cases, involving temporary or permanent marrow trauma are increasingly frequent, mainly as a result of accidents and urban violence. The person with the injury will suffer alterations in the sensory and motor functions of the lower and / or upper limbs, as well as problems in the circulatory, intestinal, urinary and respiratory systems, among others. Thus, the quality of life of the physically handicapped is hampered by sequelae, requiring rehabilitation activities [2].

According to the World Health Organization (WHO), health is defined as a state of physical, mental and social well-being. Various methodologies are used to assess well-being and quality of life in different cultures, mainly in England and the United States [3].

For Fleck, the development of methods to evaluate the psychometric value of life is a great challenge. In addition, most of these instruments were developed in the United States and Europe, which makes cross-cultural use difficult [4].

With the evolution of consumer goods, and technological resources, the development of various items of rehabilitation equipment has evolved such as: prostheses, or thoses, brain implants, and devices with involuntary movements, among others. Such adaptive devices are referred to as Assistive Technology - AT [5].

With the spinal cord injury, the individual has several health problems, as some parts of the body lose functions. The main consequences, according to Sousa, *et al.* are: medullary shock, neurogenic shock, deep venous thrombosis, autonomic dysreflexia, neurogenic bladder, neurogenic gut, spasticity, pressure ulcers and pneumonia, among others. The device proposed by this study relates to the prevention of deep venous thrombus [6].

Ergonomics has become a more comprehensive, study of human beings and their environment, and the machines and materials used. Expanding horizontally, into various sectors such as health, education, transportation, domestic activities, leisure and others areas, as well as studying minorities such as the elderly, obese and disabled people [7].

Ergonomic adaptation implies the need for changes in the design of industrial products and processes, with the aim of providing greater comfort, safety and practicality to users, regardless of gender, weight, age, and other important ergonomic factors to the project [8].

The interdisciplinary characteristic of ergonomics is combined with design in order to solve specific problems, evaluate technological progress, production, usability, product consumption and reuse, and accessible services and communication to achieve the ergonomic objectives [9].

Ergonomic design is characterized by several design methods, whose conceptions are based on the ergonomic analysis during an activity, through and, consequently, in the delimitation of ergonomic criteria and usability for the development of products [10-14].

Paschoarelli, *et al.* recommend basic methodological concepts for ergonomic design, research and development of rehabilitation and / or prevention products. They affirm that these concepts are crucial to ensure comfortable, safe and efficient products [15].

Helander argues that both physical ergonomics and biomechanics, as well as cognitive ergonomics, are important issues for, organization and design of the working environment; musculoskeletal problems related to the work process; usability assessment for consumer electronics; human-computer interface; organizational design and organization of psychosocial work; ergonomic design of the physical work environment; human reliability research; assessment of mental workload; estimation of labour cost; product liability, among others.

The originality of this study turns to the research and development of a prototype, with aspects of assistive technology (for wheelchair users), conceived and based on the literature review and methodological approaches in three aspects of Design: Ergonomic, Inclusive or Universal and User-Centered.

Foot Movements

Some Studies and Conceptions

Inclusive Design allowed, with the development of adapted products or services, the use by people, regardless of their limitations, reducing discrimination and expanding social inclusion [16,17]. According to Norwegian Design Council, Inclusive Design is based on projects centred on leading users, considering the diversities, which represent a sample of individuals such as: people with disabilities, elderly, obese, among others. In this way, when designing for extremes, the solutions are more comprehensive, to better meet the diversity of targeted users [18].

The various forms and functionalities of footrests present a common characteristic: to allow balance between the feet and the backrest in the chair, besides reducing problems such as varicose veins, edema or pain in the legs and feet, mainly destined for users who have long working hours or long periods without movements, as is the case of wheelchair users, impairing the blood flow at the extremities of the limbs. With this, the heart needs to increase the rate of beating to provide the same amount of blood produced before venous accumulation. This problem causes increased leg volume, edema and varicose veins [19].

After the design of the product, the design phase begins, with the objective of constructing the prototype, at which stage experimental models can be designed until the prototype development, which will be evaluated and adjusted as necessary. The following steps follow the process of production, distribution, consumption and withdrawal from the market [20]. Regarding this study, whose goal was to create a prototype of electronic foot support, the stages involve development and evaluation.

The prototype of this study is an assistive footrests technology, which can be adjusted according to the speed and time of rest necessary to reduce the edema of the lower limbs. Electronic support is able to move the feet passively, involuntarily.

Generally, the venous pressure at the ankle is 56 mm, when the individual is seated, and 87 mm standing. Konz and Johnson present a study, whose values were 48 mm and 80 mm respectively. And that in only 10 steps, the venous pressure of the ankle passes to 21 mm and 23 mm, respectively, and can stabilize [21].

Whistance, *et al.* say that in jobs that require permanent positions, and that one of the recommendations is to provide support for the feet, to reduce fatigue and prevent lordosis (excessive curvature of the spinal column) [22].

Rys and Konz conducted a study in which individuals used three different footrests: a flat platform, a 15° tilted platform and a 50 mm bar [23]. The bar was used in 59% of the time, and the other two platforms were used approximately 80% of the time. The authors state that the rate of recovery of fatigue is exponential.

McNally, *et al.* analyzed the effect of active ankle dorsiflexion and plantar flexion, showing that there was a 22% increase in mean venous flow using the technique strain-gauge Plethysmography, a computerized method to evaluate circulatory problems. According to the authors, the benefit of the movements implies in the improvement of venous hemodynamics, maintained until 30 minutes after the end of the exercises [24].

For O´Sullivan and Schmitz, deep venous thrombosis occurs in cases of spinal cord injury due to the loss of venous flow return mechanism, caused by the active contraction of the lower limb musculature [25]. A problem that can be diminished, when the wheelchair performs with the help of equipment or a physiotherapist, movements of dorsiflexion and plantar flexion of the ankle.

Sochart and Hardinge performed a study at the Orthopaedic Hospital Princess Margaret Rose, Edinburgh - Scotland and Wrightington Hospital, Wigan - England, on foot and ankle movements, and venous return of the lower limbs in 20 individuals (18 men, 2 women) [26]. To test the equipment proposed by this study, a similar methodology was used, evaluating four movements: ankle dorsiflexion (upper); plantar flexion (lower); inversion and eversion (horizontal movements, in and out). One of the problems also faced by wheelchair users is deep vein thrombosis (DVT). Some methods are used to reduce this problem, such as: chemical prophylaxis methods, for reducing coagulation; mechanical methods, to reduce stasis (blood stagnation) [26].

Among the various forms and functionalities of the footrest, it was possible to observe inherent characteristics: to allow the balance between the feet and the back of the chair, causing the lumbar to be in the proper position, thus avoiding health problems, such as emergence of RSI / DORV, and minimize problems such as varicose veins, edema or pain in the legs and feet.

We have investigated various foot rests available on sites in Brazil and other countries. Among them: Ergotec; Fisiostore; Ergonomize; Posturama; The Human Solution; Ergonomics Now; and Osmond Ergonomics. The purpose was to evaluate positive and negative points, dimensions, materials and functionalities. Many have similar functions, are static, have similar shapes and functions, some models have heaters, others, such as the prototype presented by this study, have the base of the feet apart.

The 20 (twenty) models of footrests researched have their own characteristics, such as massager, height adjustment, inclination change, various materials, among other attributes, but with two common principles: improving seated posture and reducing problems caused by poor circulation of legs and feet. Such models have been pointed out as examples of the others that already exist in the market, since there is similarity of form and function in many supports for the feet, however, in none there is the function of electronic movement, that is, to move the feet of the user of involuntary form, without there being the force of the person.

The developed prototype uses the methodological assumptions of ergonomic design, investigating the needs of people with physical disabilities and modifying a product to include and bring more safety and comfort.

Development Process of Electronic Foot Support

This study began with an informational survey, starting with the problem of edema (increase of volume) in the feet of wheelchair users. Thus, the design parameters were defined, by means of the survey of the problems and needs of the wheelchair users. Table 1 shows the design steps of the electronic footrest.

Based on the methodology of ergonomic design, whose basic principle is the design of rehabilitation products, the development of the prototype is a result of a requirement: prior knowledge of the pathological condition of the wheelchair. Thus, the design practices were based on the methodological proposal of ergonomic design of Paschoarelli and Silva [27].

Technical Features - Project Parameters	• Components and configuration of foot rests; • Classification of assistive technologies; • Usefulness of foot rests; • Comparative study of manufactured models; • Product design development • Analysis of materials and mechanical system • Development of the prototype • Prototype Testing

Table 1: Stages of Electronic Footrest Design

Thus, the prototype is an assistive footrests technology, which can be adjusted according to the speed and time of rest necessary to reduce the edema of the lower limbs. Electronic support is able to move the feet passively, involuntarily.

The actuation of the mechanical system to effect the movements of the platforms (angulation) is performed with alternating movements of the feet. A pulley driven by a "V" belt, connected to a reducer provides positive and negative movement in the foot support platform.

Driven by an electric motor (bi-volt power source at 110 / 220V), the rotor transfers energy by a connecting rod achieves the required movement. Speed adjustment of the equipment allows for changing the number of movements and the rest time, through a timing and potentiometer circuit, which is enclosed in the lower part of the device. The movement time of the feet (lower limbs) was determined by the control circuits considering the printed circuits and was based on the methodology of evaluation and reduction of the problems experienced by the users.

As shown in Figure 1, the prototype developed at four angles, upper (A), lateral (B), rear (C) and diagonal / front (D). The user's foot attachment to the equipment is made in a non-slip rubberized platform with a thickness of 3 mm, measuring 114 mm x 300 mm, according to the reference model of the wheelchair, according to ABNT - Brazilian Association of Technical Norms (NBR 9050: 2004). The feet are attached to the platform by means of two Velcro fasteners with 50 mm each loop so that during the test they do not escape the device, since the participants of the research do not have control and sensitivity of the lower limbs. The measure of the feet support is 210 mm by 320 mm, whose rounded edges are 78.5 mm. In the lower part of the support there are three locks that fix the cloth handle, two measuring 125 mm, and the central lock with 210 mm. During the movements, there is a simulation of dorsiflexion (20°) and plantar flexion (45°) of amplitude.

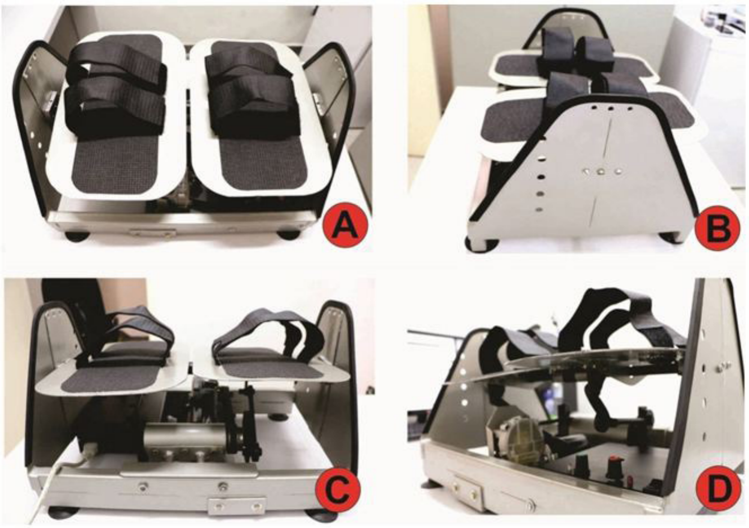


Figure 1: Prototype Developed

Methodology

To confirm the efficiency of the prototype developed by this study, 14 (n = 14) wheelchair users were invited for an experimental study (test with the prototype). The sample of 14 participants was sufficient, since the wheelchair participants present common problems, which diminishes the variables of the research. The data were collected based on the alteration of the feet volumetric of the participants, using the technique called water Plethysmography, which allows to collect data of the volume changes of the lower limbs, through the displacement of water, a procedure that was used in medicine by Glisson, in 1622 [28]. This method, still used by medical specialists in angiology, is reliable, non-invasive and reproducible.

Thus, the experimental research had seven phases, as shown in Figure 2:

1. Reading and signing of the Consent Form Free and Informed;
2. Blood pressure measurement of the participants;
3. Data collection of the participants;
4. Application of Plethysmography;
5. Test with the electronic support of foot movements for 50 minutes;
6. Application of Plethysmography, to compare with the volumetry before the test with the equipment;
7. Blood pressure measurement of participants;

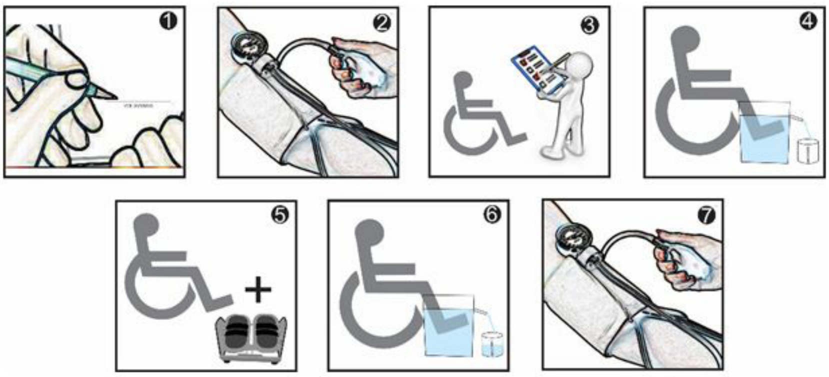


Figure 2: Stages of Experimental Research

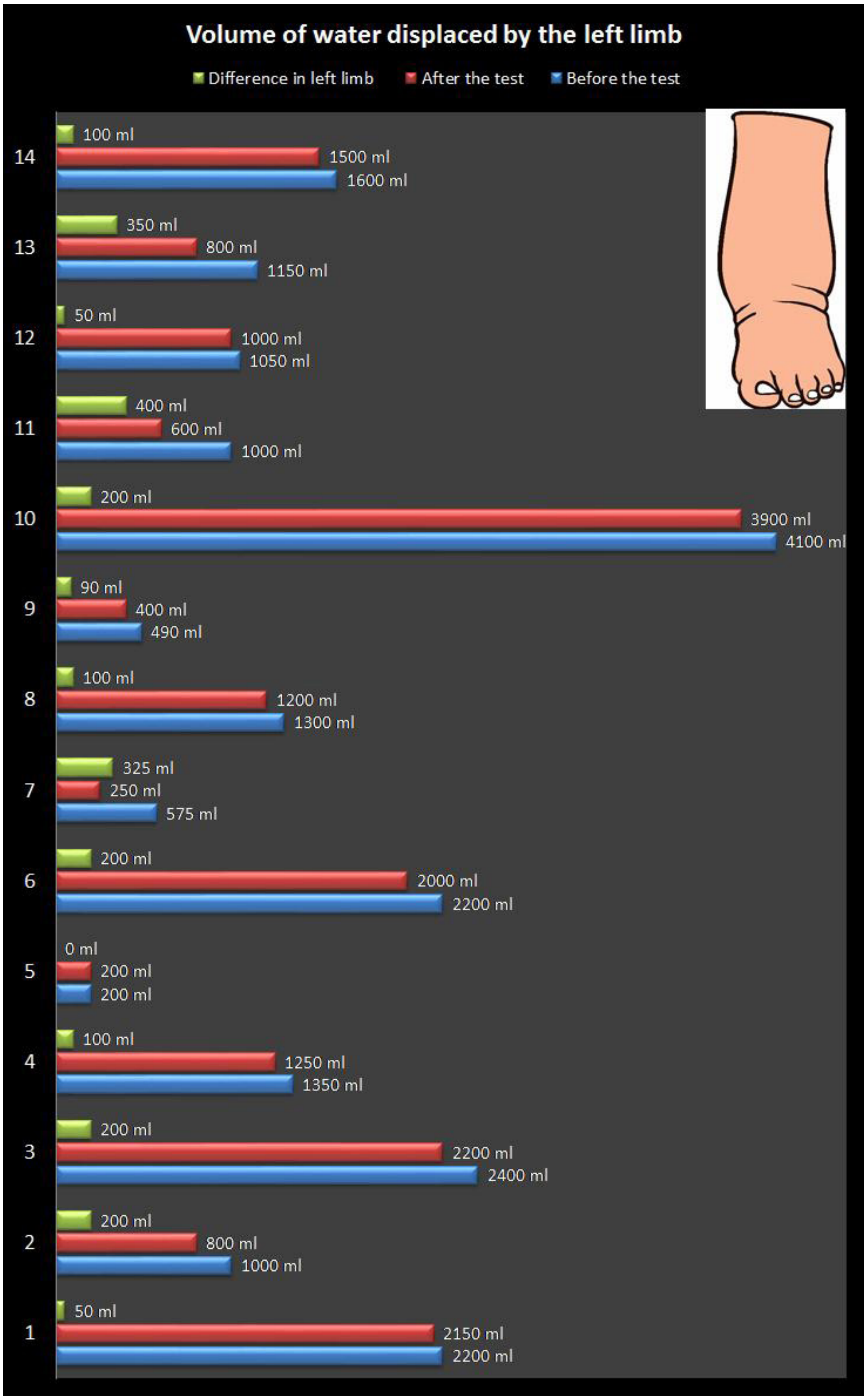
The feet were immersed in a glass vat, with water at room temperature, measuring 450 x 450 x 340 mm. The tank has an outlet for the volume of water displaced. Initial filling of the tank, and volume of water, being determined by the outlet position, any variation in tank level was eliminated ensuring safe final analysis. Final readings being obtained, by attaching a tube to the outlet feeding into a calibrated vessel.

Results

The sample of this research was composed by 14 (fourteen) participants, 09 of the masculine gender and 05 (five) of the feminine gender, of these, two were minors, of 08 (eight) and 17 (seventeen) years. In addition, some of those surveyed have atrophied hands, with no ability to hold a pen. For these last cases, the Term of Free and Informed Consent was signed by those responsible and by third parties, respectively.

The evaluation lasted an average of 90 (ninety) minutes and at all times the participant was asked if he was comfortable. An interesting fact is that even without the sensitivity in the lower limbs, many felt paraesthesia in the legs and feet. On the back, heel and sides of the feet, back of the knee and calf.

Participants were aged between 08 and 65 years, whose mean age was ± 35.6 years. Only two participants were the same age, 34 years. When asked about the time the participant uses the wheelchair, there was no repetition, each participant answered a different time. The participant who has been in the wheelchair for more than 55 years is 55 years old, a victim of poliomyelitis. The participant, who spent least time using a chair, was a traffic accident victim age 43, having used the chair for 1 year. The average time that participants use the wheelchair is ± 19.71 years.

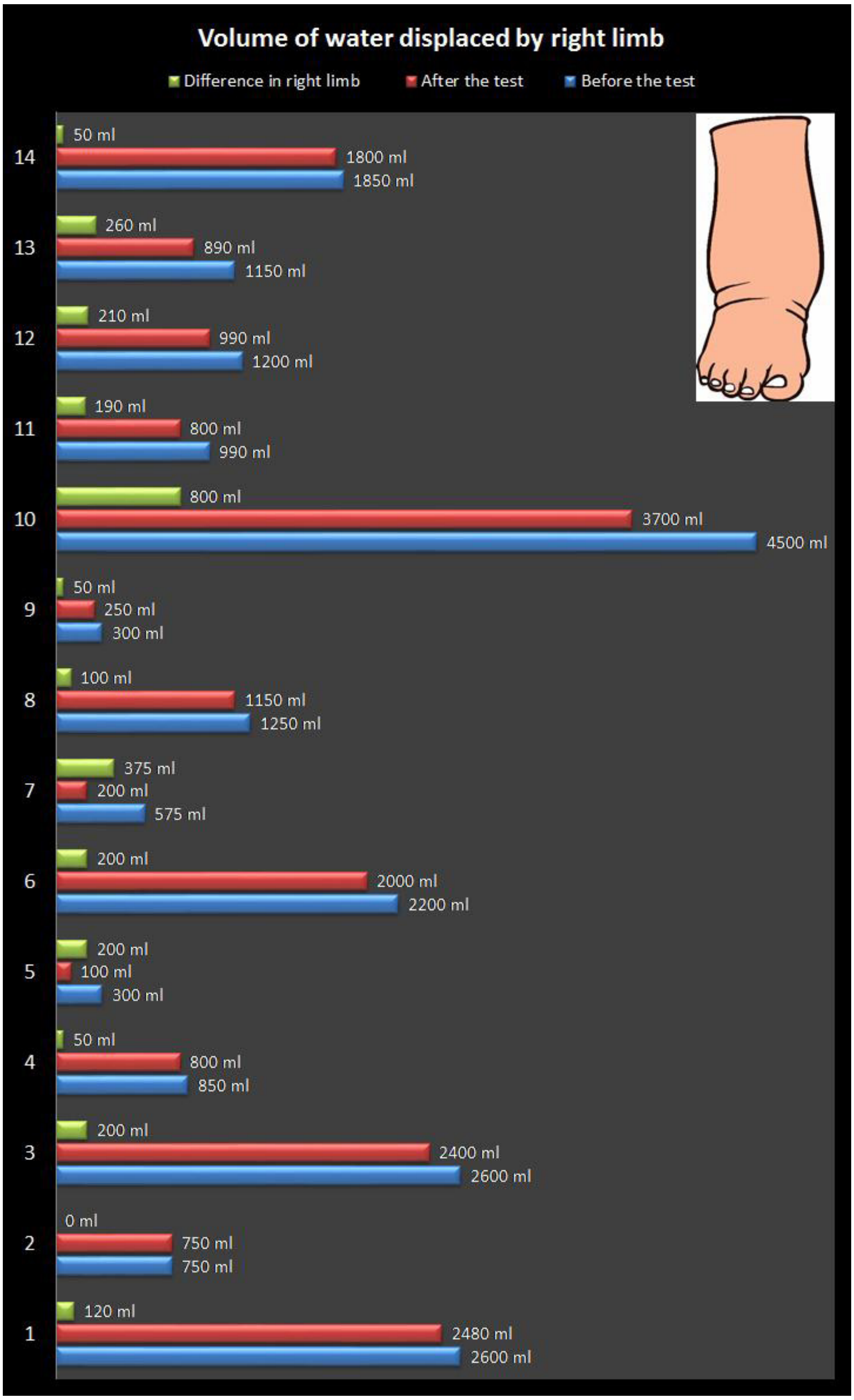


Graph 1: Volume of Water Displaced by the Right Limb

The participants when questioned about their disability 4 were born with the condition. The remaining 10 cases reported, they were victims of polio or congenital problems in childhood, as well as accidents, in adolescence and adulthood.

Participants were also questioned about the practice of sport, the objective of this question was to determine the sedentarism of the participants, and only 2 participants play sports others were prevented by health problems. Also questioned regarding the practice of physical therapy, which influences the problem, of the 14 participants, only 8 gave a positive answer

Before the prototype test, participants were asked if the feet usually had edemas due to the long periods without movements. Only two participants said they had no problem with their feet swelling. However, it was found after the test that there was a decrease in volume. The water displacement technique resulted in a decrease compared to the start of the test. Regarding the participants' blood pressure, measured before and after the test, some presented the pressure common to others, three of them with 13x9mmHg; and two with 14x9mmHg and 11x8mmHg.



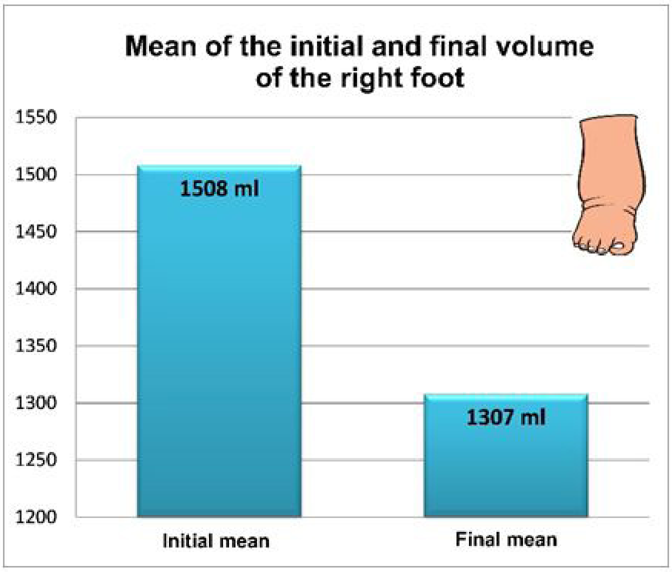
Graph 2: Volume of Water Displaced by the Left Limb

In some tests, after using the prototype, there was a significant reduction in blood pressure in some participants. The participant 1 was 13x9 mmHg at the beginning, and after the test passed to 12x8mmHg; in participant 4, from 13x8 mmHg to 12x8mmHg; in participant 5, from 13x9 mmHg to 11x8 mmHg; in participant 6, from 13x7 mmHg to 12x8mmHg; in participant 8, from 13x10 mmHg to 13x9 mmHg; in participant 9, from 14x9 mmHg to 13x8 mmHg. In the other participants, the initial pressure was the same as that measured at the end of the test.

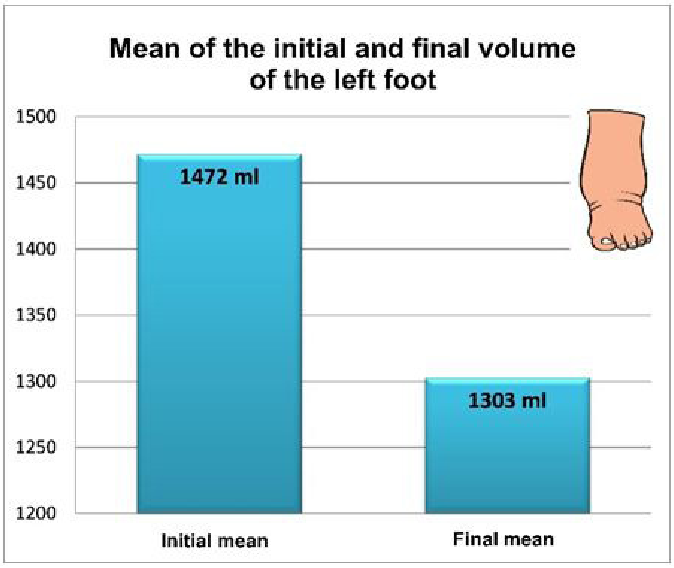
In relation to the differences between the right and left limbs, shown by the Water Plethysmography, the difference between the Initial Volume and Final Volume, in the right limb, only the test of the participant 2 did not change volume. In participant 10, there was the largest displacement of water, 800 ml. And in participants 4, 9 and 14, the lowest displacement occurred, 50 ml (Graph 1-6).

According to the data of the mean volume, the right limb was larger than the left limb. Comparing the averages of the right and left limbs, the initial volume difference is 36 ml and the final 4 ml. The initial mean on the right limb is 1508 ml and the final 1307 ml.

The mean of the volume was calculated by summing all the data (ml) obtained from the participants and dividing by the total number of the sample (n = 14). The mean of the initial and final volume of the right foot has the difference of 200.35 ml. In studies using the Plethysmography technique, Belczak, *et al.* obtained 82.5 ml of the right limb, comparing the volumetry in the morning and afternoon; and Brito, *et al.* 205,7 ml, without specifying the limb, with the volumetry in the sitting and standing position [29,30].

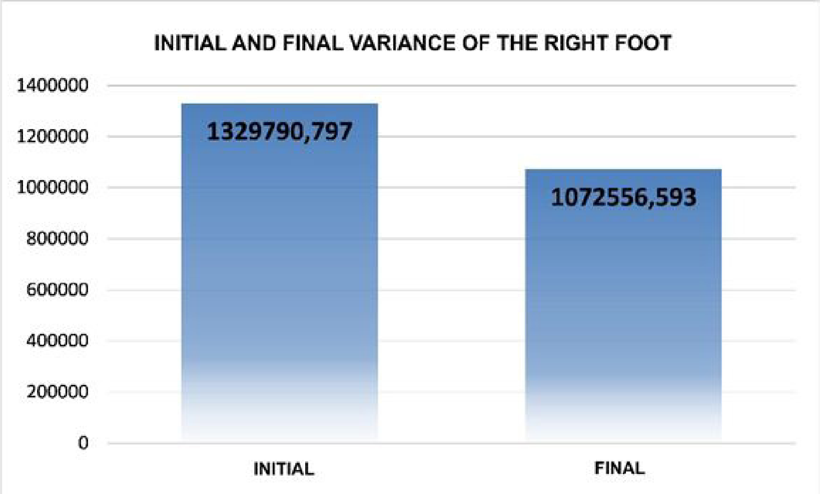


Graph 3: Volumetric Mean of the Right Foot

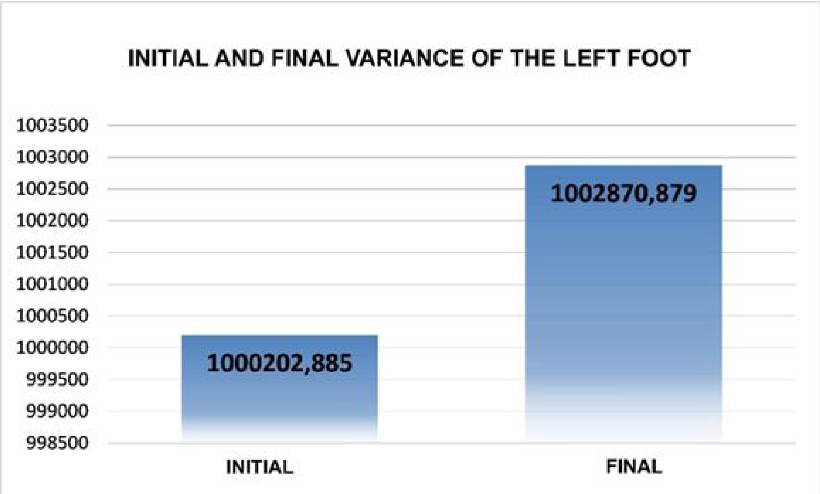


Graph 4: Volumetric mean of Left Foot

The Variance (initial, final) of the volumetry was calculated by first subtracting the value of the volumetry (ml) obtained from each participant, by the mean (initial, final). Then, we added these and divided by the sample number minus one (n-1), that is, by 13. The Variance and Standard Deviation have dimensionless measures. Variance of the right foot was higher at the beginning of the test (1329790.797) than at the end (1072556.593). The difference was 39871.01648. Different from the right foot, the left foot Variance was lower at the beginning of the test (1000202.885) than at the end (1002870.879). The difference was 14746.84066.



Graph 5: Variance of the Right Foot



Graph 6: Variance of the Left Foot

The Standard Deviation is represented by the square root of Variance. The square root of the Variance obtained before and after the test was calculated. The Standard Deviation of the right foot was higher at the beginning of the test (1153.16555) than at the end (1035.643082). The difference was 199.6772808. Standard deviation of the left foot was lower at the beginning of the test (1000.101437) than at the end (1001.434411). The difference was 121.4365705. Both the Variance and the Final Standard Deviation in the left foot were lower at the beginning than at the end of the test.

Conclusion

Through the data of the experimental research with the wheelchair users, it was possible to confirm the efficiency of the equipment, with the decrease of foot edema the Final Volume was lower than the Initial Volume. The sample of 14 participants was sufficient, since the wheelchair participants present common problems, which diminishes the variables of the research. According to the averages indicated in the result, participants' right foot edema was larger when compared to left foot edema.

The great difficulty in carrying out this research refers to the lack of references, both in Brazil and in other countries. The base of the theoretical foundation could have more citations, however, studies on foot supports are few, and most refers to physiotherapy and medicinal treatment of edema in the legs and feet. This study was able to meet the proposed objectives. The need for improvement for the physically disabled was evaluated, reducing the problem of bad blood circulation in the feet. However, it has been found that many items need to be improved, such as the material used (to make it lighter), design and functional aspects. In this way, the equipment can be more convenient and safe for the users.

The problem raised stimulated the research and development of the prototype, which aims to improve the quality of life, and confirmed the research question: an electronic foot support, such as involuntary and controlled movements, which simulate dorsiflexion (upper) and flexion (lower), can reduce the pathological consequences of the sedentary lifestyle.

It is important to emphasize the great importance of Design, especially of the Inclusive and Ergonomic Design, as mediators of the accessibility of people with reduced capacities.

Of the 14 (fourteen) participants surveyed, 8 (eight) answered that they are doing physical therapy sessions, a relevant data that allows rehabilitation or guarantees a better quality of life for people who use a wheelchair. Even in the participants who stated that they did not have edema (volume increase) there was a reduction in water volumetry after the use of the equipment.

Another relevant finding is that the spasms, common symptoms in the wheelchair users, were frequent in the initial plethysmography test, and in the final test, none of the 14 (14) participants participated. In addition, the use of the prototype brought a benefit that was not expected in 6 (six) of the 14 (fourteen) surveyed, the blood pressure decreased.

Althoughthe relevant number of wheelchair users, it is possible to reflect on three aspects: people with reduced capacities are still smaller, so the production on a smaller scale is expensive; one of the barriers to designing affordable products is to predict how the user will use the product and whether it will meet their needs; and finally, many assistive technologies are not accessible, have a high cost.

In addition to the data related to the test with the prototype, the subjective evaluation regarding the perception of the participants can help in the ergonomic approach. During the tests, in addition to the data that were measured, it was possible to observe and receive satisfaction from the participants, whose prototype was well accepted due to the functionality.

The great challenge in creating an assistive technology, assessing and confirming research question of this study can contribute to future research related to design, ergonomics and also to health areas, according to the needs of users with foot edema.

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