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FENCING, REHABILITATION AND INCLUSION: CONSTRUCTION AND EVALUATION OF THUMB ABDUCTING AND ADUCTING UNIMANUAL HAND-WRIST ORTHOSIS, ARTICULATED AND SELF-ADJUSTABLE FOR THE INDEPENDENT PRACTICE OF WHEELCHAIR FENCING FOR ATHLETES WITH TETRAPLEGIA

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Abstract: *Wheelchair Fencing is a paralympic sport whose comprehension demands serious study of its singularities needing an approach that integrates different areas of knowledge for the sake of the athletes that possess the least functional capability between this modality's categories. The objective of this work is to amplify the independence and provide safer practice of this sport through the development and construction of a self-adjustable thumb abducting and aducting hand-wrist orthosis. The product in development if compared to the ones in the market, has as disadvantages higher cost and higher mass applied to the orthosis. However, they are compensated by the reduction of the operational cost of the tournaments and for the fact that the orthosis can improve the sportive performance, as well as the athletes' quality of life making them more independent for the practice of everyday activities. The functional tests of the device involving clinical evaluation and social activities with the athletes are being development, allowing the redesign and construction of the final product.*

Keywords: Wheelchair fencing, assistive technology, paralympics, bioengineering

1. INTRODUCTION

The development and construction process of an orthosis for the Wheelchair Fencing (WF) modality for paralympic athletes involves technology and human limits, with the objective of awakening values regarding the independence of people with disabilities in society. The development of this product is a multidisciplinary process which involves competence and responsibilities in several areas of knowledge, in the research at issue the symbiotically involved areas are engineering and health, including physical educators.

The approach and redefinition of symbiogenesis constitute a theoretical resource to the comprehension of the complexity originating from the organical and inorganical interactions between body and machine (Lima, 2005), in this case, the symbiosis occurs between the athlete with tetraplegia with functional deficit in the manual prehension movement and the self-adjustable orthosis which provides independency in the handle of the fencer's sportive weapon.

The project originated from the observation of the difficulties and the dependency of the athletes that, as they are practising the modality, need several people involved throughout a Wheelchair Fencing tournament, increasing the cost of the event and making the athlete almost a secondary character in the sportive scene.

Assistive technology is an interdisciplinary area of knowledge that encompasses resources, methodologies, practices and services with the objective of promoting the participation of people with disabilities, incapacities or reduced mobility aiming at their autonomy, independency, quality of life and social inclusion (Brazil, 2012).

In the universe of the people with disabilities, the assistive technology develops orthosis, a term that refers to all non invasive orthopedic mechanisms, positioned externally, with the function of aligning, preventing or correcting deformities, as well as improving the functionality of the movable parts of the body (Pratt, 1994).

To prescribe, manufacture and evaluate the real benefit of an orthosis, it is necessary to know the functional anatomy of the limbs, clinical aspects of the pathology and of the material chosen for the manufacturing of the orthosis (Teixeira, 2003), as well as the good engineering practices.

For the development of an orthosis to assist the manual prehension movement in order to wield a sportive weapon in the Wheelchair Fencing modality, it is essential to know the sportive equipment, specifically the weapons, their quirks and wielding techniques, as well as the type of biomechanical movement demanded during the WF combat (Pavani, 2011).

2. Theoretical Referential

2.1. Wheelchair Fencing

Wheelchair Fencing (WF) is a paralympic sport whose comprehension demands serious study of its singularities, needing a symbiogenesis approach that integrates different areas of knowledge for the sake of the athletes that possess the least functional capacity between this modality's categories, Jovane Guissone standing out, as he was the champion in the London 2012 Paralympics (CPB, 2015).

Three kinds of sportive weapons are used in WF: foil, saber and épée, who differentiate from one another by the shape and the way of dueling, being used indistinctively by men and women. Each weapon consists of a pommel, a grip, a bellguard and a blade, but the grip can be anatomical or French (Nazareth, 2001).

The symbiogenesis approach allows debating the complexity originating from the organical and inorganical interactions between machines and human life (Lima, 2005), being resignified by debating the interactions between the paralympic athlete and the assistive technology, aiming to the construction and evaluation of thumb abducting and aducting unimanual hand-wrist articulated and self-adjustable orthosis made in polymer, for the independent practice of wheelchair fencing.

Considering the extension of the adaptive processes, it is defined as adapted sport that which was adjusted in its physical structures (equipment, localization and materials) and procedures (rules and organization) in the sense of allowing its practice by people with disabilities (Castro, 2005).

Sportive activities are essential in the medical treatment of spinal cord injured people, assisting in the healing and maintenance of self confidence and mental activity (Guttman, 1981), but all people with some sort of disability can practice physical and sportive activities, as it helps in their rehabilitation (Souza, 1994).

Paralympic fencing requires reflexes and speed from the athletes, as its rules are the same as regular fencing's, according to the International Fencing Federation, while adapted fencing is practiced with wheelchairs, being the only modality officially recognized in paralympics (Nazareth, 2009).

Wheelchair Fencing originated as an adaptation of regular fencing and developed as a paralympic sportive modality practiced by people with physical disabilities, being recognized by the International Wheelchair & Amputee Sport Federation (IWAS) (Martinez, 1994).

The large variability of physical disabilities of WF athletes led to the creation of a specific system for the classification of the athletes according to the type and level of the injury, as well as the motor execution potential in the performance of fencing actions, placing them in the official categories, among which the "C" class stands out in which the athlete has no balance in the fencing wheelchair, damaged extension of the elbow of the arm holding the weapon, absence of functionality in the dominating hand, needing the weapon to be fixated with bandages, for tetraplegics (CPI, 2004).

2.2. Orthosis

Orthosis have the objective of increasing the functional performance and preventing musculoskeletal deformities, being essential for the independency of the paralympic athlete when externally fixed to the body, increasing the amplitude of movements, increasing the quality of movements when the muscular strength is insufficient.

These devices can replace the lost muscle action and also provide support for the inclusion of other devices that assist in member's functionality (Silva, 2008), as the sportive weapon in the case of WF, as the hand orthosis to provide an increase of muscle strength (Vaz, 2006).

Upper-limp orthosis are classified according to the objective, configuration, material or anatomical area, and one of the most used classifications groups them according to their mechanical characteristics as static or dynamic orthosis (Elui, 2001). Static orthosis avoid movement, immobilizing or stabilizing articulations in a specific position, providing the basis for articular alignment and protection of the repaired structures, aiding in the positioning of the edema and allowing the tissues to adapt to their new function (Fess, 1995).

Dynamic orthosis, also called functional or kinetic, allow controlled movement of articulations through traction that acts directing the movement, avoiding or restricting unwanted movement, replacing absent or weakened muscular strength, besides maintaining muscular balance (Trombly, 1989).

Facing the importance of finding solutions for the treatment of the impairment of the manual prehension movement of WF athletes, came the proposal of developing a product aimed at the independence of this paralympic athletes.

3. METHODOLOGICAL PROCEDURES

3.1. Characterization of the research

The theme of the research was decided based on the author's experience in the physical preparation of the athletes of the Association of Security Servers With Disabilities (ASASEPODE) team since 2008, and in the physical preparation of the current Brazilian national wheelchair fencing team, allowing the monitoring of the difficulties of class "C" WF athletes in training and tournaments, as well as their dependence of a third party to be able to wield the weapon.

The symbiogenesis approach and the interdisciplinary work allowed us to obtain satisfactory results in the development of the prototype, whose purpose is obtaining the patent, needing a work team that includes professionals in areas of health, as well as physical educators and engineers, who complete each other when we consider symbiogenesis.

The methodology used in the present work involves action research and case studies.

The experimental action research was done with class "C" Wheelchair Fencing paralympic athletes, with hand and wrist palsy caused by tetraplegia. The action research acknowledges that the problem appears in a precise context and that the researcher testifies it, helping the collectivity in determining the crucial details of the problem, through collective decision making (Barbier, 2002).

Thus, identifying the difficulties of WF athletes in wielding the sportive weapons, the author was driven to develop an innovating product in order to provide more independence to the athletes.

Action research consists in solving specific problems, in which the researcher becomes part of the change process to encourage those involved to study their own problems in order to solve them (Roesch, 1994).

In this research, the actions aim to demonstrate the adequacy of new technological processes and products adapted to qualify the social inclusion involving the sport, seeking the independence of Wheelchair Fencing athletes with tetraplegia, aiming to minimize their functional deficit with the development of a self-adjustable and articulated thumb aducting and abducting hand-wrist orthosis.

The research also utilized individual case studies, with a qualitative approach, with the objective of making the tetraplegic athlete enjoy his sport in an independent manner, through the use of the aforementioned orthosis for the independent practice of WF.

Case studies allow investigations that preserve the significant characteristics of real life occurrences (Yin, 2005), allowing the researcher not to start from a closed scheme, which would limit his interpretations, interfering in the issue's constatation that, in this case, is the dependence of the athletes in the practice of paralympic sports.

3.2. Delimitation of the research

The choice of the WF modality for this was due to its uniqueness at a sportive level, as this work is about the development of a product aimed at athletes with disabilities through the integration between technology and the rehabilitation power of sports, aiming to achieve an engineering solution that allows more independence in the competitive scene.

The admission criteria for participating in the research were not having active hand or wrist movement, taking into account the dominant side for the sport's practice; stable neurological condition according to a medical report; being 18 years old or older; complete passive movement of hand, wrist and finger articulations; presence of active muscle contraction of the upper limbs for the practice of the modality at issue; capacity of understanding the commands and, at least, one year of experience in WF.

The institution chosen for the research was ASASEPODE, the only location in Porto Alegre, Rio Grande do Sul, Brazil where paralympic WF athletes can practice the sport.

The orthosis' development project was approved by the research ethics committee of IPA's Universitarian Methodist Center that followed the procedures of Resolution nº 466/ 2012, which regulates research involving human beings in Brazil, and the patent request being sent to the National Institute of Industrial Properties (INPI).

4. DEVELOPMENT PROCESS OF THE ORTHOSIS

The study was divided in three phases: the first phase had the objective of defining the technological pattern for the development of the orthosis construction process. The second phase had the objective of building the mold and the template in thermomoldable material and its printing in 3D, as well as the construction of the orthosis' prototype in polymer. In the third phase manual prehension tests where made, first in unimanual activities and then in the practice of the WF modality.

Initially, we searched the international patent databases, verifying the existing technologies that guide the development process of the orthosis for athletes with tetraplegia that practice WF in the "C" class.

The ethnography technique of records and static and moving images of the process of a combat with the sportive weapon fixed to the athlete's hand (Rose, 2002), contributed to the consolidation of the orthosis' project. The filming was done in order to verify the critical points of the fixing process to the athlete's hand with the help of a third party and of the sportive combat, where we measured the time spent in the weapon's fixing process to the athlete's hand.

The structure of the model of the orthosis in development was based on existing technologies in the market, opting to work with thermomoldable material to build the anatomical template of the articular complex of forearm, wrist and hand of the paralympic athlete.

The mock-up was made in a three-dimensional printer associated to three-dimensional drawing systems (Solid Works), as well as laser based three-dimensional reading systems in order to rapidly meet the need for components for the orthosis and accessories aimed at paralympic tournaments.

The materials used in the *mock-up* don't need to have great durability or surface finishing, as these characteristics increase the time needed for the project and generate unnecessary additional costs (Gomi, 2011).

The construction of the mock-up in thermomoldable material offered practicality and ease in the production of a template in different positions of the articular group for later fixing of the layers that will be in direct contact with the athlete's epithelial tissue, offering comfort and allowing transpiration, as well as higher adhesion of the orthosis to the sportive weapon. The templates must meet the feasibility regarding the articular amplitude of the movements that the athlete must be able to do with the sportive weapon, as well as the flexion and extension movements of the wrist's articulation, allowing rotational movements of the wrist's articulation made during WFA.

The choice of the material for the construction of the orthosis was based on the feasibility for the practice of the modality at issue, meeting the biomechanical characteristics of the paralympic athlete, as well as presenting ergonomic characteristics, flexibility and durability, in order to allow movements while wielding the weapon. The material chosen for the construction of the orthosis is polymeric, anti-allergic and with porosity of 30-50% to allow transpiration.

The orthosis has two layers: the first is in contact with the skin of the paralympic athlete and has as its objective ergonomics and protection of the skin and soft tissues of the articular complex, with a certain degree of resistance for the fixation of the weapon the athlete's hand.

The second layer has the objective of covering and protecting the internal system, fixating the weapon for the practice of the WF modality. The ventral region of the orthosis' first layer contains nonslip textures to facilitate the prehension and prevent the weapon from slipping from the athlete's hand.

Between the orthosis layers, was put a splint made of thermomoldable material, made in molds specific for each athlete, whose objective is positioning the articulation of the wrist in flexion, final movement for the manual prehension and later adhesion of the articulation for wrist movements.

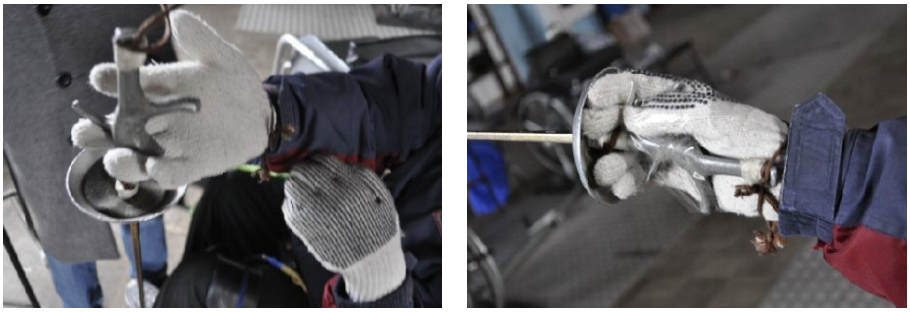
In order to evaluate the athletes' ability to grip objects we used the Grasp Release Test (Wuolle, 1994) which requires the athlete to hold, move and release in a box each one of the objects of different shapes, weights and sizes:

Object 1: pen;
Object 2: fork;
Object 3: drinking glass;
Object 4: cellphone;
Object 5: fencing weapon (épée, foil and saber);
Objects 3,4 and 5 are bigger and heavier like WF weapons, adequate to evaluate palmar grasp.

After the Grasp Release Test, the athlete must wear the orthosis and perform a test with the *Plastron* (static target for training), and then utilize the orthosis in a real combat situation, in accordance with the modality's rules.

The development project of a product is the group of activities resulting from the needs and possibilities of the market and of technological restrictions (Rozenfield, 2006) that in the research at issue comes from the evident need of the class "C" WF athletes with functional deficit.

The organic obstacles that restrict the potentiality of individuals can be fought against with a technological arsenal put at the service of the reconfiguration of what is alive (Sibilia, 2002). From this point of view, the tools used for the fixing process like adhesive tape and strings are against the technological evolution, as shown in Images 1 and 2 where the process of the fixing of the sportive weapon to the hand of the athlete with tetraplegia through strings is shown.



Images 1 and 2. Sequence of the sportive weapon's fixing process to the athlete's arm
Source: author's image bank, 2010

In this work a foil with anatomical grip was used as the model for the construction of the hand-forearm-arm conjunction with the sportive weapon, as shown in Image 3.

Image 3. Foil with anatomical grip
Source: author's image bank, 2010

The orthosis' development process is briefly represented in Chart 1:

Chart 1 – Questions analyzed in the idea generation stage

Target Audience	Class "C" WF athletes - athletes with cerebral palsy and tetraplegia, with impaired manual prehension
Innovative character	Allowing the independency of the WF modality athlete
Manufacturing Process	Modeling, cutting, machining and assembly
Materials	Thermomoldable, polymers and articulation in metallic alloys

All products that can be found in the market can be classified, depending of the source of their development, determining when it's a new product or an improved product (Ullman, 2007).

The articulated and self-adjustable thumb aducting and abducting hand-wrist orthosis for the independent practice of wheelchair fencing for athletes with tetraplegia is categorized as part of the invention, as it meets all patentiability criterion, in accordance with the Industrial Property Law nº 9.279/96 that states that in order for an invention to be protected by a patent, it needs to meet the requisites of originality, inventive activity and industrial application (INPI, 2013).

Besides the three aforementioned requisites, the Brazilian law states that the descriptive sufficiency requisite that refers to the fact that the description of the invention or utility model is clear and complete must be met, in order to allow its reproduction by a technician in the subject.

During the patenting process, the work is usually done secretly, with the objective of avoiding early divulgation of information, and, as the target consumer hasn't been identified clearly yet, the problems and attitudes that could originate from the use of a new technology are usually predicted (Asimov, 1968).

5. SOCIAL IMPACT AND EXPECTED RESULTS

The census of the year 2000 classified around 14,5% of the Brazilian population as people with disabilities, i.e., 24,5 millions (IBGE, 2000), but the number of WF athletes in Brazil is really low, with 40 (forty) paralympic athletes signed up for the 2013 Brazilian Wheelchair Fencing Championship, only 6 (six) being class "C" athletes, i.e., athletes with tetraplegia.

Athletes with tetraplegia are completely dependent for the practice of the sport, including the preparation for the tournaments, wearing the apparel, moving to the sportive wheelchair and the fixing of the weapon to the athlete's hand, needing contracted assistants to work in tournaments, reducing the number of annual tournaments through the sportive confederation due to the high costs.

The role of these assistants is basically helping the athletes in the preparation for the game, fixing them to the WF fixing plate that allows the competitive practice, but the class "C" athletes also need help for the fixing of the weapon to their hand through bandages and adhesive tapes.

The main contribution of this work is allowing more independence in the fixing of the weapon to the athlete's hand, as well as giving them better quality of life by making some activities easier, like feeding, personal hygiene and even the usage of electronic devices like computers and smartphones, through the development, construction and evaluation

of an articulated and self-adjustable thumb aducting and abducting orthosis for the independent practice of wheelchair fencing, for athletes with tetraplegia, with a functional deficit in the manual prehension movement.

The orthosis tends to amplify the rehabilitation of athletes with tetraplegia with functional deficit, allowing research actions capable of minimizing or suppressing these deficits, as well as providing people with disabilities with a more inclusive and independent life through the wheelchair fencing modality.

The specific goals of this work are the following:

- Construction of a product that facilitates social inclusion through wheelchair fencing;
- Rehabilitating and integrating treatment of volunteer wheelchair users through the use of the functional prototype;
- Use of the final product in training sessions and official tournaments;
- Evaluation of the orthosis' functional effect in tetraplegia, as well as the effectiveness in the practice of wheelchair fencing, in its three modalities: épée, foil and saber;
- Evaluation of the feasibility of the orthosis in reliability, portability and minimization of its handling, aiming to the maximum independence for the practice of wheelchair fencing;
- Patent with the organ responsible for granting the title of industrial property, the National Institute of Industrial Properties (INPI).

6.CONCLUSION

The importance of this interdisciplinary work utilizing assistive technology stands out because of the inclusion and rehabilitation of paralympic athletes in society through the development of a self-adjustable and articulated thumb aducting and abducting hand-wrist orthosis for the independent practice of Wheelchair Fencing by athletes with tetraplegia, with functional deficit in the manual prehension movement, aiming to a safer practice of this sport.

The independence of these paralympic athletes must be reached through the development of the construction process of this orthosis that utilizes low cost material for its structure and of the polymer base with an articulation made of metallic alloy for the independent practice of Wheelchair Fencing.

The study was divided in three phases: the first phase had the objective of defining the technological pattern for the development of the orthosis' construction process. The second phase had the objective of building the mold and the template in thermomoldable material and its printing in 3D, as well as the construction of the orthosis' prototype in polymer. In the third phase manual prehension tests where made first in unimanual activities and then in the practice of the WF modality.

The orthosis demonstrates the adequacy of new technological processes and products adapted for the social inclusion involving the sport and the disability, seeking the independence of Wheelchair Fencing athletes with tetraplegia with functional deficit in the manual prehension movement, aiming to minimize the development time of a self-adjustable orthosis.

The functional tests of the device involving clinical treatment and systematic social activities with paralympic athletes are being developed, allowing the redesign and construction of the final product, i.e., the tested prototype with its due improvements.

The bibliographic research has revealed the scarcity of literature about the theme, even in the anteriority search of technologies available in the market in order to guide the construction process of the self-adjustable and articulated thumb aducting and abducting hand-wrist orthosis for the independent practice of wheelchair fencing for athletes with tetraplegia.

The product development process presents disadvantages and advantages when compared to the technologies found in the anteriority search in the international patent databases. The disadvantages of this research are associated to the higher cost because of the mechanical components and the higher total mass applied to the orthosis.

However, these limitations are compensated by the reduction of the tournaments' operational costs due to the reduction of needed manpower and the fact that the self-adjustable orthosis will be able to perfect the sportive performance as well as the athletes' quality of life, making them more independent for the practice of activities like feeding and hygiene.

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