Implementation of Integrated Instrumentation in Assistive Technology

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Abstract. There are few studies that use integrated evaluation instruments for the design, preparation and adaptation of orthoses that reflect very specifically the physical conditions of the patients. Therefore, the present study aimed the application of integrated instrumentation for the development of assistive technology products for patients of the Psychiatry Institute of Santa Catarina (IPq-SC). As instruments we used infrared thermography, surface electromyography, manual dynamometry and motion capture by inertial sensors, along with a collection protocol established by the team through observation and audiovisual recordings of the activities. As a result, we obtained data suitable for the diagnosis of the physical condition of the patient, requiring some adjustments into the collection process in order to respect the physical and cognitive limitations of the patients. In addition, the collection and the use of data should take into account the appropriate instruments of analysis and the factors that may influence the results.

Keywords: Motion capture · Surface electromyography · Infrared thermography · Muscle strength dynamometer

1 Introduction

Acquiring a disability at any stage in an individual's life is a condition that can impact their daily life in terms of body structures and functions, activities and social participation, as recommended by the International Classification of Functioning [1]. In order to reduce this impact, technological development has influenced the field of rehabilitation and there is a growing investment in the production of resources that have become part of the therapeutic actions to meet the needs of people with disabilities who, in the census 2010, represented 45.6 million people, about 14.5% of the Brazilian population [2].

The term Assistive Technology, was officially created in 1988, based on American law, as an important legal element within the US law, known as Public Law 100-407, which, with other laws, the ADA – American with Disabilities Act. This American law establishes the criteria and legal bases that regulate the granting of public funds and

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subsidies destined to the acquisition of this material called Assistive Technology, a synonym of resources and services for the deficiency. In the text of the American With Disabilities Act, Resources constitute "any and all items, equipment or parts there of them, a product or system manufactured in series or custom-made, used to increase, maintain or improve the functional capabilities of persons with disabilities." Services are "those that directly aid a person with a disability to select, purchase or use the resources defined above" [3].

In the world and also in Brazil, these resources have been called "Assistive Technology" (AT). This terminology was made official by the Technical Assistance Committee of the National Undersecretariat for the Promotion of the Rights of Persons with Disabilities and is considered as an interdisciplinary area of knowledge that encompasses products, resources, methodologies, strategies, practices and services to promote the functionality, related to the activity and participation of persons with disabilities, disabilities or reduced mobility, to provide them with autonomy, independence, quality of life and social inclusion [4]. In the context of health services performed with people with disabilities, the implementation of AT is fundamental to support the different stages of their neuropsychomotor development, to offer conditions for their social participation and to assist the families in the care actions. As part of these responsibilities, it is the responsibility of health professionals, in addition to technical work, to develop strategies for health promotion and maintenance, through appropriate preventive measures for the population [5].

Therefore, the application of AT covers a range of human performance possibilities, from basic self-care tasks (mobility, communication, home maintenance, food preparation, occupational tasks) to leisure and work activities. Obtaining autonomy, or maximum autonomy, is certainly one of the ways for the perfect social integration of the elderly and disabled people and must therefore be the premise for any intervention in rehabilitation and inclusion [6]. When discussing the relationship between disability and poverty, they point to a greater concentration of people with disabilities in low-income families who access restricted goods and services that could favor their conditions of survival and well-being [7]. It is demonstrated that the presence of people with disabilities interferes negatively in family income, since their families must assume the burden related to the care they demand.

Given this scenario, it is important to consider that, for many families, access to AT is restricted to the resources available in the Unified Health System (SUS), which are included in the list of orthoses and prosthetics and with only a few basic equipment models for locomotion and devices for visual and auditory deficiency [5]. These AT resources available in the SUS don't ofter the minimum ergonomic requirements against the limiting factors of human movement found in the deficiency or transient disability in the course of the disease. Generally, they offer medium-sized solutions that are short of what is proposed and require effort, cause injuries and discomforts with frustrating results for the patient and the rehabilitating professional. In addition, they present a manufacturing process considered to be handmade, due to the need to reduce costs and the lack of access to high-cost technology for a significant percentage of the population in Brazil (low resources and dependent on SUS). Thus, in order to reduce the gap between what the orthosis and the generic prosthesis proposes and the result that it reaches, considering the importance of AT, the integrated instrumentation emerges, which has been the object of research and development increasingly constant in several areas of human knowledge [6]. Especially in the health sector, the great emphasis has been given to instruments that allow the acquisition and storage of physiological and biomechanical information, opening new possibilities for the development and application of techniques to elaborate projects for this reality [6].

The objective of the integrated instrumentation is the use of several biomechanical and physiological measuring in order to obtain objective (quantitative) measurements of the physical, biomechanical and physiological characteristics of the individuals, in order to characterize the needs of this individual and their movement dysfunctions, producing important data and information on the design issues of the AT resource that the individual will use, such as comfort, usability, biomechanics and others. In view of the above, the present study had as its objective the application of the integrated instrumentation for the development of assistive technology products for patients of the Psychiatry Institute of Santa Catarina (IPq-SC).

2 Materials and Methods

2.1 Experimental Protocol

A collection protocol was developed by the research group encompassing the use of integrated instrumentation. First, the cameras were positioned to record the activities developed. After this procedure, the integrated instrumentation process was started with the use of dynamometry equipment, surface electromyography, infrared thermography and motion capture by inertial sensors (X-sens). The collections were performed on different days to avoid interference between the collected data and due to the physical and psychic conditions of the patients.

2.2 Study Site

This research was carried out at the Psychiatry Institute of Santa Catarina (IPq-SC) located in the municipality of São José (SC) (27°35′59″ S and 48°42′51″ W), being the only public hospital in the State of Santa Catarina that provides psychiatric care, serving mainly the low-income population, coming of several cities of the state.

2.3 Sample

Participated in the study two patients, one male (Patient A) (59 years) and one female (Patient B) (54 years), who presented multiple deficiencies, based on different psychiatric diseases, presented reduced mobility, requiring of hygiene, feeding and locomotion care, assisted by nurses in the activities of daily living. Patient A presents a diagnosis of mental disorders associated with Alzheimer’s degenerations, Parkinson’s syndrome symptoms, right hemiparesis, cerebral degeneration and motor problems such as difficulties in maintaining standing posture, flexion deformities in the metacarpophalangeal joints. On the other hand, paciente B presents cerebral palsy, mental disorders, left spastic hemiplegia, equine foot and fatty cysts in the left foot. The data obtained with the instrumentation were based on the type of deficiency that the patients presented. Due to this condition of individuality of the patients, surface electromyography, manual dynamometry, infrared thermography and motion capture by inertial sensors (X-sens) were used for analysis in patient A and for the analysis of patient B, only infrared thermography and motion capture by inertial sensors (X-sens) were used, since each motor dysfunction presents a special need for adjustment through AT resources. This study was approved by the Research Ethics Committee of Federal University of Santa Catarina (n. 1.257.716) and the Informed Consent Term (ICF) was previously signed by the responsible tutors of the patients.

2.4 Dynamometry

For muscle strength measurement, a SAEHAN ® hand-held dynamometer (SAEHAN Corporation, Korea, Model DIGI II) with a maximum capacity of 90 kg and a scale of 1 g was used. For the positioning of the subjects, the methodology suggested by the American Society of Hand Therapy (ASHT) [8] was adopted. The data collected was tabulated in Microsoft Office Excel® 2007.

2.5 Surface Electromyography (sEMG)

For the quantitative evaluation of the muscular electrical activity of the patients, the electromyographic record (Miotool 400) (Miotec Equipaments, Brazil) was used. The methodology suggested by the Surface EMG for the Non-Invasive Assessment of Muscles - SENIAM [9] was adopted. To collect data, rehabilitation and locomotion activities were carried out, which are part of the prescribed exercise routine for these patients, in order to characterize the greatest movement deficit in relation to the limitations imposed by the disease. It was carried out using the parallel or fixed bars, independent locomotion and bicycle (cycloergometer).

2.6 Infrared Thermography (IT)

Before and during the evaluation, the ambient temperature was measured and maintained constant at 22 °C and air humidity at 55%, throughout the procedure. Before the images were taken, the patients waited 15 min to stabilize the body temperature with the ambient climate [10]. The thermal images were captured by a FLIR E40 (FLIR Tools) thermal imager. The camera was positioned horizontally at a distance of 1 m and vertically adjusted to the midline of the lumbar to be evaluated. It was considered emissivity of 98% for human body. Records were made before and after the activities [11]. The thermographic diagnosis of the changes in intensity, size, shape, distribution and margin, as well as the thermal difference between the pain points and the presence of thermal asymmetry compared to the opposite side according to the criteria of Brioschi et al. [12].

2.7 Capture of Movements by Inertial Sensors (X-Sens)

For the evaluation of movements was used the MVN Biomech Link (Xsens) to evaluate movements using 17 inertial sensors that track body segments, their orientation, position and movement with a frequency of 120 Hz. For the data collection, the procedures of the manual equipment was adopted [13]. For the analysis of the data the regions of the knees were chosen for patient A and the ankles for patient B. These regions were determined based on previous evaluations for the development of specific orthoses for each patient.

3 Results and Discussion

The integration of technologies for data collection is still a recent issue. The precise criteria and selection of the measuring instruments allow the formulation of an accurate diagnosis of the movement dysfunction found in the patient, thus allowing clear treatment guidelines, besides the possible establishment of a motor and functional recovery prognosis of the patients. Patients and the development of AT products, even through the limitations presented by them. The collection of patients on different days was requested by the physiotherapist responsible for the patients, due to fatigue resulting from the placement, calibration and data acquisition with the equipment, corroborating the study by Speck et al. [14].

The mean of the isometric hand strength of patient A before the activities was 17.8 Kgf (±1.77) in the right hand (dominant side) and 22.0 Kgf (±2.16) in the left hand and 19.3 Kgf (±2.26) right hand (dominant side) and 24.7 Kgf (±2.45) in the left hand after the activities.

Regarding the manual grip strength before and after the activities, the patient A was able to print more force with the left hand than with the right in both situations. The force after the activities were performed was higher than before their accomplishment, a fact that can be explained by the increase of the blood circulation due to the accomplishment of the activities. In addition, another factor that can be considered is the verbal stimulus for the realization of collections as affirmed by Johansson et al. [15]. This difference may be related to the motivation with which the individual performs the force measurement, since the procedure is considered as a measure of performance and can be improved [16].

In this study, differences of dominance were found between right and left hands in patients, with 20.47% in patient A, data considered to be high and not corroborating with Watanabe et al. [17] that when evaluating the dominance in the hands of individuals considered healthy, values approximately 10% of difference.

For Newman apud Moreira et al. [18], manual grip strength has been considered as a most reliable clinical test for the detection of human force. It is an important indicator in determining the integrity of both upper motor neurons and the motor unit. The internal consistency of the measures of force exerted by different muscle groups supports the use of manual dynamometry to characterize general muscular functional status [19].

The functionality of the hand depends on the integrity of the upper limb, which allows the proper positioning to accomplish the desired task. The motor and sensory tasks performed by the hand are all organized in order to meet the general functioning of the body performance of daily living activities, necessary for survival. For patient A, hand grip means independence and gait of locomotion, allowing the aid of it in passages from the wheelchair to the bed and to other chairs, such as that used for bathing. The gripping ability is also used in simple tasks such as self-feeding. In addition to self-care aids, the patient uses manual gripping for training in physical therapy, where through support devices, such as walker and parallel bars, he performs his walking training. Thus, through the manual gripping measurement, an estimate of the strength gain in the lower limbs can be estimated and the level of adaptation of the orthosis in the training process, since this will decrease the use of force performed by the upper limbs.

Regarding surface electromyography, analyzing the signs of the right and left paravertebrae during gait in patient A, a greater activation was observed in the right paravertebral, with signal peaks of 247.04 uV, against 203.16 uV of the left paravertebral, which presents with less capacity of recruitment during the phases of gait evaluated. When left and right semitendinals are observed, the predominance of muscle recruitment in the posterior right thigh (semitendinosus) with 1751.09 uV, compared to 810.47 uV in the posterior of the left thigh (semitendinosus) is also observed. We can affirm that hemiplegia is left, causing lower motor activity on the left side than the one registered to the right side, and consequently the reflex for this is the inability to produce adequate force for the left side gait, fatigue early in exercise, allied with incoordination and inability to maintain movement.

From the difference of recruitment found, it is believed that exercises can cause disturbs in the balance when stimulate greater muscular activity [20]. These exercises are used to aid in rehabilitation, being related to the muscular stabilization of the lower limbs, as well as providing important data for further development of orthoses and prostheses that can aid the process of gaining independence and mobility of the patient [21].

For patient A, these data obtained on surface electromyography demonstrate the level of effort and consequently the level of neuromuscular imbalance in the gait attempt. In the study of the muscle groups most directly involved in gait, we can clearly have the voluntary electric signal amplitude deficit of these muscles, comparing with the value expected by normal muscles described in the literature and also with active limb muscles not affected by hemiplegia. Thus, it increases the possibility and the vision, the need to design more stabilization or more mobility in the orthosis that will be used by the patient.

In order to collect the thermographic images, the room remained with a local temperature of 22 °C, relative humidity of the air ranging from 55% to 60% and ventilation of the air zero without recording in the thermoanemometer. In patient A, the mean temperature increase observed in the thermographic changes found before and after the gait effort was 1.9 ± 1.0 in the posterior region of the back, from the cervical to the lumbar region. A mean temperature difference of 0.6 ± 0.2 °C between the hemiplegia (highest temperature) and the corresponding normal side (Fig. 1) was also observed.

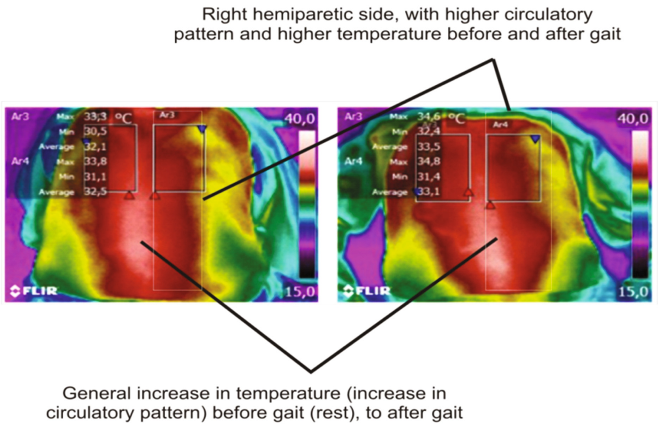

Fig. 1. Thermographic evaluation before and after the activities in patient A.

These changes in temperature, before and after gait, demonstrate the level of exertion performed by the paravertebrae of the spine to maintain orthostatic posture during gait. When comparing the effort of the shoulder girdle with the lumbar waist, there is a greater activity in the shoulder girdle (thoracic spine), which characterizes the use of the upper limbs as the main stabilizers in the standing posture. It is worth mentioning that in the traditional gait without support, the predominance of muscular activity is concentrated in the lumbar region, due to the responsibility of the lumbar spine in stabilizing the movement of the pelvis and trunk during gait.

In patient B, the two images of Fig. 2 demonstrate the temperature difference in the soles of the feet due to the greater blood flow on the right side. In the same figure, the higher temperature of the right foot (34.9 °C) is observed due to the patient supporting most of the body weight in this region during gait due to the decrease of the muscular

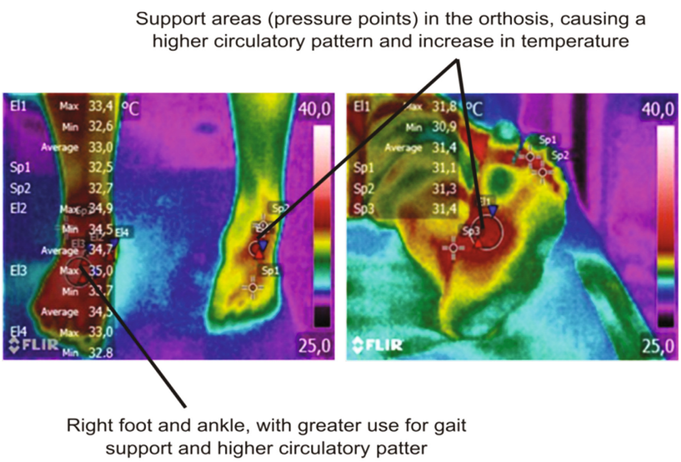

Fig. 2. Thermographic evaluation before and after activities in patient B.

strength of the left lower limb and it is verified the temperature increase in the regions of the patient's left ankle.

There is strong evidence regarding differences in thermal behavior between the genders, regardless of the measurement techniques performed [22]. These authors, in a critical review of the use of thermography in the medical field, observed that subtle changes in surface temperature may occur, and this increase or decrease in temperature may be a direct expression of exacerbation or reduction of inflammation. Neves et al. [23] reported that thermography is a good tool for confirming points of complaint of pain and is a useful approach for the diagnosis and follow-up of several physical disorders, corroborating the present study.

The evaluation of the feet and ankle for patient B, is directly related to the stabilization capacity of the orthosis, with its comfort and usability. The images show not only the greater demand for support in the ground by the right limb (non-affected side), but also the irregular pressure areas, and consequently inflammatory areas, that the affected foot undergoes when supporting the ground during gait.

Based on the data generated by Xsens, after analysis and interpretation of the data, it was possible to understand and obtain quantitative information on the angles of movement, body segment velocity, frequency of movement and displacement of the center of mass of patients A and B.

In patient A, the results observed in the analysis of the data obtained with the Xsens were that the movements of the patient, both the upper and lower limbs tend to the right side that is used as support for the accomplishment of the gait and the movements of rotation. In addition, the right leg is "dragged" at the moment of the gait, with the left leg being the best performing gait movement and rotational supports as observed in Fig. 3. When analyzing the graph, it can be seen that the bending movements and extension are more intense in the left knee. With the right leg the patient performs only 20° of knee flexion during gait, and with the left leg, this movement increases its amplitude

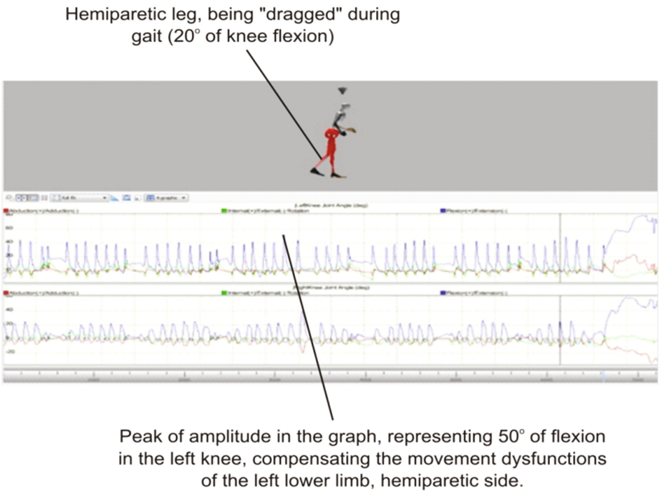

Fig. 3. Motion capture by inertial sensors in patient A in gait activity.

reaching approximately 50°, compensating for the deficit of joint mobility of the right lower limb.

The data observed in the Xsens accurately characterize the landslides that hemiplegia causes to patient A, showing categorically the compensations of movement during gait. These changes and compensations in the movement cause imbalances and force the patient to double his muscular effort to get his locomotion. Due to the sequelae that cause the decrease in strength for the lower limbs, added to the spatiality and consequent lack of neuromotor control.

It is found that during gait of patient B, when the foot is raised, the movement angles of the left ankle separate from “level 0” (value 0 of the Y axis for the angles represented in the wave chart of the movement of the left ankle), while stepping on the ground, the angles approach level 0. By supporting the left foot on the ground, due to the decrease in stability and strength in this leg, the patient performs an uncoordinated movement with less neurological control motor in the right leg during the March, due to the sequelae caused by the cerebral paralysis. From these data, a new designed orthosis should provide more stability in the left foot, avoiding these errors of movement in the right lower limb and increasing the muscular efficiency to perform the gait (Fig. 4).

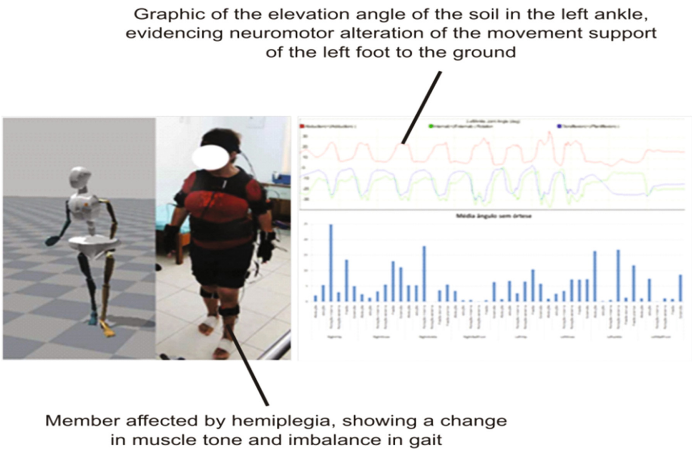

Fig. 4. Motion capture by inertial sensors in patient A in gait activity.

In the hemiplegia of patient B the muscles demonstrate a loss of activity and tone, leading to a shift to the unaffected side. Muscle weakness and lack of proprioception provide the individual with the inability to discharge body weight on the compromised side. This can be proven when observing the study of Pavan et al. [24], where 100% of the patients in the sample did not adequately discharge the body wight on the affected side, leading to a position of postural asymmetry.

The central nervous system receives, analyzes, and integrates information, where decision-making and the sending of orders occur, and in it come impulses from all sensitivities that become conscious and are interpreted, and deflate impulses nerves that initiate and command voluntary movements. O’Sullivan and Schmitz [25], showed that

44% of stroke patients presented significant proprioceptive loss, noting associated impairments in motor control, postural function and balance. The perception of body orientation in relation to gravity requires integration of information from the vestibular, visual, proprioceptive and tactile systems, data observed in the volunteers of this study, in which the patients presented a deficit of balance, lack of proprioception and asymmetry.

The limitations of this research are the small number of patients evaluated, but it certainly presents a contribution to the integrated biomechanical instrumentation method for the development of products for people with disabilities or reduced mobility, where through the data collected and analyzed we can compare the affected side with the "unaffected" side by the motor sequela, observing possible ipsilateral influences on the error or compensations of the movement of these patients. It is suggested that more research should be carried out, with integrated instrumentation that allows comparison, analysis and a solid understanding of the course and duration of the sensorimotor recovery of the patients affected by neuromotor dysfunctions, so as to aid in the planning and implementation of rehabilitation programs more effective and effective for the patient, as well as to generate products that can assist in the daily tasks of these people.

4 Conclusion

Today, with all technological evolution, it becomes increasingly possible to quantify human performance. Any evaluation of sports technique, performance, functional capacity, among others, must be preceded by measurement, description and analysis. The protocol proposed in this work was effective for obtaining the data in the development of AT projects based on orthoses. The development of this study demonstrated that the practice based on the instrumentation of equipment and processes for the development of AT projects is a complex method, which requires the knowledge support of several professionals. Especially when it comes to meeting patients with limitations, in which the participation of health professionals has a greater importance in the process of obtaining these data. Based on the data obtained from the equipment collection, it is possible to confirm the relevance of its use in understanding the patient's muscular status, as well as in the validation stages of the products developed, bringing more and more designers and engineers closer to the user's real needs.

In this sense, this study looked through protocols and methods, to compose a collection protocol that meets the needs of the researchers and respects the limitations of the user, adapting the processes according to the need. It should be noted that, as future studies, this protocol will be used in data collection stages of new projects in AT, in order to continue implementing its procedures.

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