Accessible technologies for kinetic and kinematic analysis of people with disabilities: a literature review

Tecnologias acessíveis para análise cinética e cinemática da pessoa com deficiência: uma revisão da literatura

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ABSTRACT

Locomotion is the process by which a being moves from one place to another, including stopping, changing speed, changes in direction and adaptation to changes in terrain. Human walking follows a pattern, and it is one of the forms of locomotion that most calls the attention of researchers. Its variation among a group may indicate pathological conditions that influence the treatment and rehabilitation of patients with low mobility. The objective of this article is to carry out a review for the development of a low-cost instrumented treadmill that can assist in the rehabilitation, treatment and follow-up of patients with stroke, and for that, a search of articles related to the topic was carried out in databases such as ScienceDirect, PubMed and others. The results obtained were satisfactory and enabled the creation of a good database. It was possible to conclude that there is a diversity of existing resources and that it is up to the professionals to direct their choice to the one that suits them best.

Keywords: instrumented treadmill, rehabilitation, stroke, human gait.

RESUMO

Locomotion é o processo pelo qual um ser se move de um lugar para outro, incluindo parada, mudança de velocidade, mudanças de direção e adaptação às mudanças de terreno. A marcha humana segue um padrão, e é uma das formas de locomoção que mais chama a atenção dos pesquisadores. Sua variação entre um grupo pode indicar condições patológicas que influenciam o tratamento e a reabilitação de pacientes com baixa mobilidade. O objetivo deste artigo é realizar uma revisão para o desenvolvimento de uma esteira instrumentada de baixo custo que possa auxiliar na reabilitação, tratamento e acompanhamento de pacientes com AVC, e para isso, foi realizada uma pesquisa de artigos relacionados ao tema em bancos de dados como o ScienceDirect, PubMed e outros. Os resultados obtidos foram satisfatórios e possibilitaram a criação de uma boa base de dados. Foi possível concluir que há uma diversidade de recursos existentes e que cabe aos profissionais direcionar sua escolha para aquela que mais lhes convém.

Palavras-chave: esteira instrumentada, reabilitação, curso, marcha humana.

1 INTRODUCTION

Human movement presents a complex possibility of movements depending on several parameters: age group, physical conditioning, mental and physical health, among others. Amid such movements, it is possible to highlight the gait that consists of a succession of rhythmic and alternating movements of the lower limbs, trunk and lower limbs that cause an anterior translation of the body's center of gravity. One of the regulators of postural balance control is related to the positioning of the center of gravity.

The internal forces (such as the forces produced by muscle activity) interact with external forces (such as the reaction forces of the ground), promoting harmonic displacement in the center of mass of the body. The dynamic balance of human gait is given by the angular variation of the articular axes of the lower limbs combined with the joints of the upper limbs.

According to QUADROS (2020), the study of human gait has been done with different objectives. In the field of sports, the main focus is the analysis and performance of athletes. Therefore, it is possible to find flaws that can be remedied for a greater chance of success in competitions. In the field of health, this study may contribute to any deviation of gait that the individual may have, either due to a disease or to monitor patients who have undergone surgery and are in recovery.

An example of a dysfunction that can significantly alter these movement interactions is that caused by a stroke. According to GONÇALVES (2013), in Brazil, in 2008, about 200 thousand hospitalizations were registered, of which 33 thousand died, and those who survived presented a series of deficits, such as: changes in the level of consciousness, impairment of the senses, motor skills, cognition, perception and language. Regarding motor function, paralysis or paresis of the muscles on the side of the body is observed contralateral to the brain injury, standing out hemiplegia.

Hemiplegia will affect movements and, significantly, gait, promoting a way of walking that can be denoted as hemiplegic gait. Hemiplegic gait is described by MIZRAHI et al. (1982), as being slow, abrupt and laborious, due to the various injuries in perception-cognition, joint mobility, strength, motor control, tone and balance.

Particularly, in the area of health or rehabilitation, assistive technology comes to support or combat the restrictions and limitations that deficiencies can bring. It covers devices, techniques and processes that can provide assistance to improve the quality of life for people with disabilities. To understand and intervene on these individuals, the first step is to analyze their condition.

When analyzing human gait, two requirements must be observed: the continuous ground reaction force that supports the body and the movements that together comprise the kinetic and kinematic analysis of biomechanics.

This work aims to review the literature on technologies that are being developed for kinematic and kinetic analysis of human gait to assist in the assessment and treatment of individuals who have suffered a stroke.

2 METHODOLOGY OF THE REVIEW

For the elaboration of this review, articles were searched on the Capes database and patents on Google Patents, in the period of the first half of 2021.

The inclusion criteria used were based on the relevance of the theme, content and timeliness of the information.

The researches were carried out by engineers and physiotherapists, aiming at an interdisciplinarity of sciences.

3 DEVELOPMENT AND DISCUSSIONS

Instrumented treadmills allow the analysis of locomotion over long distances in confined spaces, with controlled progression speed (WILLEMS and GOSSEYE, 2013; HONG et al., 2017). Since the mobility of neurological patients is restricted and the clinical environment limited, the treadmill can be adapted with force platforms and movement acquisition systems, for long-term gait analysis (WILLEMS and GOSSEYE, 2013;).

Comparative studies of treadmill and ground gait show equivalent movements (WILLEMS and GOSSEYE, 2013; FORNER-CORDERO et al., 2006; EDGINTON et al., 2007; HONG et al., 2017). However, for both young people and the elderly, a higher cadence, shorter length and less stride time were observed during walking on the treadmills (RILEY et al. (2008) and WATT et al. (2010)). Such changes can be positive in the activity, since a higher cadence, with a shorter step length, can reduce the impact forces during the displacement. However, this premise must be investigated for each individual. For the elderly, there was still a reduction in the angles of the joints and, consequently, a reduction in the range of movements on the treadmill in relation to the ground, which can be justified by the adaptation time of the elderly walking on the treadmill (RILEY et al., 2008; WATT et al., 2010). In trials involving the elderly and patients with low mobility, such as hemiplegics, an adaptation time on the treadmill of 4 to 5 minutes is suggested before starting data collection for a research, for example (EDGINTON et al., 2007) .

3.1 FORCE PLATFORMS

Among the applications of force platforms, in the various areas of research in health and rehabilitation, the following stand out: measurement of strength during walking and running, study of static upright posture, rehabilitation of post-stroke patients, study of the balance of the elderly , study of children in the growth process, among others (ALBUQUERQUE, 2015).

The force platform is a flat surface supported by load sensors, force transducers, which provide an electrical signal proportional to the applied load (HONG et al., 2017). Knowing the intensity of the force on each sensor, it is possible to determine the resulting force on the platform. As the patient's body oscillates on the force platform during static balance, the intensity of the force applied to each load cell is changed, however, the sum of forces on the plate remains constant (RODOWANSKI, 2011). According to EDGINTON et al. (2007) there are two main types of sensors for load capture: strain-gage load cells and piezoelectric load cells. Strain-gage cells are more accurate when compared to piezoelectric cells, as they have less rigidity. The force platform with piezoelectric load cells is more suitable for dynamic tests, such as running and jumping (RODOWANSKI, 2011).

The power platforms can have three load cell positioning configurations: (1) a single load cell positioned in the center of the platform; (2) three cells positioned at the vertice of a triangular platform; (3) four cells positioned at the vertices of a rectangular platform (BARELA (2011).

The force platforms can be installed directly on the ground, leveled with the walking surface. However, you must be able to collect data from each foot while walking. For a continuous walk, it is necessary to install a large number of platforms, which limit the distance of the cycle. The high cost related to the installation and implementation of force platforms on the ground, in addition to the need for large rooms to carry out the tests, hinder their installation in clinics (EDGINTON et al., 2007; FORNER-CORDERO et al., 2006) . This can be minimized when performing tests on instrumented treadmills, as these are mobile and are suitable in clinics and doctors' offices. SLOOT et al. (2015) suggests performing tests according to the standard protocol to assess and report sources of error in force measurements and to minimize their effects on gait analysis.

According to EDGINTON et al. (2007), platforms can be positioned on the belt in three ways: a single force platform on the treadmill, two force platforms positioned side-by-side (in parallel) and two force platforms positioned antero-posterior (in series) . The use of two platforms benefits the collection of ground reaction force data from each foot independently (EDGINTON et al., 2007). In general, side-by-side force platforms are used more frequently in analysis of external forces of human gait (RILEY et al., 2008; WATT et al., 2010).

As for the assembly of platforms on the treadmill, they can be divided into two categories: (1) treadmill for direct reaction force with installation of the platforms below the runing belt (WILLEMS and GOSSEYE, 2013; FORNER-CORDERO et al., 2006; HONG et al., 2017); (2) indirect force measurement belts, with the installation of transducer platforms below the treadmill structure, (WILLEMS and GOSSEYE, 2013; FORNER-CORDERO et al., 2006) or load cells in the legs that support its body (HONG et al., 2017). The direct measurement treadmills, presents results in a simpler way and does not consider the structural dynamics of the belt for calculating the reactions, however, they can present measurement errors due to vibration induced by the treadmills in the sensors, which introduce significant noise in the measurement of peaks of forces. (WILLEMS and GOSSEYE, 2013). Indirectly measuring belts must have rigid structures and dynamic modeling of force transmission from the mat to the force sensors, below the belt structure (HONG et al., 2017).

WILLEMS and GOSSEYE (2013) point out the questions found in meetings and congresses that address the theme: The friction between the belt and the floor surface is added to or subtracted from the anterior-posterior component of the forces applied by the feet on the mat, therefore, the force measure does not correspond faithfully to the applied force; it is not possible to identify the forces of the treadmill, either by accelerating the mat or deflecting plates that tend to modify the force exerted by the feet during the walk. However, despite these limitations, the capture of forces by the platform brings much more accurate information than the subjective visual analysis and abstract inferences about this variable. Another option presented in the literature, are wearable force platforms, with implantation of load cells in personalized insoles. LIU et al. (2012) and ADACHI et al. (2012), present a mobile force platform, composed of three small tri-axial force sensors, fixed on two aluminum plates, installed under the insole of specific shoes, at the main pressure points. On this platform, each sensor presents a summary of the local coordinates, in the three dimensions, of the reaction forces of the soil.

3.2 MOTION CAPTURE

Motion capture consists of capturing real moving objects and inserting these movements into a three-dimensional computational model (ZOHAR et al., 2011). The main systems applied are: Optical Systems and Inertial Systems.

3.2.1 Optical Systems

Standard optical systems use high-speed video cameras, referenced by markers to record, in real time, an individual's movement. These markers are responsible for defining the position and orientation of each body segment (PINHEIRO et al., 2013) and are captured and analyzed by software that converts 2D data into 3D coordinates when crossing information from different planes. In this system, the cameras are arranged around the individual in order to triangulate the position of each marker established according to Figure 1.

Figure 01
Example of Figures that can be presented in the article.

An operational limitation of this system is the attachment of the markers. Such devices must be fixed precisely on anatomical references following the norms established by the International Society of Biomechanics (ISB) (WU et al., 2005; WU et al. 2002) under the occlusion of the markers and the risk of losing the accuracy of all data. The difference in millimeters in the positioning of the marker can significantly affect the joint angle recorded by the system.

In addition, the use of standard optical systems in clinics is limited because they require ample space for the implementation of equipment, use of expensive cameras and software for data collection and treatment, and the lack of training of professionals to operate the capture systems (CALDAS) et al., 2017; DUBOIS and BRESCIANI, 2018; ELTOUKHY et. al, 2017).

In some cases where the optical system is used, 2D data converted to 3D presents small noise and precision errors, making it necessary to previously filter the data to capture movement closer to reality (ARAUJO, 2015).

Optical systems can be classified according to the type of markers used. The most common types of markers are passive, active and inconspicuous semi-passive. In some cases it is still possible to dispense the use of markers.

In passive optical systems it is not necessary to use wires and electronic equipment by the actor (ARAUJO, 2015), since the video cameras responsible for capturing the movement in these systems emit an infrared light that is reflected, with low dispersion and high efficiency, by markers. (PINHEIRO et al., 2013).

Thus, as the light is only reflected by the markers, the cameras are able to distinguish what is a marker and what is skin and tissue, ignoring the latter in the treatment of data by the software. To calibrate the cameras, it is necessary to fix a marker in a known position, and compare it with the position obtained after tracking (ARAUJO, 2015).

The active marker is a Light Emitting Diode (LED) capable of emitting its own light. It, like the other markers, is also arranged in the main joints of the actor's body, tracked by the cameras and identified by the software.

The semi-passive imperceptible markers are photosensitive markers, they can both calculate the position of each point as well as the incident lighting and the reflected light rate (ARAUJO, 2015).

Optical systems without markers are cheaper, since they require little equipment such as a camera or depth sensor (ARAUJO, 2015). Recent research presents the Microft Kinect sensor, consisting of a set of sensors capable of capturing the movement of the human body without the use of markers, as a promising low-cost tool for functional analysis of patient assessment (CLARK et al., 2019; BONNECHÉRE et al., 2014; BORENSTEIN et al., 2012).

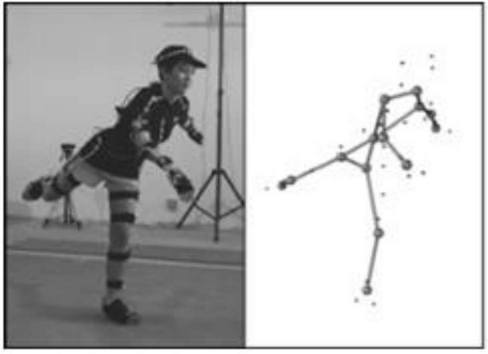
The kinect is a low-cost, portable device that combines a color camera (RGB), a depth camera (infrared) and software based on the detection of a skeleton, which tracks human movements by estimating the 3D position of the main joints of the body (BONNECHERE et al., 2014; LATORRE ett al., 2018, KHOSHELHAM and ELBERINK, 2012;). It is applied to accurately evaluate the lateral inclination angles of the trunk during tests of postural control, stride dynamics during walking, space-time variables and gait kinematics, therefore, it can be a useful tool in the prescription and assisted gait training in clinical and home environments (ARNRICH et al., 2020; DUBOIS et al., 2018; CAO et al., 2017; PFISTER et al., 2014;).

The first version, Kinect V1, used a structured infrared light camera to create an in-depth 3D representation of the space in front of you (CLARK et al., 2019). The second version of the device, Kinect V2, uses the Time of Flight method, which determines the distance to an object by measuring the time that a laser pulse needs to travel from the sensor to the object and vice versa, this reduces the interference from other sensors, it has less image degradation and a higher resolution (KOZLOW et al., 2018, CLARK et al., 2019; MULLER et al., 2017). Currently, the Azure Kinect DK version, launched in March 2020, is available commercially, with a measurement method similar to Kinect V2, but with a greater acquisition of points, than the previous version (ARNRICH et al., 2020).

3.2.2 Inertial Systems

Inertial systems use accelerometers and gyroscopes attached to the body segment that will be tracked virtually, as shown in Figure 2.

Figura 02
Inertial capture system



This system does not require the use of multiple sensors, since each sensor is able to define the position of the segment to which it is attached. The measurement frequency, in turn, is limited by the information processing capacity varying from one system to another.

Inertial systems, as they do not require the use of high technology cameras and software for the treatment of the obtained data, present a lower cost in relation to the optical system. A disadvantage of this type of system can be the difficulty in keeping the sensor in the same position during the evaluation.

The inertial system can suffer electromagnetic interference from the environment, which causes the propagation of measurement noise. To solve these noises, it is common to use the Kalman filter (SABATINI et al., 2006) that corrects the reading based on statistical predictions of the next measured value. A good calibration has a positive impact on the sensor readings and, therefore, can improve the performance of the system (DUARTE, 2020).

4 CONCLUSIONS

There are a number of resources available for the kinetic and kinematic analysis of human movement that allow its use in assistive technology. The understanding of each of these resources and the understanding of their advantages and limitations brings them closer to their use in patients, favoring the understanding of their condition and therapeutic decision making. Among the resources available for analyzing each variable (kinetic or kinematic), each one has some advantage or limitation for its use. The professional, based on the information presented, should direct his choice to what best suits him.

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