METABOLIC EFFORT BASED ON HEART RATE IN USER OF THE ORTHOLEG ACTIVE ORTHOSIS

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Abstract— Due to the complexity of human gait system and individual body reaction when wearing an active lower limb orthosis, the efficacy and performance of such devices are still in current analysis. Taking the metabolic effort realized during gait in consideration, this work exposes the first performance analysis of the Ortholeg orthosis, an lower limb active orthosis developed in the Federal University of Rio Grande do Norte (UFRN). The performance is directly related to the user metabolic effort, which is obtained through the measurement of the heart beat rate. A series of experiments were realized in a healthy subject in order to analyze the orthosis performance. The metabolic effort was compared when the user was not wearing the orthosis.

Keywords— Robotics, Assistive Technology, Powered Orthosis.

1 Introduction

Nowadays, in the field of robotics more devices have been used and developed focusing assistive technology purposes. Among those devices, an active orthosis is a powered suit which can augment or replace the user member limb strength. Focusing in lower limb active orthoses, the most commonly used design controls the knee and hip joints across the sagittal plane, while the ankle joints are passive. Torso balance is controlled by the user using a pair of forearm crutches. The gait trajectory is guided by the user through manual commands, usually using a control panel in the crutches, while turns are mainly guided by the body’s movement.

Due to the complexity of human gait system and the degree of spinal cord injury which the user can have, the efficacy and performance of such devices are still in current analysis. Although active orthosis can be used to improve muscle activity and bone hardness (Arazpour et al. (2013)) from spinal cord injury patients, the main objective of most active orthosis is to reproduce a healthy human gait. Therefore, one widely used way to analyses a lower limb active orthosis performance is through the user walking speed and joint responses when wearing the orthosis (Talaty et al. (2013), Arazpour, Bani, Kashani, Ghomshe, Mousavi and Hutchins (2012), Arazpour, Chitsazan and Hutchins (2012b), Arazpour et al. (2015)). This approach usually consist in analyzing the user movement and speed through motion capture systems and comparing it to the ones captured from a healthy person.

Although this approach has led to improvement and a better knowledge of active orthosis usage, evidence has shown that a spinal cord injury subjects habitually abandon their mechanical orthoses, due to the high level of energy expenditure needed to ambulate. (Franceschini et al. (1997), Arazpour, Chitsazan and Hutchins (2012a), Arazpour et al. (2015)). Hence, an important performance analysis factor of a active orthosis is the metabolic cost associated with the user during gait. In past, some researches, regarding both active and traditional orthosis, evaluated their performances taking into account metabolic cost during gait, collecting information such oxygen uptake, activity energy consumption and heart rate. (Nakashima et al. (2003), Arazpour et al. (2013), Gregorczyk et al. (2006))

Due to the importance of metabolic cost analysis in an active orthosis performance, this work presents the first performance analysis of the Ortholeg orthosis (Araújo et al. (2012)), taking into consideration the metabolic cost consumed during gait, which will be obtained through the measurement of the heart beat rate.

This paper is organized as follows. In section 2 a brief explanation about general aspects of the Ortholeg orthosis and how heart beat is used to calculate metabolic effort is presented. In section 3, important details about the experiments are shown. Finally in section 4, the results, conclusion and future works are discussed.

2 Method

2.1 Ortholeg Orthosis

An active autonomous orthosis is being improved under Ortholeg project (Araújo et al. (2012), Araújo et al. (2011), Araújo et al. (2009)), whose gait cycle study is inspired in biped robot approaches (Fig. 1). This device was designed to provide lower limb movements (such as walk) to spinal cord injured people unable to move their legs. Ortholeg weights 20 kg and can be worn by users within a heights range between 1.55 m to 1.70 m,
Figura 1: Ortholeg Orthosis

This robotic device has two actuators for each leg, one at the knee and the other at the hip. Each one of the actuators controls one degree of freedom on the sagittal plane. Each pair of actuators, related to one leg, is controlled by a control board, which is commanded by a central embedded computer. This computer synchronizes joints angle movements during gait. To ensure balance and safety, the user uses a pair of crutches, once the actuators control only the movement on the sagittal plane.

2.2 Metabolic effort

The heart beat rate is directly related to the intensity of muscle activity (Chiu and Wang (2007)). It is possible to determine how intense a specific physical activity is from a combination of metabolic characteristic, such as cardiac output, beats per minute (bpm) and others. Some of these characteristic do not need to be directly measured. The heart rate can be measured during any moment through electrocardiography signals (ECG), even when the user is resting.

In this work, the heart rate will be measured by a similar signal called photoplethysmogram (PPG), which is obtained from an optical sensor attached to the user skin. In the presented work the measured signal correspondent to the metabolic effort is called pulse rate or \( PR \). The normal resting adult human pulse rate ranges from 60-100 bpm (American Heart Association (2015)).

In order to determine the amount of metabolic effort someone was under during a certain activity it is necessary to calculate its maximum pulse rate \( PR_{max} \), which can be obtained using the following equation (H.Tanaka et al. (2001)). This equation is related to a male subject.

\[
PR_{max} = 220 - age
\]

Using the \( PR_{max} \) as reference, it is possible to determine the metabolic intensity of a given physical activity based on the measured bpm percentage as \( \%PR = \frac{bpm}{PR_{max}} \times 100\% \) (American Heart Association Inc. (1996)). Comparing the observed \( \%PR \) within the Table 1 (H.Tanaka et al. (2001)) we can associate a certain effort level to a specific activity.

<table>
<thead>
<tr>
<th>%PR</th>
<th>Effort Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>%PR &lt;= 50</td>
<td>Soft</td>
</tr>
<tr>
<td>50 &gt;= %PR &lt;= 63</td>
<td>Very Soft</td>
</tr>
<tr>
<td>64 &gt;= %PR &lt;= 76</td>
<td>Moderate</td>
</tr>
<tr>
<td>77 &gt;= %PR &lt;= 93</td>
<td>Heavy</td>
</tr>
<tr>
<td>94 &gt;= %PR &lt;= 100</td>
<td>Very Heavy</td>
</tr>
</tbody>
</table>

Tabela 1: Metabolic effort by observed measured bpm percentage

3 Experiment Description

In order to analyze the Ortholeg performance, two series of experiments were accomplished. In the first one the user was not wearing the orthosis, walking along a straight line trajectory. The user was asked to walk this course straight 6 times (48 m total), in a slow walk (approximately 0.3 m/s). The course did not have any obstacles or ground slipperiness that could influence the gait.

The second series of experiments was conducted when the user was wearing Ortholeg orthosis. During these experiments, the actuators controlled the user joint movement. During the experiments the subject was asked to not resist the orthosis joint movement. This could lead to an unnecessary muscle activity, thus, an undesired incensement in the heart beat rate. As mentioned before, the user guided the coronal balance using crunches.

The distance and the trajectory were the same used in the first series of experiments. The subject walked each course 6 times in two different days. The observed average walking speed with the orthosis was around 0.1 m/s.

The orthosis joint trajectory was based on that of an average person, as show in (Perry and Burnfield (2010)). The maximum flexion and extension of hip and knee were changed due to mechanical limitations of the orthosis and desired gait speed during experiments. The average angle information collected from the encoders attached to each joint motor is shown in Figure 2.

The user was a healthy person, without any heart or gait related disease. At the time of experiment his age was 24 year, height 1.67 m and weight of 55 kg. The experiments were conducted at the same hour, in different days, with a time interval of 1 week between them.
The subject did not perform any intense physical activity or took any medication before the experiments. Also he was not was exposed to any harm, and agreed the Declaration of Helsinki (World Medical Association (2015)).

Figura 2: Measured hip and knee angles for one gait cycle (Right Leg)

In order to collect the pulse rate during both series of experiments, the pulse sensor (World Famous Electronics llc.©) was used. The sensor uses the ambient light sensor from Avago, which is a photoplethysmograph generating a photoplethysmogram or PPG. Photoplethysmography reflects the blood movement in the vessel, which runs from the heart to the blood vessels. The sensor uses an infrared light sent in the skin tissue where the amount of the backscattered light is directly related to the variation of the blood volume (Elgendi (2012)). The peak sensitivity for the used sensor is 565 nm, the sample rate is 500 Hz, and beat-to-beat timing resolution of 2 ms (World Famous Electronics llc (2015)).

The sensor was connected to an microcontroller Arduino Mega 2560 (Arduino ©), which sent the collected information to the orthosis central embedded computer during the experiment using the orthosis, and to a personal computer, during the experiments without the orthosis, with a 10 ms sample rate. The orthosis synchronized the information collected with the movement and stored the data related to each experiment.

The sensor was attached to the user ear, to reduce the noise observed during experiments. In order to calculate number of pulses by minute, or bpm, each pulse cycle was identified by its early systolic wave (Elgendi (2012)). The considered minimum duration for each cycle was 300 ms. The total number of identified pulses is then multiplied by the fraction between 60 and the time of each experiment in seconds, giving us the bpm.

4 Results and Conclusion

The pulse rate was extracted from each course. According to the experiment duration, the bpm and the $\%PR$ were calculated. The bpm results found in both experiments series are shown in Figure 3. Figure 4 show the $\%PR$ according to each experiment. Finally, Figure 5 shown the comparison between the time used to finish each experiment.

It was observed that the user pulse rate when wearing the orthosis increased around 23% compared to the walk without it. Although the increase, the effort level is still under moderate activity, as observed comparing the results shown in Table 4 with the Table 1.

Also, the walking time need to finish the course was increased around 2.23 times when not wearig the orthosis, although a slow walk speed was imposed to the orthosis due to safety reasons. Those results provide useful information regarding future experiments on the orthosis, once some users suffering from spinal cord injury cannot be put under a certain level of physical effort.
Hence, it is possible to confirm that, according to metabolic cost when wearing the orthosis, it is possible to carry out further experiments in injured cord patients without imposing a demanding activity to the user.

As future works regarding the Ortholeg performance analysis, we intend to analyze other metabolic related characteristics, such amount of CO\textsubscript{2} consumed during gait. Also, we intend to perform experiments with a large number of subjects, including spinal cord injury subjects. Finally, it is also our objective to try new joint angle references to study how different gait patterns can influence the metabolic cost when the user is wearing the orthosis.

Acknowledgment

The authors would like to thank CAPES for the financial support given by the CAPES Brazilian agency.

Referências


