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# LOWER LIMB EXOSKELETONS AND THE DIFFICULTIES OF THEIR USE IN THE AUTOMOTIVE ASSEMBLY LINE: THE VIEW OF ERGONOMICS

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## Abstract

Inserted in Industry 4.0, the exoskeleton is an electromechanical or mechanical structure that combines the shape and functions of the human body, working in parallel with it. According to Chen et al. (2016), exoskeletons can be classified according to the segments of the human body supported by the structure. The authors classify exoskeletons of upper limbs, lower limbs, whole body and exoskeletons of joint support. This article focuses on the use of lower limb exoskeletons, which according to Chen et al. (2016), can eliminate loads in manual work, decrease the likelihood of injuries and improve work efficiency. Objectives: exoskeletons of lower limbs allow spine rest and postural alternation of body segments; however, few tests are performed in the work environment to raise the difficulties of adaptation. Thus, the objective of this study was to present the tests carried out and to raise the difficulties of their use by the assembly line operators of the company Hyundai Motor Brasil. Method: The case study was divided into three stages: the first was researching suppliers, selecting the type of product and selecting the size of the exoskeletons. The choice of the lower limb exoskeleton was due to the observation of processes that made it possible to alternate standing and sitting postures. The second stage was to study and understand the characteristics of the product so that it could be implemented in the line and start the third stage, tests with exoskeletons. Results: After use, employees were interviewed and raised the main difficulties, which were separated into two classifications: regarding the use of the exoskeleton and how to adapt it in the work stations. Conclusion: Although there are studies that present the benefits in the use of exoskeletons in

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rehabilitation, the adaptation of their use in the production processes in the automobile assembly line is not simple, since the intrinsic characteristics of the production must be considered and influence the implementation of the devices. It is concluded that tests in work environments with exoskeletons are necessary for the adaptation difficulties to be raised, for a later definitive implementation of the devices, so that the workers' satisfaction is positive and increases the comfort.

**Keywords:** industry 4.0; exoskeleton; ergonomics.

## 1. INTRODUCTION

Industry 4.0, also called Advanced Manufacturing, Industry of the Future and Smart Factory, is characterized by the integration of production processes with the virtual environment, through modern technologies, such as Machine-to-Machine Communication, Big Data, Internet of Things, Artificial Intelligence, Cloud Storage, Advanced Robotics and others (Bortoluci, 2018).

Inserted in industry 4.0, the exoskeleton is an electromechanical or mechanical structure that combines the form and functions of the human body, working in parallel with it. It can perform a mechanical or control system function, with the aim of increasing human power, rehabilitating, or performing haptic interactions (Anam and Al-Jumaily, 2012). According to Chen et al. (2016), exoskeletons can be classified according to the segments of the human body supported by the structure. In this way, the authors classify them as upper limb exoskeletons, lower limb exoskeletons, whole body exoskeletons and specific joint support exoskeletons.

Lower limb exoskeletons are commonly called *wearablechair, chairlesschair, kneeexoskeleton,* or wearable chair, which allows people to walk, stand or sit using the exoskeleton. Thus, this article focuses on the use of lower limb exoskeletons, which according to Chen et al. (2016), can eliminate loads in manual work, reduce the probability of injuries and improve work efficiency. This is in accordance with the Manual for the Application of Regulatory Standard NR 17, published by the Ministry of Labor in 2002, which highlights the importance of alternating standing and sitting posture. According to the manual, postural alternation allows the alternation of use of muscles, since the muscles used to maintain the standing posture are different from the muscles used to maintain the sitting posture (MTE, SIT, 2002).

## 2. GOAL

In the design stage of modifications and changes in work conditions of the Ergonomic Work Analysis, the ergonomics analyst must propose improvements aimed at both production and health (MTE, SIT, 2002), taking into account the analysis of the required postures and possible variations throughout a given activity at work (Abrahão et al., 2009), in this way the exoskeleton can be an option for improvement, as the benefits of its use for the human body are known.

The lower limb exoskeletons allow the spine to rest and the postural alternation of these body segments, however few tests are performed in the work environment to raise adaptation difficulties (Chen et al., 2016). Thus, the objective of this study was to present the tests performed and raise the difficulties about the use of the *wearablechair* or exoskeleton of the lower limbs by the assembly line operators of the company Hyundai Motor Brasil.

## 3. Methodology

The present case study was divided into three stages, the first of which was the search for suppliers, selection of the type of product and selection of the size of the exoskeletons. The choice of the lower limb exoskeleton was due to the observation of processes that allowed the alternation of standing and sitting postures.

The second stage was to study and understand the characteristics of the product so that it could be implemented in the line and start the third stage, the tests with the exoskeletons.

## 4. Size selection

The selected supplier presented 5 recommendations, which varied according to body height, presented in Table 1.

**Table 1.** Available sizes of lower limb exoskeleton.

| **Size** | **Measurements (height)** |
|---|---|
| 2 Good Game | 183 cm or more |
| GG | 174 cm to 182 cm |
| G | 164 cm to 173 cm |

| | |
|---|---|
| M | 155 cm to 163 cm |
| P | 145 cm to 154 cm |

Due to the use being carried out exclusively by the male gender, two sizes of exoskeletons were randomly acquired:

1) G: recommended for people from 164 cm to 173 cm in height;
2) XL: recommended for people from 174 cm to 182 cm tall.

### 4.1. Product Features

The structure has 2 metal rods with articulated arms of 7075 Aluminum, which allow the movement of the knee and hip joints. The fabric material is Polyester and Cordura, with Polyethylene cushions, it has adjustment with velcro at the waist and calves and adjustment with loops on the thighs (Data provided by the supplier). The feet have a rubber cover. According to the supplier, both sizes support up to 120 kg.

### 4.2. Tests

The testing phase was carried out in three stages, totaling a sample of 30 people. In the first stage, in August 2016, the exoskeletons were tested by the engineering team (5 people), in order to understand the operation, use, effectiveness and possible risks of using the product. The tests were first carried out in the Materials Room, with a study of the instructions for use and clothing.

After the engineering approval, between September 2016 and October 2016, the second test took place, which was on the Engine Assembly Line. This line was chosen because the operators worked in front of benches, in a standing posture. First, there was a brief training with team leaders and group leaders (approximately 20 to 30 minutes), who passed on the information to the operators. An internal instruction for use was also prepared. The test was carried out with 15 people, who wore the exoskeleton for one to two hours, non-consecutively, from Monday to Friday.

The second test was carried out between January and March 2018, with 10 people, 5 who perform administrative functions, chosen randomly, and 5 experienced production workers. In production, the tests took place on 3 different lines: Door Assembly Line, Final Assembly Line 1 and Final Assembly Line 2. The use of the exoskeleton in the third stage of testing was 10 to 30 minutes per person.

## 5. FINDINGS

After using the exoskeletons, the employees were interviewed and raised the main difficulties, which were separated into two classifications: regarding the use of the exoskeleton and its adaptation to the workstations (Table 2).

**Table 2.** Difficulties pointed out during and after the use of the exoskeleton.

| Classification | Details |
|---|---|
| How much to use | Learn how to put on and fit the girdles. |
| | Feeling of heat. |
| | Feeling of imbalance when sitting. |
| | Discomfort in relation to the fit in the buttocks. |
| | When walking, the rubber feet could hit the ground. |
| | Risk of rubber feet getting tangled in the shoe. |
| | Tiredness in the lower limbs when sitting. |
| Adjustment in the procedure | Restriction in movement along the line, when in the sitting posture. |
| | Difficulty fitting the rubber feet into the workstations where the car advances on the track. |
| | Risk of getting the rubber feet tangled in the belt gap. |
| | Restricted reach on the door assembly line. |
| | Replacement by benches. |

Source: interview with the workers (Prepared by the authors).

Regarding the use of the device, the seven discomforts immediately reported by the people who used it were the difficulty in putting on and fitting the belts, regarding the adjustment, especially in the calves and waist, as seen that, in the production lines, every hour there is a rotation between workstations and the change of the exoskeleton between operators; sensation of heat during movement on the production line, with reports of sweating in the abdominal region and calves; feeling of imbalance when sitting; feeling of instability and pain in the gluteal region when sitting; the rubber feet can touch the ground or get tangled in the shoe when walking; fatigue in the lower limbs when sitting on the exoskeleton (right and left quadriceps region).

Regarding the production processes of assembly, five difficulties were raised. The first was the restriction that the exoskeleton generates in following the progress of the car on the assembly line, especially in the assembly of the doors, since the parts advance on a rail and the person remains in the static posture of the lower limbs, when seated. The second was in relation to the advancement of the treadmill on the Assembly Line of Final 2, the work takes place on the sides of the car, and when sitting with the exoskeleton, it may happen that one of the feet is out of the treadmill, or both. For work that takes place on top of the treadmill, it may happen that rubber feet fit into the gaps of the same, which increases instability in the sitting posture, there is no risk of falling, however for people who are not adapted to the device, it can be a factor that generates insecurity. On the door assembly line, the sitting posture was not feasible, due to the reach, which conditions trunk flexion close to 45º. Another point raised during the tests was the option of replacing the use of the exoskeleton with benches in workstations where there is the option of performing activities in a standing and sitting posture and allowing the presence of seats.

## 6. Conclusion

This article presented the difficulties of adapting the exoskeleton of the lower limbs in the automotive assembly process, through tests carried out with two different sizes. Although there are studies that show the benefits of using exoskeletons in rehabilitation (McGibbon et al., 2017; Villa-Parra et al., 2015; Lo and Xie, 2012), the adaptation of its use to production processes in the automotive assembly line is not so simple, because the characteristics intrinsic to production (such as automatic line advance, automatic belt advance, floor unevenness and rotation between processes) must be considered and influence the implementation of the devices.

Similarly to Chen et al. (2016) it is concluded that more tests are needed in work environments with the various types of exoskeletons so that the adaptation difficulties are raised, as well as those shown in the present study, for a subsequent definitive implementation of the devices, so that the satisfaction of the workers is positive and there are gains in comfort, well-being at work and, consequently, productivity gains.

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