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LOWER LIMB EXOSKELETONS AND THE CHALLENGES OF THEIR USE IN AUTOMOTIVE ASSEMBLY LINES: AN ERGONOMIC PERSPECTIVE

Almir Paribello: almir.paribello@hyundai-brasil.com; *Chefe do Departamento de MeioAmbiente, Saúde e Segurança Hyundai Motor Brasil, Piracicaba, Brasil*

Ana Carolina Parise Diniz: ana.diniz@hyundai-brasil.com; *Ergonomista*

Douglas Rodrigo Sérgio: douglas.sergio@hyundai-brasil.com; *Técnico de Enfermagem doTrabalho*

Edgard de Oliveira Neto: *Médico do Trabalho*

Lucas Alves de Andrade Volpe: lucas.volpe@hyundai-brasil.com; *Analista de Processosde Montagem*

Luiz Marcelo Marcondes Coelho de Oliveira: luiz.oliveira2@hyundai-brasil.com;
Médico do Trabalho

Vilson Paulo Tauffer: vilson.tauffer@hyundai-brasil.com; *Médico do Trabalho*

Reinaldo Rodrigues de Oliveira: reinaldo.oliveira@hyundai-brasil.com; *Técnico deEnfermagem do Trabalho*

Thiago Alves Oliveira: thiago.oliveira@hyundai-brasil.com; *Coordenador e Médico doTrabalho*

ABSTRACT

Introduction: 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 rehabilitation, the adaptation of their use in the production processes in the automobile assemblyline 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 referred to as Advanced Manufacturing, Future Industry, 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).

Embedded within Industry 4.0, the exoskeleton is an electromechanical or mechanical structure that mimics the form and functions of the human body, working in parallel with it. It can serve a mechanical function or act as a control system, aiming to enhance human power, rehabilitate, or perform haptic interactions (Anam & Al-Jumaily, 2012). According to Chen et al. (2016), exoskeletons can be classified based on the body segments supported by the structure. Thus, the authors classify them as upper limb exoskeletons, lower limb exoskeletons, full-body exoskeletons, and specific joint support exoskeletons.

Lower limb exoskeletons are commonly referred to in the international market as wearable chairs, chairless chairs, knee exoskeletons, or wearable seating devices, which enable people to walk, stand, or sit using the exoskeleton. Therefore, this article focuses on the use of lower limb exoskeletons, which according to Chen et al. (2016), can reduce loads in manual work, decrease the likelihood of injuries, and improve work efficiency. This aligns with the Application Manual of Regulatory Standard NR 17, published by the Ministry of Labor in 2002, which emphasizes the importance of alternating between standing and sitting postures. According to the manual, postural alternation allows for the variation in muscle usage, given that the muscles used to maintain a standing posture are different from those used to maintain a sitting posture (MTE, SIT, 2002).

2. OBJECTIVE

In the stage of designing modifications and changes to work conditions in the Ergonomic Work Analysis, the ergonomics analyst should propose improvements that aim at both production and health (MTE, SIT, 2002), taking into account the analysis of required postures and possible variations during specific work activities (Abrahão et al., 2009). Therefore, the exoskeleton can be an option for improvement, as its benefits for the human body are well-known.

Lower limb exoskeletons allow for spine rest and postural alternation of these body segments; however, few tests are conducted in the workplace to identify adaptation difficulties (Chen et al., 2016). Thus, the objective of this study was to present the tests conducted and identify the difficulties regarding the use of wearable chairs or lower limb exoskeletons by assembly line operators at Hyundai Motor Brazil.

3. METHODOLOGY

The present case study was divided into three stages. The first stage involved supplier research, selection of the type of product, and sizing of the exoskeletons. The decision to choose lower limb exoskeletons stemmed from the observation of processes that allowed for the alternation of standing and sitting postures.

The second stage focused on studying and understanding the product's characteristics to facilitate its implementation on the assembly line. This stage served as preparation for the third stage, which involved conducting tests with the exoskeletons.

4. SIZE SELECTION

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

Table 1. Available Sizes of Lower Limb Exoskeleton

Sizes	**measurements (height)**
XXL	183 cm or taller
XL	174 cm a 182 cm
L	164 cm a 173 cm
M	155 cm a 163 cm
S	145 cm a 154 cm

Due to the fact that the exoskeletons are exclusively used by male operators, two sizes of exoskeletons were randomly acquired:

a) Large (L): Recommended for individuals ranging from 164 cm to 173 cm in height.
b) Extra Large (XL): Recommended for individuals ranging from 174 cm to 182 cm in height.

4.1. PRODUCT CHARACTERISTICS

The structure consists of 2 metal rods with articulated arms made of Aluminum 7075, allowing movement of the knee and hip joints. The fabric material is Polyester and Cordura, with Polyethylene pads. It features adjustment with Velcro at the waist and calves, and adjustment with buckles on the thighs (Supplier-provided data). The feet have rubber caps. According to the supplier, both sizes support up to 120 kg.

4.2. TESTES

The testing phase was conducted in three stages, involving a total sample of 30 individuals. In the first stage, in August 2016, the exoskeletons were tested by the engineering team (5 individuals) to understand their functionality, usage, effectiveness, and potential risks. The tests were initially conducted in the Materials Room, where the usage instructions and attire were studied.

Following the engineering approval, the second test took place between September 2016 and October 2016 on the Engine Assembly Line. This line was chosen because operators worked facing workbenches in a standing position. Initially, there was a brief training session with team leaders and group leaders (approximately 20 to 30 minutes), who then passed on the information to the operators. An internal usage instruction was also developed. The test involved 15 individuals who wore the exoskeleton for up to two non-consecutive hours, from Monday to Friday.

The second test was conducted between January and March 2018, involving 10 individuals: 5 randomly selected administrative staff and 5 experienced production workers. In the production area, the tests took place on 3 different lines: Door Assembly Line, Final Assembly Line 1, and Final Assembly Line 2. In the third stage of testing, the exoskeleton was used for 10 to 30 minutes per person.

5. RESULTS

After using the exoskeletons, the employees were interviewed, and they identified the main difficulties, which were divided into two categories: regarding the use of the exoskeleton and regarding its adaptation in the workplaces (Table 2).

Table 2. Difficulties reported during and after the use of the exoskeleton.

Classification	Details
Regarding usage	Learning to put on and fasten the straps.
	Feeling of heat.
	Feeling of imbalance when sitting.
	Discomfort regarding fitting on the buttocks.
	When walking, rubber feet could hit the ground.
	Risk of rubber feet getting caught on shoes.
	Fatigue in lower limbs when sitting for extended periods.
Regarding adaptation in the process	Movement restriction along with the assembly line when in a seated posture..
	Difficulty in fitting the rubber feet at workstations where the car advances on the conveyor belt.
	Risk of rubber feet getting caught in the gap of the conveyor belt.
	Movement restriction in the door assembly line.
	Replacement with benches.

Source: Interview with workers (Own elaboration).

In terms of device usage, the immediate discomforts reported by individuals who used it included the difficulty of putting on and fastening the straps, particularly in the calves and waist. This difficulty was exacerbated by the rotational nature of workstations and the exchange of the exoskeleton among operators every hour on the production lines. Additionally, there was a sensation of heat during movement on the production line, with reports of sweating in the abdominal region and calves. Furthermore, individuals experienced a sense of imbalance when sitting, as well as instability and pain in the gluteal region. There were also instances where the rubber feet of the exoskeletons touched the ground or got caught in footwear while walking. Lastly, individuals experienced fatigue in the lower limbs when remaining seated in the exoskeleton, particularly in the region of the right and left quadriceps.

Regarding assembly line processes, five difficulties were identified. The first was the restriction caused by the exoskeleton in monitoring the advancement of the car on the assembly line, particularly in door assembly. This was due to the parts advancing on a rail while individuals remained in a static lower limb posture when seated. The second difficulty was related to the advancement of the conveyor belt on Final Assembly Line 2, where work was carried out on the sides of the car. When sitting with the exoskeleton, one or both feet could be off the belt, and rubber feet could get caught in the gaps of the belt, increasing instability in the seated posture. In door assembly, the seated posture was not feasible due to the required trunk flexion of approximately 45°. Finally, during testing, there was consideration of replacing the use of the exoskeleton with benches in workstations where activities could be performed in both standing and sitting postures and allowed for the presence of seats.

6. CONCLUSION

The present article addressed the challenges of adapting lower limb exoskeletons in the automotive assembly process through tests conducted with two different sizes. Despite existing studies demonstrating the benefits of exoskeleton use in rehabilitation (McGibbon et al., 2017; Villa-Parra et al., 2015; Lo & Xie, 2012), adapting their use to productive processes in automotive assembly lines is not straightforward. This is because intrinsic production characteristics such as automatic line advancement, automatic conveyor belt movement, floor unevenness, and process rotation must be considered and influence device implementation.

Similarly to Chen et al. (2016), it is concluded that more tests in work environments with various types of exoskeletons are necessary to identify adaptation challenges, as shown in the present study. This is crucial for subsequent definitive implementation of the devices, ensuring positive worker satisfaction and gains in comfort, well-being at work, and ultimately productivity.

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