https://doi.org/10.4322/rea.v13i2.28.en

ABERGO

ASSOCIAÇÃO BRASILEIRA DE ERGONOMIA

Revista Ação Ergonômica

www.abergo.org.br

Ação Ergonômica
Revista da Associação Brasileira de Ergonomia - ISSN 1519-7859

ASSESSMENT AND TESTING OF THE EXOSKELETON ON AN ASSEMBLY LINE

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ABSTRACT

This work presents an initial study to evaluate and test a passive exoskeleton for upper limbs in an automotive production line. The tests were carried out at the painting area and at the assembly area during a day of production compound of two work shifts with the participation of different sectors of the company. A total of seven operators participated in the test and six workstations were evaluated. It was observed that in both areas, the use of the exoskeleton did not change the cycle time of the activities performed by the operators. In activities where the

operator needs to maintain the arms raised, the exoskeleton is more favorable. However, in activities where the operator needs to lower and raise the arms several times during the work cycle, the equipment is unfavorable, because the operator finds resistance to lower the arms. It is necessary to deepen the studies with other exoskeleton models available on the market and carry out tests with a longer duration.

KEYWORDS: exoskeleton; ergonomics; assembly line; upper limbs

1. INTRODUÇÃO

The automotive industry seeks to achieve better robustness and precision of automated devices in its facilities. In this context, some workstations demand from the operator complex body movements, reasoning, and precise skills, while current robotics technologies have some limitations regarding feasibility, perception, speed, or flexibility to be implemented at workstations.

In Brazil, there is a prevalence of automotive industries that have manual workstations in vehicle assembly, which require postural loads, repetitive movements, and reduced task duration.

Ergonomics in the automotive industry has as one of its main objectives the reduction or elimination of workstations where the operator has to adopt inadequate postures, heavy loads for manual handling, or excessive efforts (SYLLA; BONNET; COLLEDANI; FRAISSE, 2014), always aiming for the reduction of exposure to acute and cumulative occupational risk factors (SPADA; GHIBAUDO; GILOTTA; GASTALDI; CAVATORTA, 2017).

The reduction of these risks is treated as a priority topic in the planning of production managers in assembly line plants (KARVOUNIARI; MICHALOS; DIMITROPOULOS; MAKRIS, 2018).

Tasks involving shoulder or hands lifting above the head are considered a risk factor for the onset of musculoskeletal disorders in the shoulders (NORDANDER; HANSSON; OHLSSON; ARVIDSSON; BALOGH; STRÖMBERG; RITTNER; SKERFVING, 2016). These disorders are considered an occupational health concern in workplaces, as they may require a long recovery period for operators. Jobs performed with upper limbs above the head are still necessary in some tasks, and in certain situations, they are not easily eliminated from some workstations due to cost and the nature of the task itself (KIM; NUSSBAUM; ESFAHANI; ALEMI; ALABDULKARIM; RASHEDI, 2018). Shoulder or hands elevation above the head imposes physiological and biomechanical demands on the worker's shoulder (GRIEVE; DICKERSON, 2018).

Different interventions, such as the use of manipulators, hoists, and other devices, are introduced in workplaces with the aim of addressing musculoskeletal complaints related to manual tool use and material handling (KARVOUNIARI; MICHALOS; DIMITROPOULOS;

MAKRIS, 2018).

Among the interventions applied in workplaces, the exoskeleton presents itself as an alternative to control physical demands, especially those related to material handling (LOOZE; BOSCH; KRAUSE; STADLER; O'SULLIVAN, 2015).

The exoskeleton is used in different areas, such as in medicine for patient rehabilitation (LO; XIE, 2012), in the military with application to soldiers (LEE; WANSON; HAN; CHANGSOO, 2012), and in industry (LOOZE; BOSCH; KRAUSE; STADLER; O'SULLIVAN, 2015).

Exoskeletons are examples of collaboration between humans and robots. The collaborative robot is designed to assist the worker in performing a task. Exoskeletons are a particular type of collaborative robot that has functionalities that can meet ergonomic needs in industries, such as compensating for postural load and upper limb demand (SYLLA; BONNET; COLLEDANI; FRAISSE, 2014).

The exoskeleton is an external mechanical structure that can be worn, and it is designed to work in harmony with the human being to provide support or enhance their ability. There are two types of exoskeleton. It can be passive, when it provides support or protection, or it can be active, by providing additional force (KARVOUNIARI; MICHALOS; DIMITROPOULOS; MAKRIS, 2018).

This work presents an initial study to evaluate and test a passive upper limb exoskeleton in an automotive production line. The objective is to describe the systematic adopted by the company's Ergonomics Department in the first contact with the equipment and to understand its operation in certain workstations in vehicle painting and assembly operations.

2. MATERIALS AND METHODS

2.1. EQUIPMENT DEFINITION

The exoskeleton model used for testing on the production line is characterized by being a passive assistance system aimed at the upper limbs. The model lifts and supports the operator's arms to assist them in activities involving movements and/or maintaining the arms raised and extended from chest level to above the head. Additionally, the model used allows for the use of work tools during assembly tasks.

The tested equipment features an adjustable vest harness, a total weight of 4.3 kilograms with adjustable lifting assistance in four levels (1 to 4), ranging from 2.2 to 6.8 kilograms, respectively, per arm, and a working height between 152 and 193 centimeters.

2.2. DEFINITION OF WORKSTATIONS

The definition of workstations where the exoskeleton was tested followed the following criteria: operations performed under the car involving the adoption and/or sustenance of postures with shoulder elevation above 45° and workstations with complaints related to musculoskeletal demands of the upper limbs. Based on these criteria, three workstations were selected in two distinct sectors of the factory floor, where the vehicle body travels suspended above the operators, in the painting and assembly sectors.

The selected workstations in the painting sector are located in a closed and cooled area. Each workstation covers a region of the car where the operator performs their tasks. The floor is made of metal grating and has two levels delimited by guardrails, where operators carry out their activities wearing waterproof overalls, in addition to other personal protective equipment. The operators use tools such as a brush, an extruded sealing compound application gun, and a PVC spray application gun, weighing approximately 1.11 kilograms to 2.15 kilograms, respectively. The operations at the evaluated workstations involve applying and brushing the sealing compound bead and applying PVC to the floor and wheel arches, where the operator moves along the workstation and performs linear and trigger finger movements with sustained upper limb support during 90% of the cycle time (See Figure 1).

Figure 1. Workstations in the painting and assembly area.

The workstations selected in the assembly area are characterized by being located in an open area cooled by directed fans, where each operator performs their tasks. Operators stand on a sliding platform that moves along with the vehicle body, delineating the workstation area. The tools used include pistol and angle screwdrivers, weighing approximately 2.7 kilograms and 3.15 kilograms, respectively. During task execution, operators pick up various parts and screws placed near the work areas to assemble and fasten them, which involves shoulder abduction and adduction movements for more than 30% of the cycle time.

2.3. OPERATOR SELECTION

The operators who participated in the exoskeleton test are male, with approximately one year in their position and aged between 20 and 35 years old. In total, seven operators participated in the test, with three from the painting sector and four from the assembly sector.

The test in the painting sector took place in the middle of the first shift. The test in the assembly sector occurred at two different times: at the end of the first shift and at the beginning of the second shift.

2.4 AREAS INVOLVED

The sectors involved in the production line test were manufacturing, industrial engineering, process engineering, ergonomics, and the exoskeleton representative.

Manufacturing determined the operators participating in the test based on their experience level at the workstation. The operator performed all workstation tasks wearing the exoskeleton without any changes to the operational procedure.

Industrial engineering analyzed the time per operation during on-site operations to identify any changes in the workstation's cycle time.

The study related to the operation and maintenance of the equipment was the responsibility of the process engineering sector.

The ergonomics department was responsible for the test, evaluation, and reintroduction of the exoskeleton's use on the production line. This department made contact with the equipment representative, aligned information with the involved sectors, scheduled the test, and established the test steps. Ultimately, the ergonomics department conducted the reintroduction through data compilation and presentation of the results to the company's management.

The exoskeleton representative made necessary equipment adjustments throughout the test according to the operators' requests.

2.5 TEST STAGES

Before starting the test, each participating operator received clarifications from the ergonomist regarding the study of the exoskeleton on the production line and the importance of performing tasks normally. Subsequently, the equipment representative explained the exoskeleton's operation and assisted the operator in wearing it. The operator then proceeded to their workstation and commenced the tasks. In the initial minutes of equipment use, the representative made adjustments to the exoskeleton parameters as per the operators' requests. The duration of the tests at each workstation was approximately thirty minutes, recorded in audio and video.

Throughout this time, all involved sectors participated in the test near the workstation. However, only the ergonomist and the workstation supervisor closely monitored all operations performed by the operator and, at times, questioned their perceptions of using the exoskeleton.

Observation techniques (KIRWAN; AINSWORTH, 1992 and JONASSEN; TESSMER; HANNUM, 1999) were used to collect data on how tasks were performed with the use of the exoskeleton. The observational techniques in this study were employed to record the complete sequence of actions and capture visual events present in the operators' actions and interactions between the operator and the exoskeleton.

At the conclusion of the test, the operator evaluated the equipment on a scale of 0 to 10, where 0 represented the lowest satisfaction index and 10 the highest. Additionally, the operator reported their experience and sensation of using the equipment during the execution of work activities on the assembly line.

The final step involved compiling data from different participating sectors and presenting the results from the perspective of each involved sector to the company's management.

Tests conducted in painting and assembly took place over a production day, given the representative's availability to provide and oversee the equipment test. Importantly, during the tests, the assembly line and production processes were not interrupted. The production's operation and pace remained unchanged.

4 RESULTS

The test began in the painting department in the morning, during the operators' mid-shift. The adjustment of exoskeleton parameters for load support at each workstation started with the lowest setting (level 1). Throughout the test, the adjustment level was gradually increased to assess the operator's perception of each equipment parameter.

Two workstations in the painting department require the operator to perform tasks with upward movements of the upper limbs, positioning the elbows at shoulder height (Figure 2). In these workstations, operators reported the need for greater attention regarding the use of the exoskeleton to avoid collisions with equipment and furniture along the production line. Regarding the exoskeleton adjustment, operators preferred the second level. At the third workstation, where the operator performs tasks with the upper limbs raised and the elbows above the shoulders with extended arms, the operator preferred the third adjustment of the exoskeleton, providing greater load support capacity. It was observed that in this workstation, the activity requires the operator to sustain the upper limbs in an elevated position for an extended period.

Figure 2. Exoskeleton test in the painting and assembly area.

Despite the different adjustments for each operation based on the operator's requirements, the satisfaction and use of the equipment received a consistent rating of eight from all operators.

In the assembly department, the test started in the afternoon, at the end of the first shift and the beginning of the second shift. The equipment adjustment was reversed compared to the tests in the painting area, starting with the highest setting (level 4) and gradually reducing it to the level deemed optimal by all operators at all workstations (level 2). According to the operators, the higher adjustment level requires more effort to lower their arms because, due to the nature of the activities, operators need to lower their arms to pick up parts and tools, and then support their upper limbs during assembly. At two workstations, operators reported the need for greater attention to avoid collisions with equipment and furniture along the production line when using the exoskeleton. One workstation where the exoskeleton was tested has a free operating area, which did not raise concerns for the operator during movement at the workstation. Regarding satisfaction and use of the exoskeleton, one operator rated the equipment with a perfect score of ten, while the other operator gave it a nine.

The third workstation in the assembly presented the peculiarity of being tested with two operators at different times, one at the end of the first shift and the other at the beginning of the second shift. This was important to identify behavior and fatigue perception after the work shift and at the beginning of the shift. Despite the different timing, both operators gave a rating of nine, and the adjustment parameter was level 2.

It was observed that in all workstations, both in the painting and assembly departments where the exoskeleton was tested, there was no change in the cycle time of the activities performed by the operators. However, there was a reduction in rework and consequently, in the execution time of the operation in the assembly area where the operator uses a torque tool to tighten screws and requires precision to position the tool, ensuring the screw is threaded.

Each operator reported their experience and sensation of using the equipment during their work on the assembly line. Of the total participating operators, 71% reported the need to exert force to lower their arms during the activity, highlighting the importance of adjusting the exoskeleton to the activity's characteristics. Regarding the bulkiness of the equipment, 43% expressed concern when remembering they were wearing the exoskeleton. Another 14% mentioned discomfort from the exoskeleton's contact with the body, especially in the waist region, and 57% described how the equipment assisted in the precision of using overhead tools, facilitating their operations.

5 CONCLUSION

The existence of manual workstations that require operators to demonstrate agility and precision is a reality in the automotive industry. Some of these tasks involve lifting the upper limbs throughout the work shift, which can lead to musculoskeletal overload and fatigue. In this context, ergonomics plays a role in studying solutions to minimize or eliminate potential risks that could negatively impact the operator's health. The exoskeleton is considered a potential solution to address these risks.

The tests conducted on the production line described above were crucial for analyzing the feasibility regarding the operator's acceptance and the equipment's functionality in tasks involving the elevation of the upper limbs. Conducting tests at three different times—beginning, middle, and end of the work shift—was important to capture the operator's perspective with varying levels of fatigue. Despite this, all participating operators rated the exoskeleton with a score above eight in terms of satisfaction and equipment use, indicating good acceptance initially.

It was observed that in activities requiring the support of the upper limbs, the exoskeleton proved more favorable. In activities where the operator needs to lower and raise the upper limbs multiple times during the work cycle, the exoskeleton showed unfavorable aspects as the operator has to exert force to lower the arm. On the one hand, the exoskeleton provided support for the arms; on the other hand, it introduced a new muscular demand. This is an aspect that needs refinement in the design of passive exoskeletons for production lines.

The participation of various involved sectors in on-site tests was important for engagement and alignment for a potential implementation of the exoskeleton on the production line. Industrial engineering highlighted the positive impact of the equipment on cycle time, as there was no change; process engineering noted no changes in operational processes but identified the need for technical studies related to equipment maintenance.

The participation and opinions of operators, potential future users of the exoskeleton, were essential for analyzing the real work situation on the production line with the use of the equipment and identifying actual needs, difficulties, and potential gains.

It is important to emphasize the need to further study other models of exoskeletons available in the market, conduct tests with longer durations, and perform tests with electromyography to assess the impact of the exoskeleton on the upper limbs.

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