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APPLICATION OF REBA AND KARAKURI KAIZEN TECHNIQUES TO REDUCE ERGONOMIC RISK LEVELS IN A WORKPLACE

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Keywords

Ergonomics, Ergonomic Design, Kaizen, Karakuri, Rapid Entire Body Assessment.

Abstract

Repetitive works and the works done with inappropriate body postures cause musculoskeletal disorders and workforce losses. Design, technology, and humans must come together in ergonomic conditions. In this study, the ergonomic risk levels that employees in automotive production lines being exposed to were determined by the rapid entire body assessment (REBA) method and by considering anthropometric measurements and ergonomic body postures at a line with high risk level, and a shelf system was designed in accordance with the Karakuri working principle. Through the computer-aided design, the system operation was simulated and solutions for ergonomic risks could be provided before the production. The ergonomic risk level, which was "high" in the current situation, could be reduced with the newly designed mechanism, and an ergonomic workspace could be provided for employees. In the new situation, the ergonomic risk level is "low." In addition to ergonomic improvements, as the manual transportation works of the employee were eliminated, the cycle time of the line, which was 120 s in the first state, was reduced to 100 s after the use of the Karakuri mechanism and the efficiency of the line increases by 17%.

İŞ YERİNDE ERGONOMİK RİSK DÜZEYLERİNİ AZALTMAK İÇİN REBA VE KARAKURİ KAİZEN TEKNİKLERİNİN UYGULANMASI

Anahtar Kelimeler

Ergonomi, Ergonomik Tasarım, Kaizen, Karakuri, Hızlı Tüm Vücut Değerlendirmesi.

Öz

Tekrarlayan işler ve uygun olmayan vücut duruşları ile yapılan işler kas-iskelet sistemi rahatsızlıklarına ve iş gücü kayıplarına neden olmaktadır. Tasarım, teknoloji ve insan ergonomik koşullarda bir araya gelmelidir. Bu çalışmada, hızlı tüm vücut değerlendirme yöntemi ile otomotiv üretim hatlarında çalışanların maruz kaldıkları ergonomik risk seviyeleri belirlenmiş ve risk seviyesi yüksek olan bir hatta antropometrik ölçümler ve ergonomik vücut duruşları dikkate alınarak Karakuri çalışma prensibine göre raf sistemi tasarlanmıştır. Bilgisayar destekli tasarım sayesinde üretim öncesi sistemin çalışması simüle edilmiş ve ergonomik risklere yönelik çözümler sunulabilmiştir. Mevcut durumda "yüksek" olan ergonomik risk seviyesi, yeni tasarlanan mekanizma ile azaltılabilmiş ve çalışanlar için ergonomik bir çalışma alanı sağlanabilmiştir. Yeni durumda ergonomik risk seviyesi "düşük"tür. Ergonomik iyileştirmelere ek olarak, çalışanın manuel taşıma işleri ortadan kaldırıldığından, ilk durumda 120 saniye olan hattın çevrim süresi, Karakuri mekanizmasının kullanımından sonra 100 saniyeye düşürülmüş ve hattın verimliliği %17 artmıştır.

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1. Introduction

Ergonomic improvements made for the working environment of the labor-intensive automotive industry are very important for both the health of the employees and the increase of production efficiency (Tanır et al., 2013). The cost resulting from musculoskeletal disorders (MSD) is high.

MSD may occur due to physical factors such as improper working position, work environment, or lifting the excessive load. If ergonomic arrangements are not made in such working environments, these ailments may increase and as a result, labor losses may occur. To be able to say that an environment or product is ergonomic, a living environment is expected to be created, or in the design of a product, it is expected to be in accordance with the characteristics and capacities of those who will benefit from it or will use it (Kaya and Özok, 2017). To create a workspace that meets ergonomic criteria, first of all it is necessary to pay attention to the anthropometric dimensions of the person who will use the equipment in the workspace (Parsons, 2000).

Ergonomics is a branch of science that studies the physical and mental characteristics and abilities of the people related to work and environmental conditions and human-machine interaction, and examines the harmony of the physical environment with the human (Kıraç, 2005).

One of the other important criteria in human-machine harmony is anthropometry. When anthropometric measurements ranging from person to person are properly determined in accordance with the size of the group to work in the work environment, the strain points of the person working on that system can also be easily estimated, thus it becomes possible to make ergonomic improvements before the design (Kaya and Özok, 2017). With a working environment where the system, equipment, and tools are arranged according to ergonomic and anthropometric data, the ergonomic workload affecting the employee can be minimized and the risks that may cause MSD can be eliminated. To increase employee productivity, the tools and mechanisms used by the individuals in the workspace must be appropriate to their sizes (Gönen and Kalınkara, 1993).

It is important to create the necessary environment and conditions for people who try to adapt to rapidly developing technological development and production conditions to work effectively and efficiently. Companies that want to increase their production power in a rapidly growing competitive environment have begun to find new methods for productivity-enhancing studies. One of the biggest increases in these studies has been mechanization and automation, but these were found to be insufficient over time. Because in the production sector, where human resources are still mainly used, productivity changes not only with the machine improvement, but also with the influence of the human factor (Akyol, 2017). The ergonomic workload can be reduced by the workspaces designed according to ergonomic and anthropometric data. A suitable workplace design for manufacturers is ergonomics studies that increase quality and efficiency (Boulila et al., 2018).

In this study, which was applied in an automotive supply industry company, firstly, ergonomic risk exposure levels of the production lines were determined according to the rapid entire body assessment (REBA) method and their primary action areas have been identified. In the production line designated as high exposure, the parts are placed in the box and then transported to the shelf system at different heights. Ergonomic improvement is aimed with Karakuri Kaizen, which is a mechanical system that can be designed and manufactured with the least cost and operational possibilities to eliminate the load carrying work and reduce the production time, and the vertical movement of the material in line with the purposes of use of the Karakuri systems is considered as the basis and a solution has been produced to the existing ergonomics problem.

2. Ergonomic Risk Assessment

Ergonomics; it is defined as an applied science branch that sets out the basic rules of human, technical, and environmental harmony, and aims to achieve productivity in terms of production by ensuring the harmony of the work environment and all the systems it contains, with all psychophysiological and sociocultural capacities and limits (Yapıcı and Baş, 2015). Anthropometry, on the other hand, is a branch of science that deals with human body measurements, shape, and working capacity (Pheasant and Haslegrave, 2005). To ensure body comfort in daily life, the equipment, tools, and equipment used should be arranged in accordance with the human dimensions of the working space and area (Kurban et al., 2016).

For an ergonomic working environment, the immediate environment that may affect people’s work and also the machines used should be examined and arranged in accordance with anthropometric measures. In human-machine interaction, the arrangements made by considering the reactions of people to their environment have effects that increase the efficiency of the work (Yararel, 2019).

Repetitive, improper body postures and movements increase the possibility of MSD (Calzavara et al., 2021). This, leads to material and moral losses for employees, employers and the state (Esen and Fığlalı, 2013). MSD occur due to forcible, rapid-repetitive movements, works that prevent appropriate movements, inappropriate postures or fixed postures (Akay et al., 2003). In particular, manual lifting of heavy loads should be avoided as much as possible. If it is not possible to eliminate it, it can reduce the risk of discomfort by designing a workplace that reduces repetitive movements, ensuring easy handling of the load, or training employees (Álvarez-Casado et al., 2011). To achieve work efficiency, it is necessary to reduce forceful movements and improve inappropriate posture (David, 2005). Remedial studies are conducted to reduce risks by determining the ergonomic workloads of the work by analyzing the working postures (Yener et al., 2019).

It is largely possible to be protected from work-related MSD and its negative effects, which is one of the most important health problems of employees and decreases work efficiency. For this reason, it is of great importance to define and evaluate ergonomic risks in the working environment to prevent or prevent the effects of work-related MSD (Felekoğlu and Taşan, 2017). It is seen that a wide variety of methods are used in the literature for the analysis of working postures (Kara et al., 2014). Based on the observation, various risk assessment methods such as Revised National Institute for Occupational Health and Safety (NIOSH) Lifting Equation, Snook Tables, Rapid Upper Limb Assessment, The Strain Index, Occupational Repetitive Actions Index, Quick Exposure Checklist, REBA have been developed (Felekoğlu and Taşan, 2017).

First of all, an ergonomic risk assessment method suitable for the jobs defined as a result of the work done during the job analysis phase was chosen. The work under investigation is putting the finished parts into a box and placing them on the shelf. It is done manually by standing and using the whole body, lifting, carrying, and placing loads. Therefore, when choosing the method, the REBA enhanced by Hignett and McAttamney (2000), a method that takes the whole body into account and considers posture, load, repetitive movement, and compound interaction, was found appropriate. The REBA method is one of the most preferred methods because it is a practical method that can be applied according to the schemes of body parts that do not require much expertise, based on direct observation (Joshi and Deshpande, 2020).

3. Karakuri Kaizen

To provide an ergonomic workplace, safety, convenience, and efficiency should be prioritized in work and workstation design. Accordingly, one of the most effective methods used to reduce unnecessary movements and eliminate transport is the lean production philosophy (Paraponiaris and Rodríguez, 2019). Lean manufacturing is a holistic approach based on eliminating system waste and continuously increasing system efficiency. Lean production is also described in many sources with terms such as “Just-in-time production (JIT)” and “Toyota production system.” JIT production system is an increasingly important production approach that increases the efficiency of the enterprise when applied correctly (Kılıç and Ayvaz, 2016; Pavnaskar et al., 2003; Xiaobo et al., 1999).

In the production lines of the automotive sector, many improvement activities are performed, especially in the transportation field. Mechanical solutions developed especially for packaging and shelf systems are of great importance in terms of production time and personnel health. Among these developed mechanical solutions, one of the effective methods suitable for the lean production system is “Karakuri Kaizen” (Katayama et al., 2013). Kaizen is a Japanese originated word, “Kai” means change and “zen” means better. In the industrial area, it is the process of achieving small but continuous improvements covering all levels of the company, from factory employees to management levels (Paraponiaris and Rodríguez, 2019). Karakuri is the application of mechanical appliance instead of electrical, pneumatic, or hydraulic devices. Its name was first mentioned in the 17th and 19th centuries and was derived from the mechanical dolls named Karakuri Ningyo in Japan. The best known example of these dolls is dolls bearing tea (Anggrahini et al., 2020).

In Figure 1, the arm of the puppet moves downward with the weight of the bowl placed in the puppet’s hand. The downward bowl movement moves the tension spring attached to the arms and by this means, it enables the movement of the wheels hidden under the mechanism. When these bowls, which are usually full of tea, are taken from the puppet, the movement of the mechanism ends. When the empty bowl is replaced on the puppet, the puppet turns and returns to the starting position. Karakuri made contribution to the industrial rejuvenation of Japan with its working principle (Rani et al., 2015).

Figure 1. Tea serving puppets (Zashiki Karakuri) (Detwiler, 2006)

Today, the machines consist of mechanisms that include simple components such as lever mechanisms, springs, gears, and shafts. Even though electronic technologies continue to develop today, simple mechanical structures remain vital for machines in terms of the subjects such as force transmission and transmission of power from one place to another. Karakuri, on the other hand, ensures that the operations to be performed are conducted more conveniently and comfortably using these simple components and imagination (Bhanu and Kumar, 2018). Karakuri technology is applied to facilitate objective transactions and enhance efficiency (Murata et al., 2013). Karakuri is preferred because it is much cheaper and easier to maintain and develop than electronic systems (Roser, 2017).

4. Literature Survey

In this section, the studies in which the REBA method was applied, and the applications performed on the working principle of Karakuri were briefly mentioned.

Looking at the literature, when the studies that implement REBA are reviewed, it seems that the method is often used for different business areas. From this point of view, the studies conducted between the years of 2015 and 2021 and in which REBA was used were briefly mentioned.

Hignett and McAtamney (2000) examined 600 working positions of people working for some sectors in their study. As a result of the review, REBA, one of the widely used ergonomic analysis methods today, was developed. The REBA method is a practical method often used in the field of ergonomics. Among the studies in which the method was applied, applications in the automotive sector were mainly examined. Atıcı et al. (2015) conducted an analysis on inappropriate working positions in a cable manufacturing company in the automotive sector using the REBA method. In the analysis, the strain that occurred on the employee was determined, and improvements were suggested that could reduce the strain. Ulutaş and Gündüz (2017) identified some problems associated with MSD in a cable manufacturing factory. The Rapid Exposure Assessment and the REBA methods were applied at two special workstations determined. Ertaş and Bulut (2017) determined the ergonomically unsuitable situations by the analysis conducted in the press department of a company that manufactures clutch, improvements were made to eliminate improperness. In a survey created using the Cornell University Musculoskeletal Discomfort Survey, Gönen et al. (2017) analyzed the assembly line employees of a transformer manufacturer with REBA and OWAS. By determining through the analysis that the most risky body parts were the back, waist, foot, neck, and shoulders, they proposed an adjustable assembly stand design to reduce the risks. Thus, by harmonizing the employee and work, employee efficiency was increased, and 5% improvement was achieved on a product basis in terms of press production (cycle) times. Sakalar (2018), in their study, ergonomically evaluated the stations on the assembly line of a company producing engine oil pumps using the REBA method, identified the workstation which creates the highest physical workload and identified the most common musculoskeletal disorder.

When the literature was examined in terms of studies conducted according to the Karakuri working principle, it was observed that the studies were generally being examined in terms of design. The studies in question are briefly mentioned below.

In their study, Anggrahini et al. (2020) reduced the cycle time of mixing and baking by ~39% with an oven automation braced by a conveyor using the Karakuri Kaizen method. Tangl and Vajna (2018), with the results of the study, showed that Karakuri Kaizen can be used as a lean production tool and the productivity improvement methods should be used in parallel and together. Murata et al. (2013) examined examples of visual administration, Poka-Yoke and Karakuri technics according to lean production philosophy and presented their effects on seven key performance indicators. These are quality, cost, delivery, productivity, safety, environment, and morale indicators. They analyzed the effects on business performance by considering the integration of these seven basic performances of the lean manufacturing system. Bhanu and Kumar (2018) made a market study on the Karakuri with the help of interviews, inquiry and literature research within the scope of a master's thesis, and they emphasized the design, economic, and ergonomic solutions of the Karakuri, which are mainly used in the Asian market, for it to become widespread in the European market.

Rani et al. (2015) express how a small production facility in Asia turned the pneumatic material moving equipment into a cost effective Karakuri design. With the system designed and proposed according to Karakuri working principle, the cycle time was reduced by 27.5%. With their study in the packaging industry, Yashvant and Madnaik (2001) explained a Karakuri for making a cardboard box out of straight boards. With the new Karakuri mechanism, cardboard folding was achieved with the help of only one arm, and thus the efficiency increased by eight times.

In the Asian region, the companies operating in an extensive field, such as Toyota, Denso, Aisin, Panasonik, Mazda, and Mitsubishi, use the Karakuri mechanisms for various purposes in their facilities. In Europe, companies such as AIO, Item, Trilogiq, Virtual Manufacturing, Beewatec, and Volvo use the Karakuri mechanisms in their production plants. Volvo GTO has designed the Karakuri mechanism which it uses on the vehicle assembly line in Belgium. In a specific area of the assembly line, the operator performs the job of selecting the bolt that is identical to the other from the bolt bucket in front of him/her and does the assembly work. A spring-loaded magnetic Karakuri mechanism was designed to eliminate the time loss that occurs when the operator searches for bolts in the bucket and the inappropriate ergonomic situation (Bhanu and Kumar, 2018).

Karakuri mechanisms are low cost, easy to install, and easy to use. In the mechanism, where even electricity is rarely used, the motion is provided by gravity. It ensures the distances of the objects which are positioned too high or too low to be arranged suitable for the worker.

5. Materials and Methods

In this study, the ergonomic risk levels that employees in automotive production lines being exposed to were determined by the REBA method and by considering anthropometric measurements and ergonomic body postures at a line with high risk level, a shelf system was designed in accordance with the Karakuri working principle. According to Karakuri working principle, it was aimed to minimize ergonomic workload with a new shelf system designed by simulating it in a three-dimensional design program. After the design, REBA measurements were made again and the ergonomic risk level was minimized. The simulation allows the prevention of MSD by optimizing the body postures of the employees during the use of the mechanism (Peruzzini et al., 2020).

5.1. Ergonomic Risk Assessment with REBA

The REBA method enhanced by Hignett and McAttamney is a method that determines the risk levels of the postures, depending on the loads on the torso, neck, leg, upper arm, lower arm, and wrists of the employees during working posture and depending on whether the posture is static or dynamic (Hignett and McAtamney, 2000; Janowitz et al., 2006; Sağıroğlu et al., 2015).

When determining the REBA score of a working posture according to the REBA method, firstly the body parts were divided into groups as A and B.

- Group A: Torso, Neck, and Leg
- Group B: Upper arms, Lower arms, and Wrists

By indicating the scores of the torso, neck, and legs severally, a score consisting of a composed of those scores was determined using Table (A) given in Figure 2. A score obtained by adding the Carried Load/Force score to this score. Separated scores of the upper arm, lower arm and wrists were determined and a score consisting of a composed of those scores was defined using Table (B) given in Figure 2. B score was obtained to insert a Holding Score to this score. In the next stage, the C score is obtained by overlapping the A and B scores on Table (C) given in Figure 2. Finally, a single the REBA score is obtained by adding the activity score to the C score. The REBA score takes a value between 1 and 15 (Sağıroğlu et al., 2015).

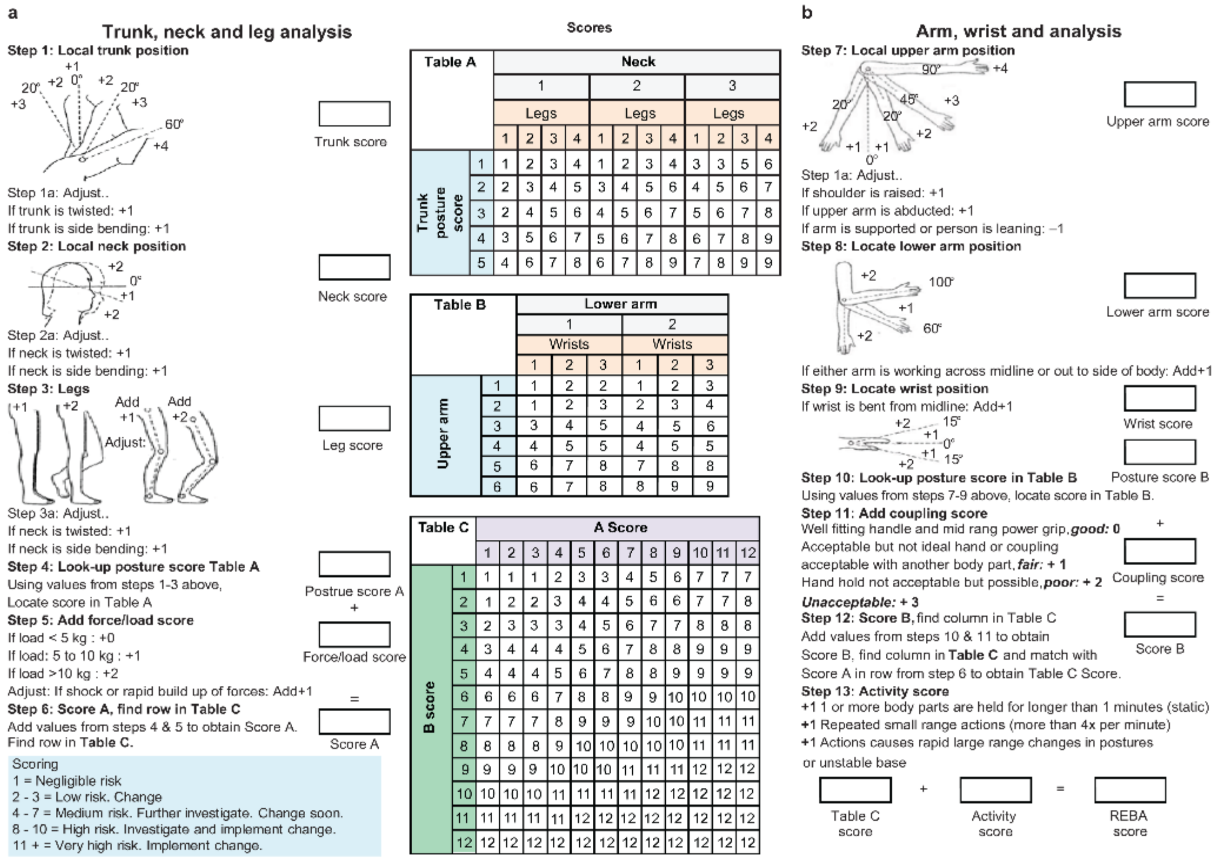


Figure 2. REBA implementation steps (Hignett and McAtamney, 2000)

In this study, the ergonomic risk levels that employees are exposed to in the production lines were determined by the REBA method, and the details of the ergonomic improvement work conducted primarily on a line with a high risk level (8 points) were explained. In the current situation, the positions of the body for the shelf layouts of four different heights during box handling and shelf placement were shown in Figure 3, respectively. As can be seen in Figure 3, the worker leans at most when he/she places the box at the lowest level on the shelf. The worker leans at an angle between 70° and 79° while carrying a 10-kg load.

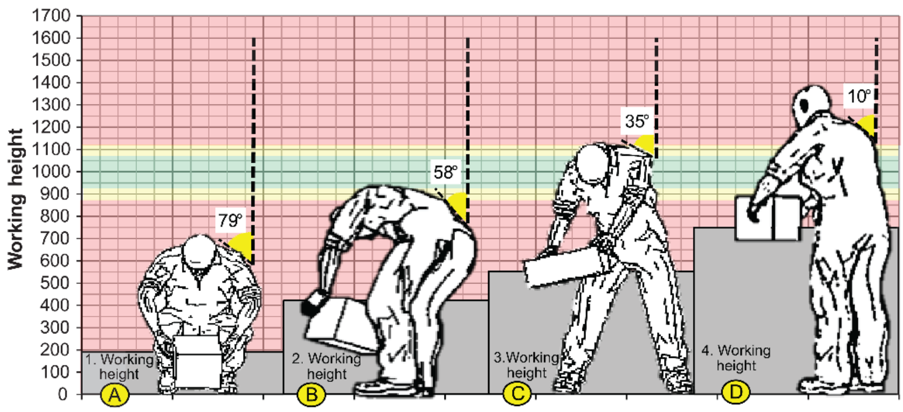
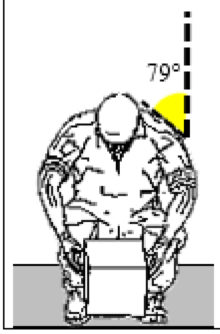


Figure 3. Working heights and body proportions before the Karakuri design

In the current situation, the REBA score of the line is given in Table 1. The torso is leaning forward with 70°–79°, the neck is leaning forward more than 20°, the legs are used bilaterally and there is flexion more than 60°. According to this assessment, through Table A, Group A scores were found. The total weight of a box is 10 kg as there are five pieces of 2 kg parts inside the box. A score was determined as 9 accordingly. In Group B evaluation, the upper arm position was between 45°–90°, and (−1) point was given as there was a gravity support for the posture of the arm. During the work, the lower arm was bent by 60°–100°. 0°–15° bending was seen on the wrists. In terms of holding, the hand grip was considered appropriate but not ideal. The B score was 3 according to these assessments. The score was 7, as the scores of A and B were combined in Table C. In addition to this score, an activity score of +1 was given, as repetitive works were performed at short intervals. As a result, the REBA score was found 8. “High load” was assessed as an ergonomic risk (See Figure 2 for Tables A, B, and C).

Table 1. Determination of the rapid entire body assessment (REBA) score before Kaizen

Body Posture	**Group A**				**Group B**			
		Movement	**Score**			**Movement**	**Score**	
	A-Body	>60 flexion	4		B-Upper arm	45–90 flexion	3	−1
	A-Neck	>20 flexion or extension	2		B-Lower arm	60–100 flexion	1	
	A-Leg	Legs Bilateral weight, carrying, walking, or sitting	1	+2	B-Wrist	0–15 flexion or extension	1	+1
	Group A Score		7		Group B Score		2	
	Load	10 kg	1	+1	Grip	Appropriate	1	
	A Score		**9**		B Score		**3**	

C Score	**7**
Activity	1
REBA Score	**8**

5.2. Design Process According to Karakuri Working Principle

The prerequisite in the design of systems is to know the measures of the person who uses the system and develops within that system. For these reasons, anthropometric measurements are the most commonly used ergonomic data (Kaya and Özok, 2017).

By taking ergonomic and anthropometric criteria into account, with the shelf system designed in accordance with the Karakuri principle, it was aimed to create an ergonomic production condition for workers working in production lines. In line with the intended use of Karakuri systems, the vertical movement of the material was considered as the basis and a solution to the existing ergonomics problem was generated.

In current standard working conditions, the worker working on the production line firstly places the finished parts in a box and after the number of pieces in the box is completed, places the box on the shelf. Figure 4 shows the current standard operating mode of the production line. Accordingly, the worker follows the 1st, 2nd, and 3rd steps respectively. The part produced in area 1 is placed inside the box after being checked in area 2. Five pieces are placed in each box and the total box weight is 10 kg. Shelves defined as A, B, and C show the parts with different references. While the reference part “A” is placed in four boxes on a shelf, the part with the reference “B” is placed in a three-box shelf arrangement, and the part with the reference “C” is placed in a two-box shelf arrangement. While doing this, the worker leans while lifting and carrying each 10 kg box and places the boxes on top of each other. Since the parts, which are produced as 675 pieces per shift, are arranged in a way that every five pieces to be placed in a box, the frequency of the worker to carry and arrange 10 kg boxes is 675/5 = 135 times. The process of carrying 10 kg boxes by leaning and turning for 135 times per shift, poses a risk in terms of MSD.

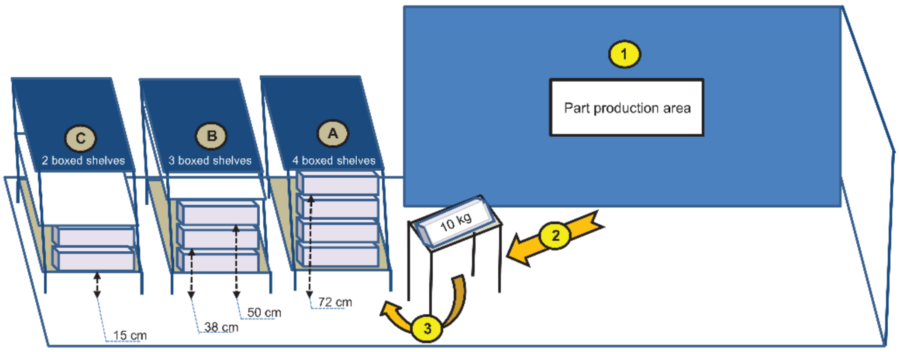


Figure 4. Line operation situation before the Karakuri mechanism design

In the literature review, it was seen that an adult person with a height of 165–185 cm should be working with a lightweight while working, 95–100 cm. Figure 5 shows the sizes of the average human body. Accordingly, the standard working height under light load should be at the height of the elbow distance when the person is in an upright position. When these dimensions or standard operating conditions are exceeded, the concept of ergonomic working is avoided.

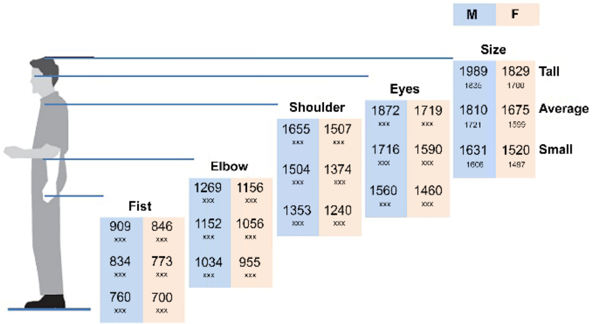


Figure 5. Anthropometric data (Paraponiaris and Rodríguez, 2019)

The strain factors on the employee can be eliminated by the system design created according to anthropometric data. Even small differences in dimensions can have big differences at some design points.

The negative effects of angular changes in body posture during working in a standing position on the spine and joints have also been proven by studies conducted in the literature. Figure 6 shows the bending angle of 20° formed between the spine and the axis of the body during the work in a standing position. The static pressure force created by this angle on the spine affects employee's health negatively and causes the person to feel pain (Daub et al., 2018).

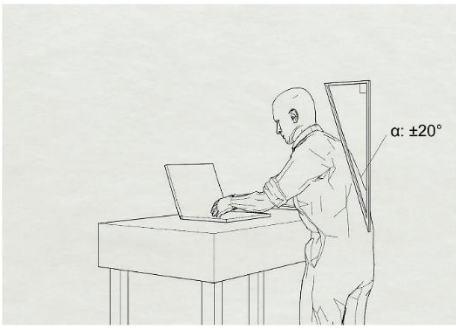


Figure 6. Slight forward leaning of the torso and static tension of the lower back when standing (Daub et al., 2018)

Nachemson's study examined the pressures on L3 and L4 spines during the operation of people with different body types (Nachemson, 1965). Table 2 shows the pressure forces generated during the operation of an individual weighing 75 kg with a height of 170 cm. According to Table 2, in the case of carrying the10 kg box subject to our study with a body angle of 20°, it was determined that it creates 49.5% more load per cm^2 on the L3 spine. This study will be a factor in reducing ergonomic workload and associated MSD for a worker working in mass production conditions, due to the increase in weight on the spine as the body leaning angle increases. For this reason, to obtain reference data before the improvement, the body leaning angles of the individual working in the mass production line were examined in the working positions specified in Figure 4.

Table 2. Pressure forces on the spine during the work while standing (Nachemson, 1965)

Age	Gender	Height	Weight	Body weight pressure on L3 spine	Pressure on the spine kg/cm^2	Pressure on the spine (leaning 10°–20°) kg/cm^2	Pressure on the spine (leaning 10°–20° with 10 kg load) kg/cm^2	Pressure on the spine (leaning 10°–20° with 20 kg load) kg/cm^2
45	Male	170	75	43.9	11.30	14.10	16.9	18.7

According to the current standard working method shown in Figure 4, the shelf layout where the worker put four boxes on top of each other was taken as the basis and the postures of the operator while placing four boxes on top of each other were depicted in Figure 3. It was found that the worker leans between the angles of 70°–79° with a load of 10 kg in his/her hand while placing the first box on the shelf.

It was observed that the work was performed with a maximum body angle of 58° and a minimum angle of 45° while the second box was placed on the shelf. During placing the third box on the shelf, the body working angle varied between 25°–35°. It was found that placing the fourth box on the shelf occurred with a body angle of 5°–10° since it was the nearest working condition to the standard working height value. The "A," "B," and "C" situations in Figure 3 significantly affect a person's health and quality of life. To eliminate this effect and improve the working conditions, a new shelf design has been made in accordance with the Karakuri working principle.

Before starting the equipment design, the standard working order of the production line was analyzed. In conclusion, the height of the parts produced by the worker to be put in the box should always be 1000 mm. A linear motion on a single axis mechanism design is required. The system that will be designed will be able to stand at three different reference points of the shelf. According to the part studied, it will be integrated into three different heights, such as the shelf heights for four boxes, three boxes, and two boxes. According to this information, the three-dimensional design was implemented using a computer-aided design program.

Figure 7 shows the three-dimensional design. The part, which is indicated by the numbers "1" and "2" in the structure, acts as a stopper, limiting the movement of the boxes during their vertical movement. The lower weight moves the counterweights upward with the addition of the boxes to the structure. There are two boxes in the system when the counterweight reaches the stopper "1." When the counterweight reaches the stopper "2," there are three boxes in the system. In the four-box system, the lower body of the construction takes on the task of the stopper. For the rope selection in the designed system, Equation (1) (Kutay, 2017) was taken as the basis;

$$Rope\ force\ (F_R) = \frac{1{,}03 * F_{load}}{n_r * \eta_{ef}} \tag{1}$$

F_{load}: it was considered as the maximum force carried by the ropes when the system was suspended in a balanced way and taken as 840 N.
n_r: Number of the ropes carrying the weights in the system (2 pieces)
η_{ef}: Roller bearing efficiency

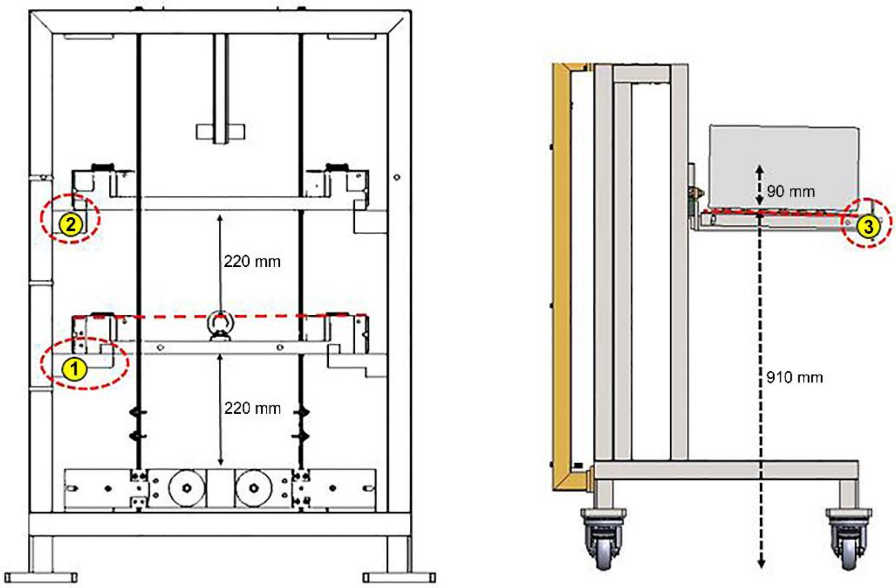


Figure 7. Karakuri mechanism design

Including the deflection rollers, four rollers were used in the system. The efficiency value for one roller was taken from Table 3. Efficiency value for all rollers in the system is Equation (2) (Kutay, 2017):

$$\eta_{ef} = \eta_{RY}^4 = 0.0995^4 = 0.980 \tag{2}$$

then the rope force is equal to;
F_R = (1,03 × 840) / (2 × 0,980) = 441.4 N

The diameter of the rope that can handle this force was calculated by Equation (3) (Kutay, 2017):

$$d_R = c_R \text{ x } \sqrt{F_R} \tag{3}$$

c_R is the rope factor, and under the conditions of infrequent operation and the normal transport of the system not exceeding 2 hours per day, it is taken as 0.085 for the steel rope with the minimum strength value of 1770 N/mm^2 by accepting the steel rope that will not rotate or can rotate a little (See Appendix-1). Therefore, it is found as $d_R \approx$ 2 mm (rope diameter should be at least 2 mm).

6 mm diameter rope is used for a safer mechanism. Rupture strength is found by Equation (4) (Kutay, 2017).

$$S_r = F_{Rmin} \ / \ F_R \tag{4}$$

F_{Rmin} is the breaking strength value of the rope and is found as 19600N using the hemp core standard steel rope table (DIN 3060) for 6 mm diameter rope with a strength of 1770 N/mm^2 (See Appendix-1). Therefore, it is found as;

S_r = 19600 / 441.4 = 44. The system was built to be 44 times safe.

Table 3. Roller efficiency (η_{ef}) (Kutay, 2017)

Description	Symbol Efficiency
Normally lubricated roller bearing	η_{RY} = 0.995
Normally lubricated seal	η_{Co} = 0.980
Cylindrical gear level, which is grinded and well lubricated	η_{DT} = 0.995
Cylindrical gear level, which is processed and well lubricated	$\eta_{Dİ}$ = 0.990
Rope roller without seal	η_{HMa} = 0.980
Rope reel	η_{Hta} = 0.980
Pulley (chain) without seal	η_{Zma} = 0.960

In Figure 7, the plate where the boxes need to be placed was indicated with the number "3." The plate was located on a vertical axis shaft, so the system was made operational. In order for the boxes to slide comfortably on the shelf, the plate was adjusted with an angle. Due to the given angle, the plate stands at an angle of 5°. In addition, adjustment blocks of 250–500 gr were integrated into the system to ensure the desired operability of the system and to make a precise adjustment. Figure 8 shows the manufactured Karakuri mechanism. The finished parts are put in an empty box on the plate in front of the mechanism. The mechanism table will move downwards depending on the weight of the box to be placed on it. The box filled is lined up on the shelf by being moved by roller system and gravity; it is shown in Figure 9. The process of lifting and transporting has been eliminated.

Figure 8. Karakuri mechanism detail

Figure 9. Karakuri and racking system integration

The working posture after the design is shown in Figure 10. Thanks to the design, it became possible to work at the same height for up to four boxes. After the boxes complete their downward movement, they manually move the locking latch mechanism, which prevents the boxes from sliding out of the table, opening the way of the boxes and ensuring that they slide safely to the shelves.

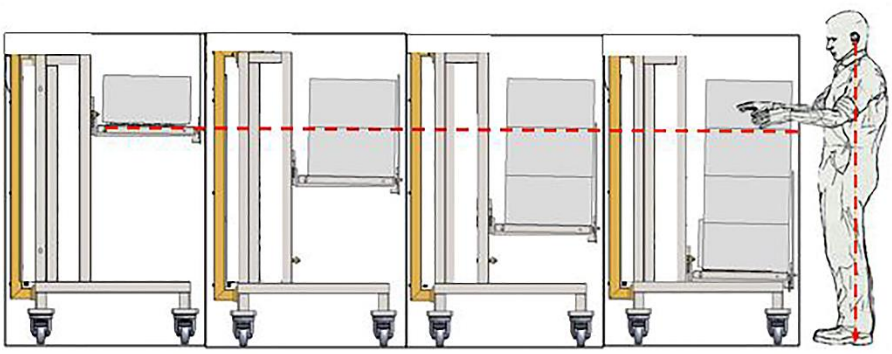


Figure 10. Working posture after the design

6. Result and Discussion

As a result of ergonomic risk assessment, the new shelf system which will work with the Karakuri principle on the existing production line whose risk status was found high was designed by taking anthropometric measurements and ergonomic body posture into account. Pre-design body postures were evaluated by being simulated. The mechanism designed to keep the operation with the minimum level of ergonomic risk was produced and started to be used. In Figure 11, working heights in the old version and after the mechanism design were simulated. In the first case, the 1st working height was 200 mm, the second working height was 430 mm, 3rd working height was 550 mm and 4th working height was 770 mm. Thanks to the mechanism design, the working height remained at a constant value of 1000 mm, within the green ergonomics zone indicated in Figure 11. The values which the graph peaked and bearing the numbers 2, 3, and 4 are the values measured when the worker first put the empty box. After the worker puts the empty box the system moves downward by itself, so the process of lifting and moving of 10 kg box was eliminated. The worker always puts the work pieces in boxes at the same height and after the box is filled, it goes down and moves according to the slope direction of the mechanism according to the Karakuri working principle.

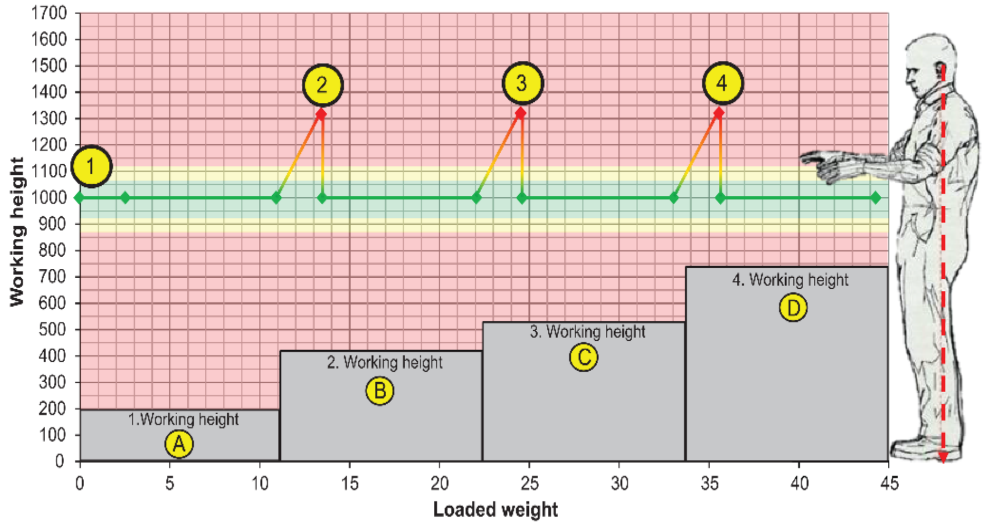
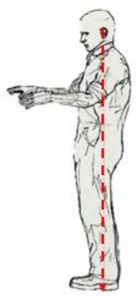


Figure11. Working heights in the old version and after the mechanism design

Table 4 shows the REBA evaluation results of the new shelf system after the Kaizen. Since the worker will work at the same height, work of the body with a leaning position disappeared, and he/she started to work with an upright posture. The neck slightly leaned forward, accordingly the Table A value is 1. As the box is placed on the lowest level and the legs are in the upright position, there is no bending movement on the lower parts, Table A value is 1. After the worker puts 2 kg parts, which he/she completed the production of, into the box, the box moves downward because of the weight, the load score is 0 since the box lifting and moving process is eliminated. The total A score is found as 2. The B score in the new situation will be 1 point since the angle of the upper arm will be lower than 20°, 1 point since the lower arm will work at an angle of 90°, and 1 point since there will be a 0°–15° bend in the wrist. As there will be no box carrying in the new situation, hand gripping of the part will be evaluated, and in this case, the gripping score is 0, since there will be a good handle and moderate grip strength. The B score is 2 according to these assessments. The score is 2 as the scores of A and B were combined in Table C. In addition to this score, an activity score of +1 was given, as repetitive works were performed at short intervals. In the new situation, the REBA score is 3 and the risk level is assessed as "Low load" (See Figure 2 for Tables A, B, and C). The high level of ergonomic risk was reduced with the help of the study and a more ergonomic working environment was provided for the workers.

Table 4. Determination of the REBA score after Kaizen

Body Posture	**Group A**				**Group B**			
		Movement	**Score**			**Movement**	**Score**	
	A-Body	Upright posture	1		B-Upper arm	<20 flexion or extension	1	
	A-Neck	0–20 flexion	1		B- Lower arm	60–100 flexion	1	
	A-Leg	Legs Bilateral weight, carrying, walking, or sitting	1		B-Wrist	0–15 flexion or extension	1	+1
	Group A Score		1		Group B Score		2	
	Load	2 kg	0	+1	Grip	Good	0	
	A Score		**2**		B Score		**2**	

C Score	**2**
Activity	1
REBA Score	**3**

It is seen that Karakuri studies in the literature are taking a box, part or any object from a certain point to another. The mechanism designed with this study has the ability to take the part box to three different positions. Furthermore, the effect of the Karakuri mechanism designed by simulating both anthropometric and ergonomic data on ergonomic workload was investigated and information was given about the data to be used during the design.

7. Conclusions

Evaluating working conditions in terms of ergonomics is increasingly becoming more of an issue. Inappropriate ergonomic working conditions increase the risk of musculoskeletal disorder formation. As a result of MSD, workforce losses and indirect cost increases are experienced, which weaken the competitive conditions in the business world.

Body sizes vary from individual to individual. Essentially, the points to be considered are that the person can be in a sitting position during the day when necessary and the person may need to perform some tasks by leaning or standing. Therefore, to ensure that a person can do the job without feeling tired or uncomfortable and without any decrease in performance and motivation throughout the day, the design should be made considering the human-machine harmony. In the study conducted, special emphasis is placed on the undeniable effect of ergonomics science on human health and the importance of the design factor is emphasized.

As part of the study, employees were observed in the situation at first, then ergonomic risk levels were determined using the REBA ergonomic risk assessment method. Kaizen (improvement) studies have been initiated in the work areas that have a "high" level of ergonomic risk and need to be improved. In this study, the mechanism working according to Karakuri working principle was designed by taking into account body postures for the production line where the box handling process is determined with an ergonomic risk score of 8. Body postures were simulated in accordance with the REBA method and the mechanism design was prepared in a three-dimensional design program. Thanks to the simulation, the mechanism could be designed in the most appropriate way to the ergonomic conditions before manufacturing, and in the new situation, a working environment suitable for both anthropometric and ergonomic body postures could be provided. Thus, ergonomic risk levels could be reduced to negligible levels and possible MSD could be prevented.

With the new mechanism designed according to Karakuri working principle, the 10 kg box handling process was eliminated. After the worker puts the finished 2 kg part into the empty box, the box moves to the lowest level without any carrying need due to the mechanism moving up from the lower level, and with the roller system and the slope of the mechanism, the box moves by sliding to the back of the shelf. The employee completes his/her work with a body posture in the upright position without lifting weights or leaning. Thus, the ergonomic risk situation, which was "high" in the current situation, could be reduced with the newly designed mechanism and an ergonomic workspace could be provided for the employee. In the new situation, the ergonomic workload score is "3" and the risk level is "low." At the same time, as the new mechanism will eliminate the lifting, carrying, and pushing works, the employee's distraction will be reduced, and thereby occupational accidents while working will decrease.

In addition to ergonomic improvements, as the manual transportation works of the employee are eliminated, the cycle time of the line, which was 120 s in the first state, decreased to 100 s after the use of the Karakuri mechanism, and the efficiency of the line increased by 17%.

Acknowledgments

None (company information is confidential).

Conflicts of Interest

No conflict of interest was declared by the authors.

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