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The Effect of Production Ergonomy on Product Quality in the Context of Built-in Oven Production Line

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Abstract

There are many studies discussing the issue of ergonomics in the context of sick leave and social expenditures. However, there are fewer studies linking production ergonomics with other factors such as quality and efficiency. It would be useful to discuss production ergonomics in a wider context. The study was carried out as a pilot study in a factory where a built-in oven was produced. The aim of the study is to show that there is a relationship between production ergonomics and the product quality produced in the factory. In the study, retrospective 20-week production line data were analyzed. As a result of the analysis, a series of quality errors were selected and the assembly tasks associated with these errors were determined. Aassembly tasks are classified by the company's Occupational Safety and Health Specialist as ergonomically appropriate or not ergonomically suitable for operators. When the difference between the number of errors related to the ergonomic categories is examined, it is found that there are three times more errors in ergonomically inappropriate tasks compared to ergonomically appropriate tasks. The work to be done to make the ergonomically inappropriate tasks suitable, the time plan and the responsible people were determined. The results of the study showed that there is a relationship between product quality and production ergonomics. The calculations in the study showed that the error rate would decrease by 90% in ergonomically optimized tasks; thus, business management has made a positive decision to invest in equipment to the relevant workstations. In return for the investment cost in the study, resources are used for value generating works and an increase in the number of correctly produced products is guaranteed.

1. INTRODUCTION

While production ergonomics is often associated with staff health and social expenditure, other factors that may be affected by inadequate ergonomics are rarely considered. The cost of improvements in production ergonomics is often compared to increased efficiency and quality gains. This study aims to focus on other possible savings and improvements from improved production ergonomics. The results will lead to a broader focus on management's perspective and a focus on production ergonomics in the context of the generally unattributed ergonomics-error rate. The results of the study aim to show that production ergonomics should be included more in the daily work and strategic works of the companies.

This pilot study focused on production ergonomics. The aim is to make production ergonomics an indicator that is continuously improved and monitored within the factory. In production ergonomics, there is a need to show what will be achieved after investments. As a result of the potential gains to be achieved, management's interest and participation in production ergonomics will increase; this will provide greater interest and funding for production ergonomics improvements.

The costs of product returns caused by quality defects because of the ergonomically impractical tasks of the assembly operators must be monitored by the factory management. In this way, a financial value can be obtained in order to compare the situation after improvement. These cost comparisons make it easier to

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present the importance of production ergonomics to management. Since the design of the product forms the basis for the ergonomic situation in the manufacturing business, it is equally important to forward the message to the product development departments.

In the start of this pilot study, the Company's objective is to facilitate communication on production ergonomics and to draw attention to the field of production ergonomics. After demonstrating the relationship between production ergonomics and quality results, the benefits of ergonomics can be defined as the reduction of costs caused by insufficient quality. The aim of the study is to convey the importance of production ergonomics to managers and product development department employees. It also provides additional data to confirm the link between production ergonomics and product quality. A deeper study is needed to clearly demonstrate the financial benefits of production ergonomics. The objectives of this study are as follows:

1. To demonstrate the relationship between production ergonomics and product quality in the context of built-in oven assembly
2. Convey the results of improvement and the importance of production ergonomics to managers and product development department employees

This study is considered as a pilot; possible benefits and constraints that are expected to be followed by ergonomics improvement studies are mentioned.

2. EFFECT OF PHYSICAL ERGONOMICS ON PRODUCT QUALITY

With the increase in the number of products in the market, production companies must be competitive in order to survive. The success of company in a competitive industrial market depends on improving employee health, efficiency and quality (Törnström et al., 2008). In order to ensure the continuity of companies in the competitive market, production systems are established to maximize profit by increasing efficiency and quality. In the meantime, ergonomics is often ignored. Ergonomics have become important in the industry as ergonomic non-conformities affect quality, cost and efficiency (Akay et al., 2003). At the same time, it is necessary to make the working environment ergonomically suitable to prevent physical and mental illnesses and to reduce operating costs (Şahin et al., 2017). Ergonomics integrated into a lean manufacturing system installed in a Brazilian automobile factory (Vieira et al., 2012). While the system includes 5S, quality control, kaizen and standardization, researchers added ergonomics to the system. As a result of the study, it was found that the rate of vehicles leaving the production line without the need for re-maintenance increased from 48% to 78% after the addition of ergonomics to the system. (Vieira et al., 2012). The positive effects of ergonomic improvements on quality and costs have emerged as a result of the studies. In a study conducted by Yeow and Sen (2006) in an electronics factory, it was observed that the quality errors detected in production decreased by 30% as a result of improvements aimed at improving low-cost physical ergonomics. At the same time, the reduction in quality errors that occurred in the end user was 11%. On the other hand, productivity increased by 50% and the factory's annual profit increased by USD 950,000.

A study by Falck (2009) at an automobile manufacturer has shown that an ergonomically inappropriate task causes more errors than an ergonomically suitable task. The study was started by mapping the ergonomic situation. The tasks are divided into three different classes according to their ergonomic status. These three classes are symbolized by traffic lights. Green light represents ergonomically good conditions; yellow light represents ergonomically neither good nor bad situations; red light represents poor ergonomically conditions. As many jobs as possible were received from each class, tasks were randomly selected. Then, the errors occurred during the tasks of this selected ergonomic classes were monitored. It was found that the time taken to complete each task was different between the classification levels. The longest tasks belong to the yellow class and the shortest tasks belong to the green class. The numbers are set so that a comparison can be made. As a result, it was found that there were fewer errors in green tasks compared to yellow and red tasks. A similar study was conducted by Almgren and Schauring (2012) at the Volvo Truck Manufacturing plant. Assembly tasks are divided into two categories as red and green tasks; yellow tasks were excluded from the analysis. As a result, the average quality error occurrence time in the red category assembly tasks is 12.68 errors/minute; the average quality error occurring time for assembly tasks in the green category was calculated as 4.79 errors/minute. When the ergonomic difficulty increases, the frequency of quality errors increases. These findings show that ergonomics has a significant effect on quality outputs.

The strong link between quality errors and high ergonomic risks has been demonstrated by other studies (Falck et al, 2010, Falck and Rosenqvist, 2014, Fritzsche et al., 2014). As a result of the studies carried out in Volvo car production plant in 2010, a strong relationship was found between inappropriate ergonomic conditions and quality defects. Of the 352 quality problems recorded in the production phase of three new car models, 23.5% were associated with ergonomic problems (Falck et al., 2010). In another study conducted in the automobile manufacturing plant, 47 assembly tasks were analyzed. As a result, the error rate was 55.1% for tasks with high ergonomic workload, 37.8% for tasks with medium ergonomic workload and 7.1% for tasks with low ergonomic workload (Falck and Rosenqvist, 2014).

Most ergonomists are concerned that ergonomic assessments are not carried out at the design stage. Ergonomic assessments are usually made after strategic decisions have been made, at a point where any changes will significantly increase costs. As a result, ergonomic improvement remains only in the size of small adaptations; the entire ergonomics process is seen as time-consuming and cost-effective. Another problem is that feedback caused by improper ergonomics persists in the form of sick leave, injuries, even a few years after the design process is completed. The relevance of these results to design is not clear at the management level. In addition, these feedbacks often do not reach the design team at all and therefore do not provide in-house learning (Dul and Neumann, 2009). Adjusting the workplace measurements according to the human body measurements will provide an increase in productivity (Eldem et al., 2019; Eldem, Sahin and Top, 2019).

According to a comparison by Auburn Engineers, an American consulting firm, the cost is 1% of the budget if ergonomics specialists are involved from the beginning; the inclusion of the system after the commissioning is a cost of 12% of the budget. If problems are addressed before the system is commissioned, changes are easier and less costly, making the total cost less (Hendrick, 2003).

3. REBA (RAPID ENTIRE BODY ASSESMENT) METHOD

REBA was proposed by Hignet and McAttamney (2000) as a requirement by observing the variable working positions of employees in the health care and other service industries in the UK. REBA is a quick and easy method to evaluate various work positions for work-related musculoskeletal disorders (Madani and Dabahneh, 2016). Divides the body into sections to be coded independently according to the motion planes and provides a scoring system for muscle activity throughout the body, in a stagnant, dynamic, fast changing or unstable manner and A handling score is used when manual handling occurs because the load is carried (Hignet and McAttamney, 2000). Only paper and pen are required when applying REBA (Madani and Dabahneh, 2016).

Before the application with some practice and after training REBA can be used by ergonomists and other practitioners (David, 2005). In Reba method, measurement of body posture joint angles is analyzed by observing force load and repetition of movements and frequency of posture change (Al Madani and Dababneh, 2016). Neck, trunk, upper and lower arms, leg and wrist positions are divided into certain value ranges. The score of each position corresponding to the evaluated anatomical areas increases as the segment moves away from the neutral position.

Table A score is the sum of the posture scores for the trunk, neck and leg and the load / force score (Figure 3.1). Group A includes 60 posture combinations of body, neck and leg positions (Table 3.1). The score obtained by adding the load / force score is between 1-9.

Table 3.1. *Reba Form A Table (Hedge, 2000)*

Table A		Neck											
		1				2				3			
	Legs	1	2	3	4	1	2	3	4	1	2	3	4
Trunk Posture Score	1	1	2	3	4	1	2	3	4	3	3	5	6
	2	2	3	4	5	3	4	5	6	4	5	6	7
	3	2	4	5	6	4	5	6	7	5	6	7	8
	4	3	5	6	7	5	6	7	8	6	7	8	9
	5	4	6	7	8	6	7	8	9	7	8	9	9

Neck Score

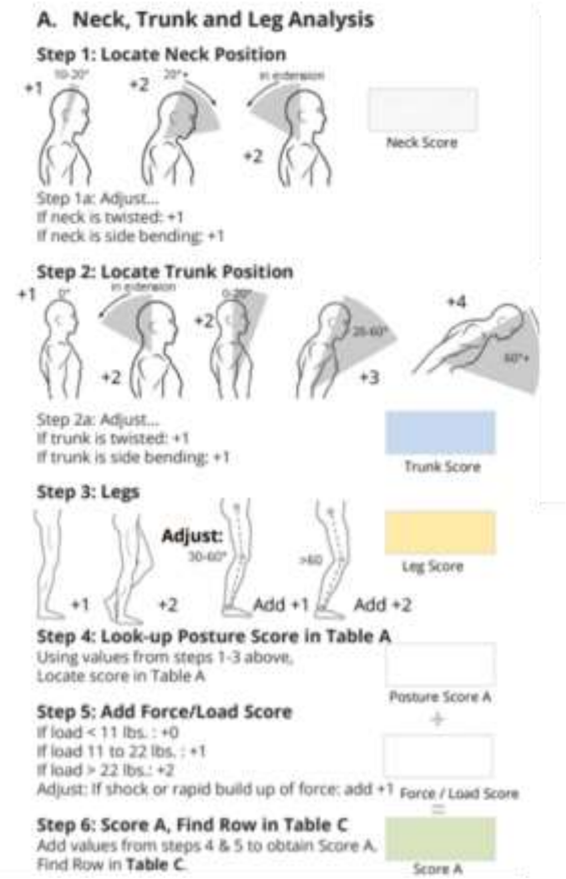

Figure 3.1. *Scores of the positions of the neck, trunk and legs (Hedge, 2000)*

Score B is the sum of the posture points for the upper arms, lower arms and wrists and the holding score for each hand (Figure 3.2). Group B has a total of 36 different posture combinations for the upper arms, lower arms and wrists (Table 3.2). The result score is obtained by obtaining the holding score.

Table 3.2. *Reba Form B Table (Hedge, 2000)*

Table B		Lower Arm					
		1			2		
	Wrist	1	2	3	1	2	3
Upper Arm Score	1	1	2	2	1	2	3
	2	1	2	3	2	3	4
	3	3	4	5	4	5	5
	4	4	5	5	5	6	7
	5	6	7	8	7	8	8
	6	7	8	8	8	9	9

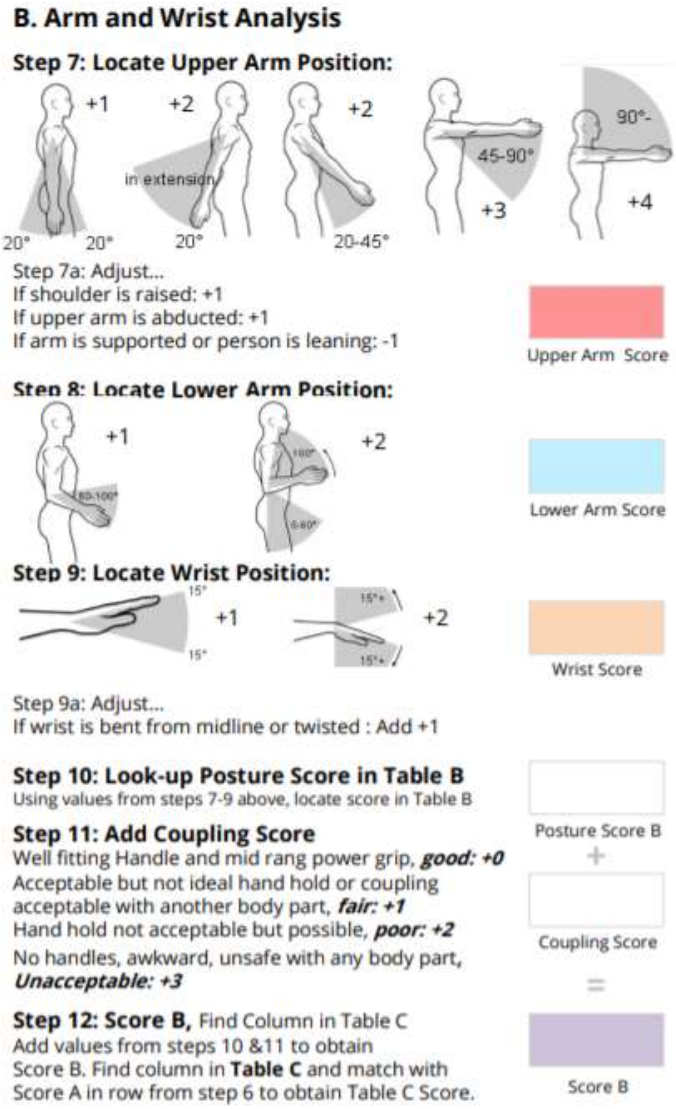

Figure 3.2. *Scores of lower-upper arm and wrist positions (Hedge, 2000)*

The A and B scores are combined in Table C (Table 3.3) to achieve a total of 144 combinations and finally an activity intensity score is added to achieve the ultimate REBA score (Figure 3.3).

***Table 3.3.** Reba Form C Table (Hedge, 2000)*

Score A	Table C											
	Score B											
	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Table C Score + Activity Score = REBA Score

Step 12: Score B, Find Column in Table C
Add values from steps 10 &11 to obtain
Score B. Find column in **Table C** and match with
Score A in row from step 6 to obtain Table C Score.

Score B

Step 13: Activity Score
+1 1 or more body parts are held for longer than 1 minute (static)
+1 Repeated small range actions (more than 4x per minute)
+1 Action causes rapid large range changes in postures or unstable base

***Figure 3.3.** Activity intensity score values (Hedge, 2000)*

Final score is evaluated in 4 different categories (Figure 3.4). Value [1-4] means low risk. Value [5-7] is considered as high risk; requires change in medium term. Value [8-10] means high risk. It requires a detailed examination of the working position and the commissioning of improvements. When the score [11 and above] is calculated, the position involves a very high risk. The necessary changes must be put into emergency operation.

Scoring
1 = Negligible Risk
2-3 = Low Risk. Change may be needed.
4-7 = Medium Risk. Further Investigate. Change Soon.
8-10 = High Risk. Investigate and Implement Change
11+ = Very High Risk. Implement Change

***Figure 3.4.** Reba evaluation final score rating (Hedge, 2000)*

4. METHODOLOGY

The pilot study consists of two main parts:

1. Data collection
2. Data Analysis

4.1. Data Collection

One of the 12 production lines in which the built-in oven is produced is identified as pilot band. The layout of the production line is shown in Figure 4.1.

Figure 4.1. *Built-in oven production line layout*

The production line consists of 18 main and 2 side stations. In the study, quality errors of the products produced in the assembly line in the past 20 weeks were collected. Errors were classified according to the station at which they occurred. The tasks performed at each station are classified as ergonomically suitable or ergonomically unsuitable for operators by the occupational safety and health specialist.

4.2. Data Analysis

Two stations with the highest number of error occurrences were detected. These are glasswool assembly and circulation motor grouping sheet assembly stations. At glasswool assembly station, operatör carries the glasswool-assemblied cavity on his shoulder and transport it to the sliding belt.

While carrying the cavity over his shoulder, the operator cannot carry out the task of checking the quality of the enamel inside the cavity defined for this station. When the quality control results of the products are evaluated, a high rate of enamel defects in cavity is encountered. If the operator is allowed to visually check the inside of the cavity during transport, the defective cavities can be sorted out at this station.
REBA evaluation of the station was completed (Figure 4.2). As a result of the evaluation, REBA score was calculated as 9. The station is not ergonomically suitable; detailed review and necessary improvements are needed. For this purpose, an arrangement has been designed to facilitate the operator to transport the cavity to the sliding belt.

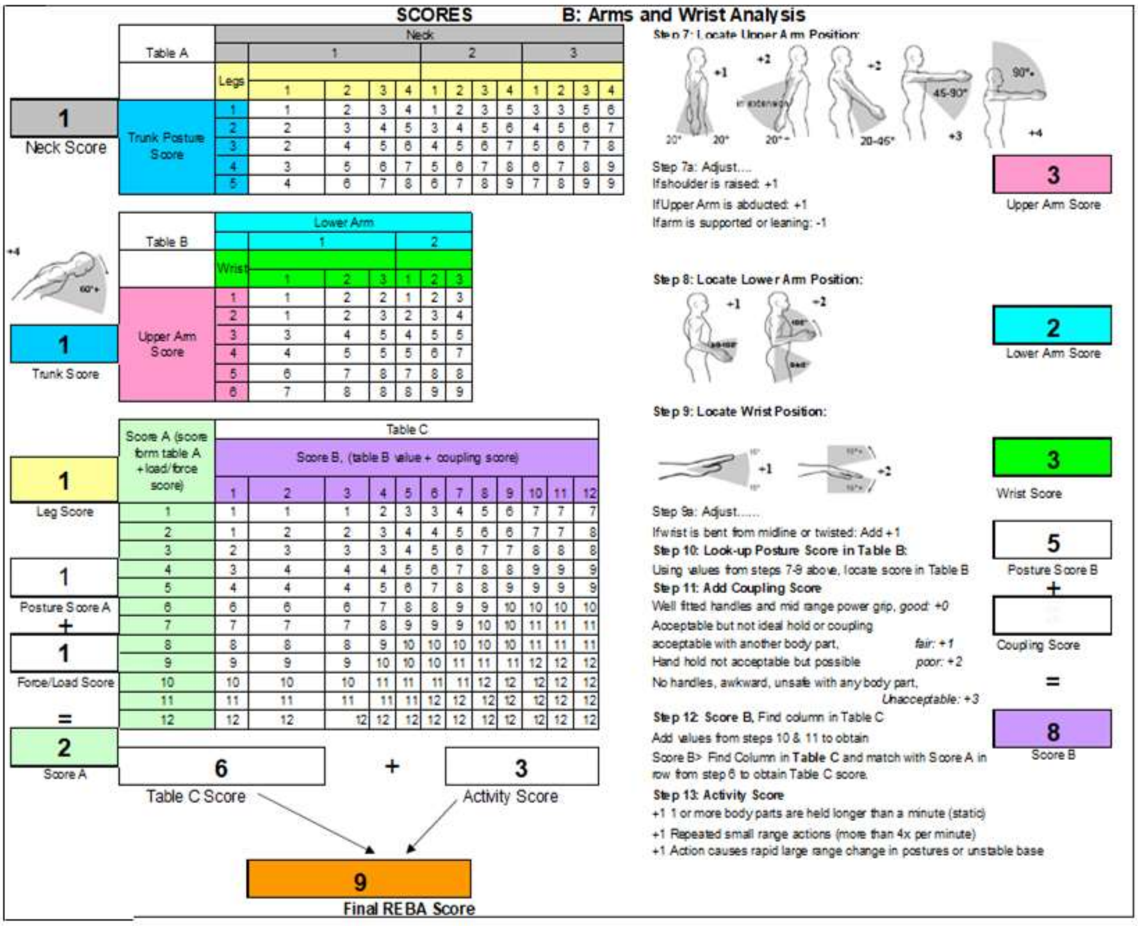

Figure 4.2. *REBA evaluation of glasswool assembly station*

Latched manipulator investment was made to the station for improvement (Figure 4.3). Cavity load was lifted from operator.

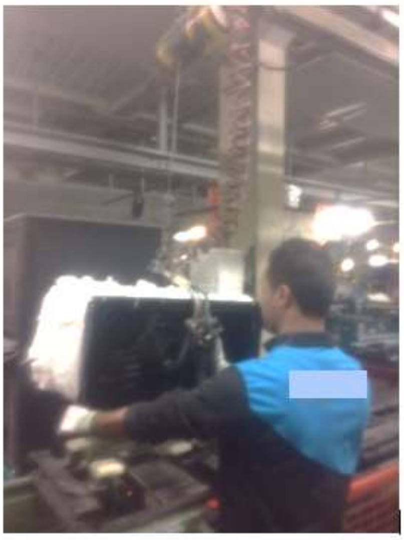

Figure 4.3. *Moving the cavity with the help of latched manipulator*

As a result of the REBA Assessment after the improvement, the risk score was calculated as 3 (Figure 4.4).

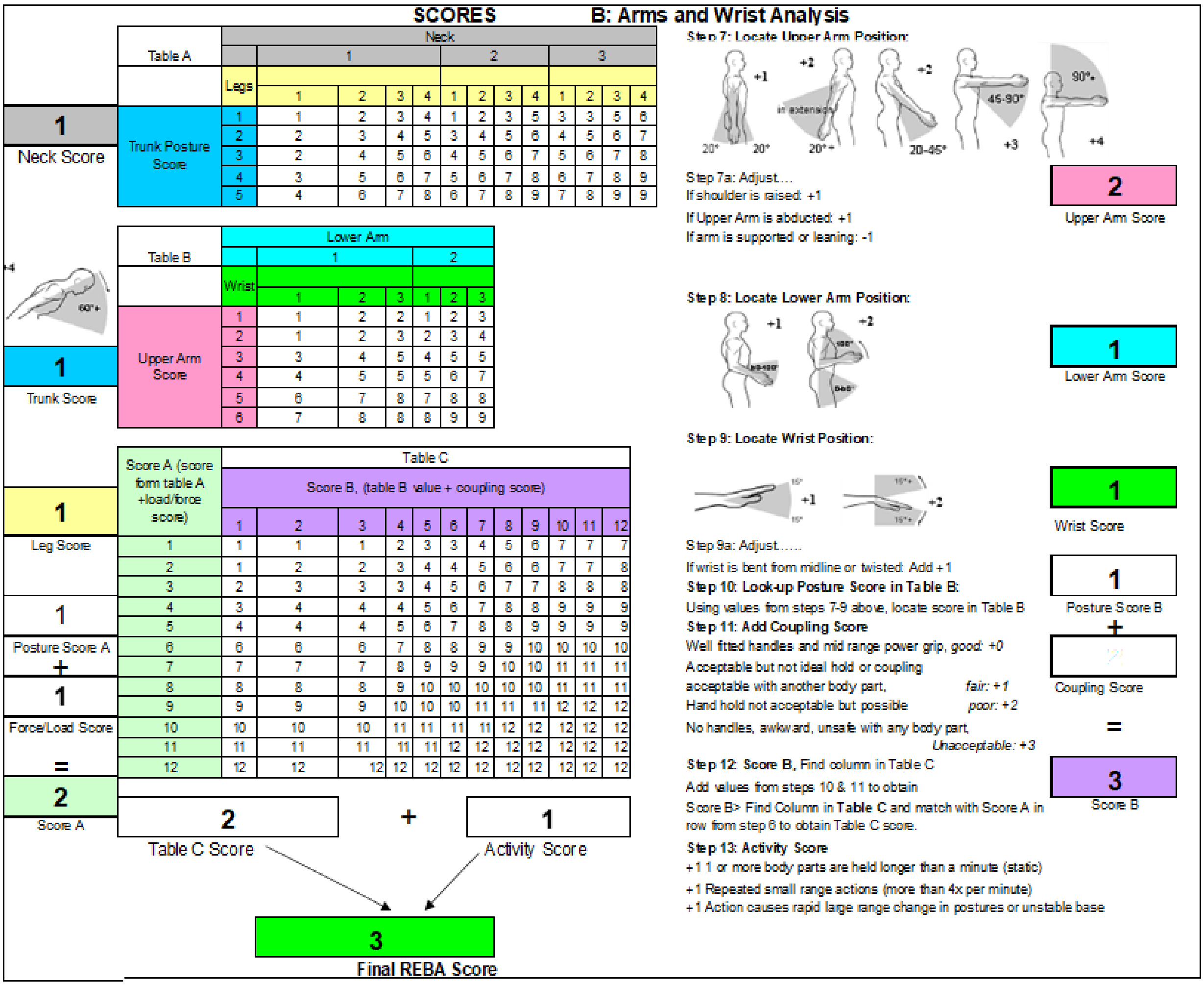

Figure 4.4. *REBA evaluation at the glasswool assembly station after improvement*

The cavity is held by the latch of the manipulator and the cavity is raised to the eye level of the operator by means of the handle. Since the operator can easily see inside of the cavity, it can easily detect enamel defects and defective cavities can be separated at this station.

The second station with the highest quality errors in the study is circulation motor grouping sheet assembly station (Figure 4.5). In this station, the operator bends to group the enamel-coated rectangular sheet into the frame and throws 4 screws, one in each corner. During operation, the circulation motor grouping sheet cannot be grouped properly as the screw enters the target point mostly inclined. The improperly grouped circulation motor grouping sheet causes a disturbing noise during operation of the built-in oven. As a result of the first REBA evaluation at the relevant station, the REBA score was calculated as 7.

Figure 4.5. *Circulation motor grouping sheet assembly operation*

A mechanism was used to raise the station to the level and angle at which the operator can easily screw (Figure 4.6). The device is controlled by the foot pedal. The cavity is held up by the 2 suction cups in the mechanism. Then, with the help of servo motors connected to the device, it keeps the cavity up and inclined at an angle suitable for the operator's viewing angle. When the assembly is completed, the device is commanded again by using the foot pedal.The cavity is lowered and released by the mechanism to the assembly line.

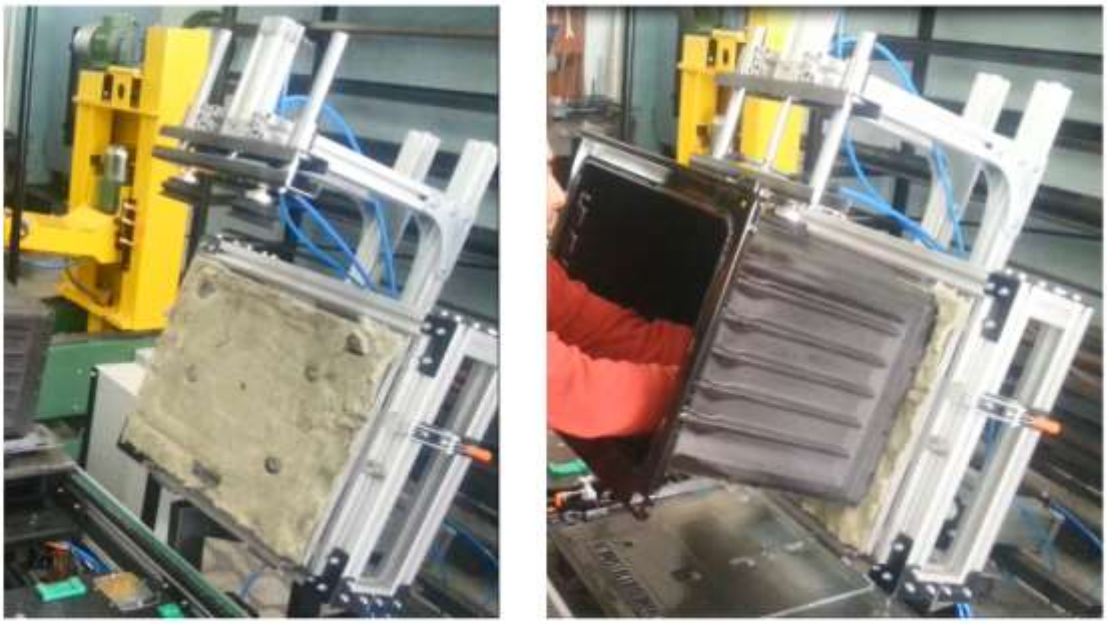

Figure 4.6. *Circulation motor grouping sheet assembly at the right height and angle*

At the respective station, the device grips and lifts the cavity with the arms on both sides and inclines backwards. In this way, the operator clearly and easily sees the points to be screwed. REBA score of the station after improvement was calculated as 3; ergonomic risk ratio is low. The number of errors occurred after the improvements were examined. It has been observed that the number of errors occurring at the relevant station decreased by 90%.

5. RESULTS

Analyzes in the study showed that the error rate decreased by 90% in ergonomically optimized tasks. By demonstrating the relationship between production ergonomics and quality results, the benefits of ergonomics can be defined as the reduced cost of poor quality for companies. This pilot study demonstrates the potential to improve production ergonomics in plants to manufacturing companies. It has also contributed to the diversity of studies demonstrating the link between production ergonomics and factors other than health and social spending. Only physical ergonomics was included in the study. The parts of cognitive ergonomics such as mental stress, information processing and autonomy were not included in the study.

In summary, two objectives were aimed in this study:

1. To demonstrate the relationship between production ergonomics and product quality in the context of built-in oven assembly
2. Present the results of improvement and the importance of production ergonomics to managers and product development department employees.

It has been shown that there is a relationship between production ergonomics and quality results since the error rate detected per product is reduced in ergonomically optimized stations.

In order to achieve the second objective, the results of the study must be returned as financial gain. This gain is calculated by adding up the cost of man-hours spent on repairing the defects and the cost of the material used. The reduction in error rate associated with the improvement of ergonomically inappropriate tasks and reduction in repair costs are presented as post-improvement savings. The savings from the reduction in repair costs can be used to increase ergonomic improvements.

Since no studies on cognitive ergonomics have been conducted in the factory so far, this field has been avoided. Further studies in the field of cognitive ergonomics are necessary. The ergonomic status in production has been scored by REBA method by experts in Production Engineering Management and Occupational Safety and Health; tasks completed in the assembly stations is divided into tasks and sub-tasks.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors

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