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Research Article

Ergonomic Risk Assessment in Automotive Welding Lines and Comparison of Method Output

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ARTICLE INFO

Article history:

Received 27 June 2021
Received in revised form 17 August 2021
Accepted 17 August 2021
Available online 28 September 2021

Keywords:

Automotive welding tasks, Ergonomic risk assessment methods, Improvements, Musculoskeletal disorders, Occupational health.

Doi: *10.24012/dumf.1002172*

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ABSTRACT

There are many studies in the literature on ergonomic risk assessment, but there are limited studies on the Germany Federal Institute for Occupational Safety and Health (BAUA) method. The aim of this study is to examine the compatibility between Rapid Entire Body Assessment (REBA) and BAUA and the ability of the methods to correctly classify the risk level of risky tasks, and to make ergonomic improvements to reduce the physical strains. The welding processes of the automotive company were examined and ergonomic risk assessment was made by using REBA and BAUA for four tasks with the most strains. The evaluation criteria and results of the methods were compared and improvement suggestions were developed to reduce ergonomic risks. The results of this study approve that the risk output of both methods depends on the exposures considered and their greatness. Both REBA and BAUA are used for work done using the whole body. The biggest difference between the methods is that the time weight evaluation is always used in the BAUA, and the time is not taken into account in the REBA. Since the aim of ergonomics studies is to eliminate the risks of musculoskeletal disorders (MSD), the results that will show where to start the improvement studies should be determined in the most accurate way and no factors should be overlooked. People who will conduct ergonomic risk assessment studies for welding employees were informed about the advantages and disadvantages of both methods and suggestions were given.

Introduction

Effectively using human resources who try to adapt to rapidly technological developments and production conditions, is of great importance for the enterprises. In the rapidly increasing competitive environment, companies that want to increase their production power, have started to find new methods for productivity-enhancing studies. One of the biggest increases within the scope of these studies are mechanization and automation however, over time, it has been found that this is also not enough. To improve production systems and improve product quality, it is not sufficient to take into account only technical parameters that affect system conditioning and quality [1]. Because in the production industry where human resources are used predominantly the productivity changes not only with the improvement of machinery, but also with the effect of the human factor [2]. This traditional ergonomics approach that focuses on physical and mental factors is called micro ergonomics [3].

Many studies have been conducted examining human-machine interaction and environment in order to prevent the decrease in the importance of the human factor against machines and developing methods and to increase employee productivity in the rapidly developing field of ergonomics [4]. As a result of developing technological studies, the need for manpower in many areas continues even the production processes are facilitated. MSD are a possible problem when working with awkward postures in tasks with high physical workload [5].

In the labor-intensive automotive industry, ergonomic improvements in the working environment are very important for both the health of the employees and the increase of production efficiency [6]. To achieve work efficiency, it is necessary to reduce forceful movements and improve inappropriate posture [7]. The cost resulting from MSD is high.

MSD may occur in employees exposed to physical risk factors such as awkward working position, working environment or lifting excessive load [8]. If ergonomic arrangements are not made in such working environments, these disturbances may increase and, as a result, workforce losses may be experienced. Costs arise due to loss of workforce, labor treatment, compensation payment, production inefficiency and poor quality. These results reveal how important ergonomics studies are. The most important step in reducing and preventing MSD in the work environment is the determination and evaluation of ergonomic risks [9]. If there is a deviation in the posture of one or more limbs according to the notral body posture, this is defined as awkward posture [5]. MSD are caused by static postures or repetitive-rapid movements, awkward postures that force the body, tasks that do not allow appropriate movement, etc. [10-12]. This, in turn, leads to material and moral losses for employees, employers and the state [13].

Although it is tried to be integrated with robots in welding processes in the automotive industry, manpower is still used intensively. Every task where manpower is used, causes physical strains in the employee and accordingly MSD. By performing ergonomic risk analysis, challenging situations for the employee should be determined and ergonomic solutions should be applied.

In the literature reviews, it is seen that many scientific methods have been carried out and academic studies have been developed for the ergonomic risk assessment for work-related MSD, but there are many problems during and after the application in practice. In the ergonomic risk exposure assessment studies performed by occupational safety, the choice of method, observation, analyse and interpretation stages cause the evaluator to hesitate and have difficulties in many issues [14].

Methods used for ergonomic risk assessment of task performed using the whole body are Quick Exposure Assessment (QEC), Ovako Working Postures Analysing System (OWAS), European Assembly Analysis (EAWS), REBA and BAUA (Bundesanstalt Für Arbeitsschutz und Arbeitsmedizin - Germany Federal Institute for Occupational Safety and Health). Observational techniques created to determine the risk exposure and make quantitative evaluations are the most used methods due to their ease of use, low cost and flexibility [15].

In welding works, manual, lifting, carrying and placing tasks are usually performed using the whole body. For this reason, methods that allow whole body evaluation can be used for analysis of employees in welding works.

In this study, ergonomic physical workload measurements were made using REBA that takes into account the postures of whole body, load, repetitive movement and compound interaction, in which observation and video recording is sufficient to collect data and BAUA, which allows detailed analysis by taking into account the duration and frequency of the work according to the type of work (lifting, holding, carrying and load pulling-pushing) in an automotive sub-industrial company. The improvement proposals to reduce the risks were suggested. Besides these, the results of the methods were compared with this study. It is important to work with the appropriate method for determining the ergonomic risk levels. It is aimed to give information about the characteristics of the methods to those who will measure the physical workload for welding works performed using the whole body.

Literature Review

REBA method is a practical method frequently used in the field of ergonomics. For this reason, not all of the studies in which the method is applied have been mentioned, but only the applications in the automotive industry have been examined. Hignett and McAtamney [16] examined in their study 600 working postures of people working in some industries. As a result of the study, REBA one of the widely used ergonomic analysis methods has been developed. Atıcı et al. [17] conducted the analysis of awkward working positions in a cable manufacturing factories in the automotive industry, by using the REBA. With the analysis made, the strains occurring in the employee were determined and, improvements were proposed to reduce these strains. Ulutaş and Gündüz [18] identified problems associated with MSD in a factory where cable is manufactured. Rapid Exposure Assessment (REA) and REBA were applied at two specific workstations. After these analyzes, new applications have been developed to improve physical risk factors. After the arrangements, re-analyzes were made and the efficiency of the results obtained was evaluated. Ertaş and Bulut [19] determined ergonomically awkward situations and, made improvements to eliminate the inconveniences with the analysis performed in the press section of a company that manufactures clutches. Thus, employee and task alignment has increased employee competence and productivity and, a 5% improvement has been achieved in press production times on a product basis. In his study, Sakalar [20] evaluated the stations from an ergonomic perspective using the REBA on the assembly line in a company that manufactures motor oil pumps and, identified the workstation with the highest physical workload and identified the most common MSD.

When looking at the studies, it is seen that by using BAUA, there are few studies in the literature. 70% of the researches have been published in German language [21]. Sevimli et al. [22] conducted an ergonomic risk analysis of the working conditions of those working in the rice packaging company. The ergonomic risk analysis of 6 stations in the production lines was made according to REBA and BAUA. After the examination, necessary measures were taken and, ergonomic risks were reduced. Acar et al. [5] conducted an ergonomic risk analysis by using REBA and BAUA on the solid fuel stove production assembly line. After the suggested improvements, they improved the REBA and BAUA scores up to 70% and, determined that the financial aspect of the suggestions was at a feasible level in order to provide a healthier working environment for the employees. Ülker [21] used the BAUA in order to determine the strains encountered during the transportation of parts in the production of furniture and, made suggestions to reduce the workload.

Yüce [23] examined the task done by automotive service employees and, ergonomic damage and risk exposure levels were examined with the help of ergonomic risk assessments. Berber [24] examined the packaging and warehouse shipping departments of a food production factory that produces sugar. For the packaging department, REBA, BAUA, NIOSH and Snook ergonomic risk assessment methods were used and for the warehouse dispatch department Snook and BAUA ergonomic risk assessment methods were used and, at the end of the study improvement suggestions have been made.

It is seen that the studies in the automotive industry are generally carried out on the assembly line by using the REBA. This study was done on welding lines. Measurements were made by using REBA and BAUA which are used for ergonomic risk analysis of the work performed by using the whole body, improvement work has been done and the results of the two methods were compared. Thus, the comparison results of REBA and BAUA shown in practice, will contribute to the literature.

Method

Working posture disorders caused by some ergonomic risk factors in the working environment, are of great importance in terms of occupational health and safety. Awkward working posture is defined as one of the main causes of MSD. With the analysis of working postures, the level of exposure to ergonomic risk factors can be determined, high-risk tasks can be identified and the risk level can be reduced by performing remedial studies for risky tasks [22]. Mostly observational methods are used when making an ergonomic risk analysis. It is seen that many risk assessment methods are used when the studies in the literature are examined. These methods differ according to the body part used during the study and other factors that paid attention [25].

Rapid Entire Body Assessment (REBA)

The REBA method developed by Hignett and McAttamney, is a method that determines the risk levels of postures depending on the loads on the body, neck, leg, upper arm, lower arm and wrists of the employee and the static / dynamic posture during a working]16]. 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 [26].

The body parts are divided into two groups as A and B when determining the REBA score of a working posture according to the REBA:

- Group A: Body, Neck and Leg
- Group B: Upper arm, Lower arm and Wrists

A score consisting of the combination of these scores is determined with the help of Figure 1 (Table A) given in by determining the individual scores of the trunk, neck and legs. A score is obtained by adding the Carried Load / Force score to this score. A score consisting of the combination of these scores is determined with the help of Table (B) given

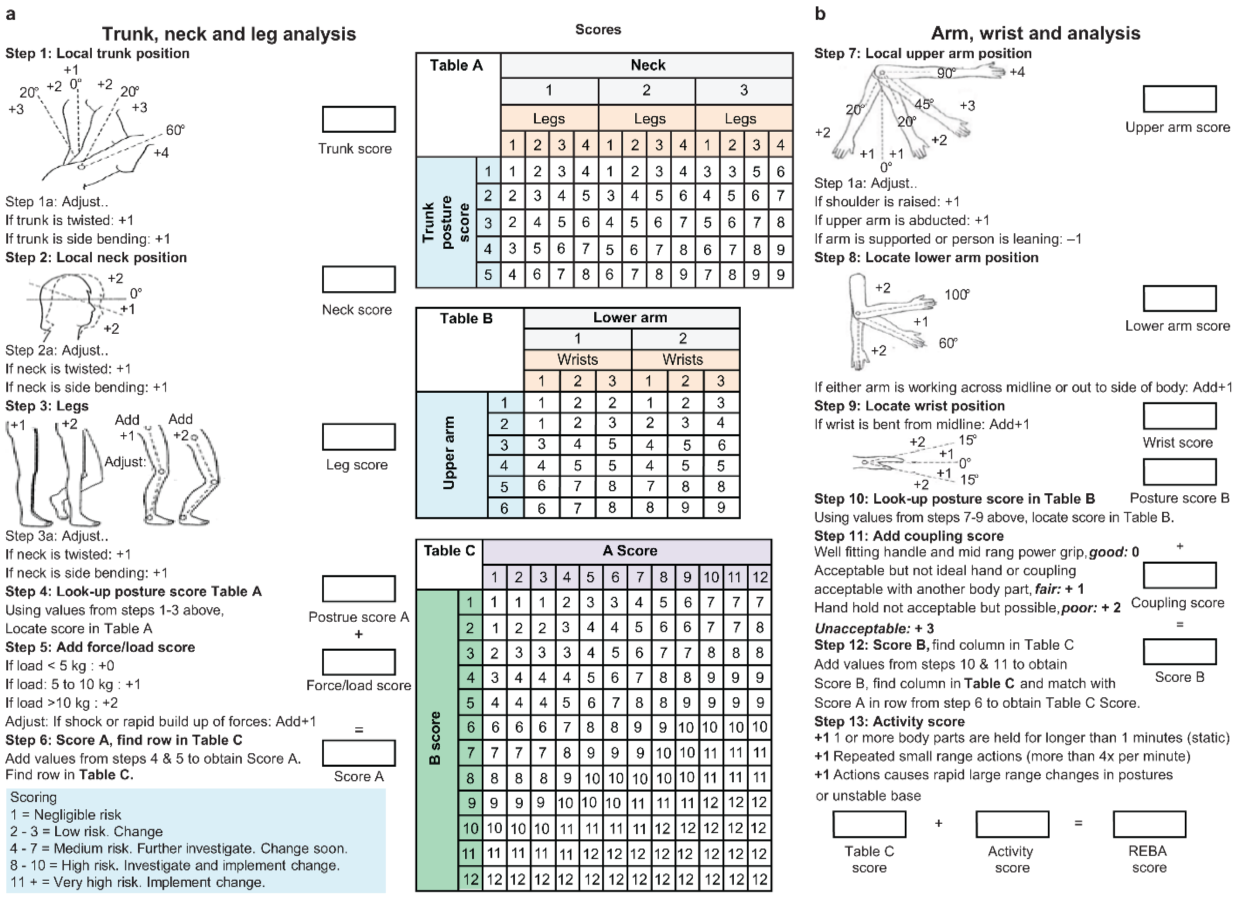


Figure 1. REBA analysis system [16].

in Figure 1 by determining the scores of the upper arm, lower arm and wrist separately. Score B is obtained by adding the coupling score to this score [27].

Figure 1 shows the REBA implementation steps. The score A is obtained by adding the load / force score to the score obtained from Table A. The score B is obtained by adding the coupling score to the score obtained from Table B. In the next stage, the C score is obtained by overlapping the A and B scores on Table C (See Figure 1 for REBA Table A, B and C). Finally, a single REBA score is obtained by adding the activity score to the C score [28]. The REBA score takes a value between 1 and 15. The degrees of these scores, risk levels and measures to be taken, are shown in Table 1.

Table 1. REBA risk levels.

Level	REBA score	Risk level	Measurement
0	1	Negligible	Not necessary
1	2-3	Low	Change may be needed
2	4-7	Mid	Change soon
3	8-10	High	Investigate and implement change
4	11-15	Very high	Implement change

Evaluation Method of the Germany Federal Institute for Occupational Safety and Health (BAUA)

This method developed by the Germany Federal Institute for Occupational Safety and Health is ensuring the evaluation according to scientific measurements of the strain limit of holding-lifting and transport tasks (LMM-1, Leitmerkmalmethoden, Key feature methods), push-pull tasks (LMM-2) and manual handling tasks (LMM-3), taking into account legal requirements. It provides the opportunity to be evaluated according to the criteria [29]. BAUA is used for manual holding and placing task or for various lifting and displacement operations [22]. The criteria and scores considered, vary according to the type of task performed. The risk coefficient is calculated as a result of the evaluation. The steps of the method are detailed below.

The most critical point of this method is the calculation of the time weighting score (TWS). For TWS, it is first necessary to decide whether the task is lifting-relocating, holding or carrying. In determining the TWS, the number of daily work done in lifting-displacement, the holding time while doing the work in one day in holding and the distance traveled while doing the work in transport determine the TWS.

BAUA (LMM-1) Steps for Holding, Lifting, Transportation Works

Step 1: Determining the TWS

When determining the TWS, it is necessary to decide whether it is holding, lifting-displacement or holding-transport work [5]. The TWS is determined by taking into account the number of repetitions in a day for lifting-displacement works, the total number of holding per day for holding works, and the total distance during the transportation process in a day [30]. The TWS are shown in Table 2.

Step 2: In step 2, (A) the load weighting score, (B) posture and load position weighting score and (C) application conditions score are determined. Table 2 shows how to score for step 2.

Table 2. BAUA (LMM-1) steps for holding, lifting, transportation works [31].

LMM-1 TWS

Lifting and Relocation (<5s)		Holding(>5s)		Transport(>5s)	
Number of work done in a day	TWS	Total time in one day	TWS	Total distance in one day	TWS
<10	1	>5 min.	1	<300 m	1
10<…<40	2	5<…<15 min.	2	300<….<1000 m	2
40<….<200	4	15<….<60 min.	4	1<…<4 km	4
200<…<500	6	1<…<2 hr	6	4<…<8 km	6
500<…<1000	8	2<…<4 hr	8	8<…<16 km	8
≥1000	10	≥4 hr	10	≥16 km	10

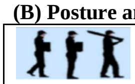
(A) Load weighting score

Active force (male)	Load weighting score	Active force (female)	Load weighting score
<10 kg	1	<5 kg	1
10<…<20 kg	2	5<…<10 kg	2
20<…<30 kg	4	10<…<15 kg	4
30<…<40 kg	7	15<…<25 kg	7
≥40 kg	25	≥25 kg	25

(C) Application conditions weighting score

Application conditions	**Weight score**
Good ergonomic conditions; e.g. sufficient space, unobstructed work area.	0
Limited mobility, poor ergonomic conditions; e.g. low ceiling and, less than 1.5 m^2 working area.	1
Very restricted freedom of movement or variable center of gravity of the load.	2

(B) Posture and load position weighting score

	The top of the body is upright, cannot be turned/ Load on the body (+1)
	Very slight bending or turning the upper body/ Load on or near the body (+2)
	Excessive bending down or forward / Turning the upper part of the body (+4)
	Turning the upper part of the body when leaning too far forward/Squatting (+8)

Step 3: Determining the LMM-1 results score

LMM-1 risk factor; It is calculated by adding the scores of all conditions determined in Step 2 and, multiplying it by the TWS (Equation 1).

$$LMM - 1\ risk\ factor = TWS * (A + B + C) \qquad (1)$$

BAUA (LMM-2) Steps for Push-Pull Works

Step 1: Determining the TWS

Evaluating TWS, the distance at once (less than or more than 5 meters), the total number of work performed if the distance covered is less than 5 meters, and the daily total distance if it is more than 5 meters [29]. The evaluation details of the TWS are shown in Table 3.

Step 2: In step 2, (A) the auxiliary tool weighting score, (B) the movement speed weighting score, (C) the body position weighting score and (D) application conditions weighting score are determined. Table 3 shows how to score for step 2.

Step 3: Determining the LMM-2 result score

LMM-2 risk factor; It is calculated by adding the scores of all conditions determined in Step 2 and, multiplying by the TWS (Equation 2). Assuming that the performance of a female is lower than of a male in the result evaluation, the result will be multiplied by a factor of 1.3 for female employees [22].

$$LMM - 2\ risk\ factor = TWS * (A + B + C + D) * 1.3 \qquad (2)$$

Table 3. BAUA (LMM-2) steps for push-pull works [31].

LMM-2 TWS

Push-pull for short distances or push-pull with frequent stops (<5m at a time)		Push and pull activities over long distances (> 5m at a time)	
Work performed in a day		Total in one day	
Pcs per day	Score	Daily total distance	Score
< 10	1	< 300 m	1
10<…<40	2	300 m<…<1 km	2
40<…<200	4	1 km<…<4 km	4
200<…<500	6	4 km<…<8 km	6
500<…<1000	8	8 km<…<10 km	8
>1000	10	>16 km	10

(A) Auxiliary tool weighting score

	Roll loading without tools	Wheel barrow	Wheel table	Pallet truck, forklift	Manipulator
Mass to move (Rolling)					
< 50 kg	0.5	0.5	0.5	0.5	0.5
50 kg<…<100 kg	1	1	1	1	1
100 kg<…<200 kg	1.5	2	2	1.5	2
200 kg<…<300 kg	2	4	3	2	4
300 kg<…<400 kg	3		4	3	
400 kg<…<600 kg	4		5	4	
600 kg<…<1000 kg	5			5	
> 1000 kg					
Sliding					
10 kg<…<25 kg	2				
25 kg<…<50 kg	4				
> 50 kg					

(B) Movement speed weighting score

Position sensitivity	Movement speed	
	Slow	Speed
	< 0.8 m/s	0.8-1.3 m/s
Minor: Movement way is arbitrary.	1	2
Major: The place where the load will be placed is definite.	2	4

(C) Body position weighting score

	Body is upright, there is no turn (+1)
	Upper body slightly bent forward or slightly twisted (One-Way Pull) (+2)
	Body is too skewed in the direction of movement, kneeling, crouching (+3)
	Skewing and turning together (+4)

(D) Application conditions weighting score

Application conditions	Weight Score
Good: The flooring is stable and flat, not slippery; dry; no slope.	1
Limited: The flooring is not flat, it is dirty, softly; Inclined up to 2°.	2
Difficult: Non fixed and unstable road paved with rough stones.	4
Very difficult: Steps and stairs on the road,all limited and difficult conditions exist together	8

BAUA (LMM-3) Steps for Manual Holding

The LMM-3 risk assessment method is used for works involving medium effort and normal work. These works are generally performed by standing with moderate force and therefore cause static load accumulation on legs, back and shoulders as well as hand and arm muscle loads due to repetitive movements [23].

Step 1: Determining the TWS

The TWS is found by using table shown in Table 4, according to the process time determined by calculating the total duration of the handwork performed during a shift.

Step 2: In step 2, (A) weighting score of the finger / hand according to holding or transport, (B) the weighting value of force transmission and holding conditions, (C) hand / arm position and movement weighting score, (D) work organization value weighting score, (E) the weighting value of the application conditions and (F) body posture weighting score are determined. Table 5 and Table 6 show how to score for step 2.

Table 4. LMM-3 TWS [31].

Process total time	1	2	3	4	5	6	7	8	9	10
TWS	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5

Table 5. BAUA (LMM-3) steps (A&B) for manual holding [31].

(A) Weighting value of the finger / hand according to holding or carrying

Force in the finger or hand (types)		Holding					Transport				
		Average Holding Time					Average repetition movement				
		Seconds per minute					Repetitions per minute				
		60-31	30-16	15-20	<4	<1	1-4	5-15	16-30	31-60	>60
Level	Identification and typical examples	Weight Score									
Low	Very low Force	2	1	0.5	0		0	0.5	1	2	3
	Low Force	3	1.5	1	0		0	1	1.5	3	5
	Medium Force	5	2	1	0		0.5	1	2	5	8
	Big strength	8	4	2	0.5		1	2	4	8	13
	Very Big Force	12	6	3	1		1	3	6	12	21
	Peak Force	19	9	4	1		2	4	9	19	33
High	Hit: e.g. with the thumb, hand, or ball of the punch	-	-	-	1		1	3	6	12	21
The higher score (left and right hands separately) should be used to calculate the total score rating values		Rating points of force application:				Left hand:			Right hand:		

(B) Force transmission / holding conditions weighting score

Force transmission, holding conditions	Score
Optimum force transmission, easy to hold work objects	0
Limited force transmission, greater holding forces required	2
Difficult to transmission (slippery, soft, sharp edges)	4

Step 3: Determining the LMM-3 result score

LMM-3 risk factor; the scores of all conditions determined in Step 2 are summed and calculated by multiplying by the TWS (Equation 3) [23].

$$LMM-3\ risk\ factor = TWS * (A + B + C + D + E + F) \quad (3)$$

Risk scores calculated according to all three BAUA LMM methods are evaluated according to the risk rating table shown in Table 7, and measures should be taken according to risk scores ranging from low to high load between 1-4.

Table 6. BAUA (LMM-3) steps (C, D, E & F) for manual holding [31].

(C) Hand / arm position and movement weighting score	
	Good: positions or movements of joints in the middle (relaxation) range
	Limited: occasional range of motion at the limit of positions (+1)
	Impractical: Frequent positions at the border of the limits range of motion (+2)
	Poor: fixed positions of the joints at the border of their range of motion or movements (+3)

(D) Work organization weighting score	Score
Frequent variation of load situation	0
Rare variation of load situation	1
No/hardly any variation of load situation	2

(E) Application conditions weighting score	Score
Good: reliable recognition of detail, no dazzle, good climatic conditions	0
Limits: impaired detail recognition, draughts, cold, wet	1

(F) Body posture weighting score determination	
	Good: alternation of sitting and standing is possible/
	Limited: trunk with slight inclination of the body towards the area of action, occasional gripping above shoulder height (+1)
	Unfavorable: trunk clearly inclined forward posture for detail recognition, frequent gripping above shoulder height (+2)
	Poor: trunk severely twisted and inclined forward (+5)

Table 7. BAUA risk rating table [31].

Risk	Field	Risk Score	Assessment
1		< 10	Low load; health is unlikely to occur.
2		10≤…<25	Medium load; Physical overload is possible for less flexibility persons.
3		25≤…<50	High load; normally, physical overload.
4		≥50	Very high load; physical overload is likely to appear.

Application

In this study, evaluation and improvement studies were carried out on the welding line where the physical stress is the highest. These are manual welding line using fixed spot machine, welding line with gun, arc welding repair line, and pedal welding line. Although there is more than one employee performing each operation in the enterprise, since the way of operation does not differ between employees, REBA and BAUA analysis were performed by randomly selecting an employee in the production line. First of all, the employees in the designated areas were observed, and their body position during the task were evaluated in detail by taking photos over video recordings.

In a welding line, an employee does more than one type of work at the same time, according to the task sequence. Body posture is not always in the same position and changes in a static way. When evaluating with the REBA, each body posture of the employee was evaluated according to the rules of the method and the highest score was taken into account in order to determine the highest workload.

For the evaluation with BAUA, first of all, the type of work was determined and it was determined which of the LMM-1, LMM-2 or LMM-3 groups would be used. Risk scores were found by evaluating the workload according to the appropriate technique.

Fixed Spot Welding Line

Welding process is performed by applying electric current and pressure to the part placed in the fixed spot machine. The employee takes the part from the hanger, places it on the machine and completes the process by holding the part with one hand and pushing the start button with the other. The tasks in the manual welding line are manual welding in the fixed spot machine, part handling in intermediate processes and part hanging trolley pushing. Employees' body postures during the operations are shown in Figure 2.

Figure 2. Manual welding line. (a) manual welding in the fixed spot machine, (b) part handling in Intermediate processes, (c) part hanging trolley pushing.

a. Manual welding in the fixed spot machine: After the employee places the part in the spot machine, he pushes the start button with his left hand and performs 4 spot welding sequentially (Figure 2a). Part weight is 2.8 kg. REBA score is given in Figure 3. The result of the evaluation is REBA score of 7. It is assessed as "medium level" ergonomic risk.

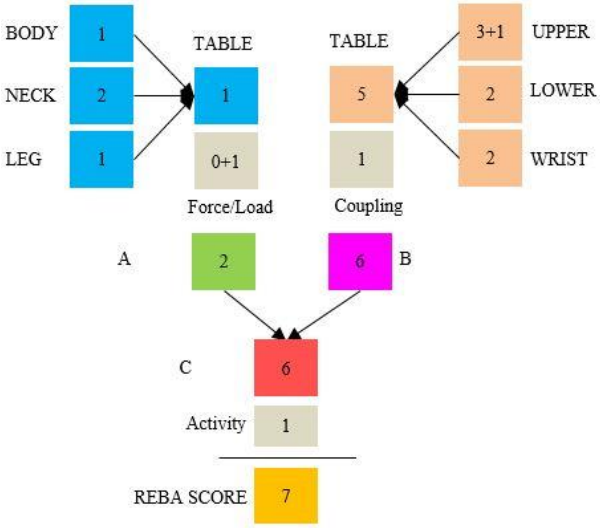


Figure 3. REBA score for manual welding with fixed spot machine

REBA scores are given in Table 8 for the current and after improvement studies of all processes.

Table 8. REBA risk assessment.

Process	Process item	Current	Improved
Manual welding line	Manual welding with fixed spot machine	7 “mid”	3 “low”
	Part handling	4 “mid”	2 “low”
	Part hanging trolley pushing	6 “mid”	-
Arc welding line	Putting the part to the pallet	10 “high”	3 “low”
	Pallet push	5 “mid”	-
	Arc welding repairs	3 “low”	-
Pedal welding/ assembly line	Box push	4 “mid”	-
	Countersinking operations	5 “mid”	1 “negligible”
Manual welding line with balancer gun	Putting the part to the pallet	4 “mid”	-
	Manual welding with balancer gun	10 “high”	2 “low”
	Welding in pneumatic jig	2 “low”	-

The manual welding process in the fixed spot machine was evaluated in the LMM-3 group, since it is in the manual work group according to the BAUA. The set part production time is 54.4 seconds in total and the amount of production per shift is 216 pcs. The TWS is 2, since the total process time in the shift is 3.2 hours. According to the measurements made, the total force the employee is exposed to is 10.6 kgf, it is considered as a very high load and the force weight score is determined as 12 since it is a holding process of 54.4 seconds. The evaluation details are shown in Table 9 and the evaluation score is determined as 46 points. According to this value, the risk level is "3" and the load generated during the process is high. The employee's body posture while performing the procedure is inappropriate.

Table 9. BAUA LMM-3 risk assessment.

Process	Process item	Method	Step 1	Step 2						Step 3	Risk Level	Explanation
			TWS	A	B	C	D	E	F	Assessment		
Manual welding line	Manual welding with fixed spot machine	Current	2	12	2	3	2	2	2	2*(12+2+3+2+2+2)=46	3	High load
		Expected	1	2	0	1	1	1	1	1*(2+0+1+1+1+1)=6	1	Low load
Arc welding line	Arc welding repairs	Current	1.5	4	0	1	0	0	1	1.5*(4+0+1+0+0+1)=9	1	Low load
		Expected	-	-	-	-	-	-	-	-	-	-
Pedal welding/ assembly line	Countersinking operations	Current	1		2	3	1	1	0.5	1*(19+2+3+1+1+0.5)=26.5	3	High load
		Expected	1	3	0	1	1	0	0	1*(3+0+1+1+0+0)=5	1	Low load
Manual welding line with balancer gun	Welding in pneumatic jig	Current	3	1	2	0	0	0	0	1*(1+2+0+0+0+0)=9	1	Low load
		Expected	-	-	-	-	-	-	-	-	-	-

An improvement proposal has been developed to minimize sudden loads during manual welding on the spot machine. Cartesian robot system was introduced to the work area by adding a linear slide sliding mechanism, servo motor, servo drive and PLC instead of manual process (Figure 4). After the employee puts the part on the machine, he pushes the button and the welding process is carried out with automation. Thanks to the automation system of the production in the slide jig, the weight of the force that the employee is exposed to has been reduced to 0 kgf per day. Thus, the unsuitable situation in the employee's body posture has been eliminated.

The time for placing the part on the machine is 38 seconds *216 pieces = 0.2 hours / shift and the TWS is 1. The applied force weight point has decreased to 2. Table 8 shows the result of the ergonomic risk assessment made after the improvement. The evaluation score is 6 and accordingly, the risk level has dropped to "1". As a result of the improvement suggestion, the REBA score is also reduced to 3 (low load).

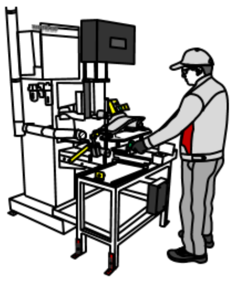


Figure 4. Working with a linear slide cartesian robot.

Table 10. BAUA LMM-1 risk assessment.

Process	Process item	Method	Step 1	Step 2			Step 3	Risk level	Explanation
			TWS	A	B	C	Assessment		
Manual welding line	Part handling	Current	8	2	2	1	8*(2+2+1)=40	3	High load
		Expected	8	1	1	0	8*(1+1+0)=16	2	Mid load
Arc welding line	Putting the part to the pallet	Current	7	3	3	2	7*(3+3+2)=56	4	Very high load
		Expected	3	2	1	1	3*(2+1+1)=12	2	Mid load
Pedal welding/ assembly line	-	Current	-	-	-	-	-	-	-
		Expected	-	-	-	-	-	-	-
Manual welding line with balancer gun	Putting the part to the pallet	Current	4	1	4	1	4*(1+4+1)=24	2	Mid load
		Expected	-	-	-	-	-	-	-

b. Part handling in intermediate processes: Since holding, lifting and handling is done during this work, it was evaluated in LMM-1 group according to BAUA. The part weight is 2.8 kg and 216 pieces are produced in 1 shift. A part is lifted and transported 4 times. 216*4 = 648 semi-finished products are transported in one shift, it is in a work group that takes less than 5 seconds. TWS is 8, because it has an average weight of 10.5 kg the load significance is 1 and the position score is 2 due to it bends slightly while transporting. The risk score is 32, risk level is high load (3). Evaluation scores are given in Table 10. According to the REBA, the score is 4 and it is evaluated as "medium load" ergonomic risk.

An improvement proposal has been developed that can minimize sudden loads. The suggestion was to place a conveyor belt in order to ensure transportation between equipment within the line (Figure 5). Thus, the semi-finished product is placed on the belt with the small support of the employee and the sudden load placed on the employee has been removed. As a result of the improvement suggestion, the BAUA LMM-1 level was reduced to medium load (2) and the REBA score to 2 (low load).

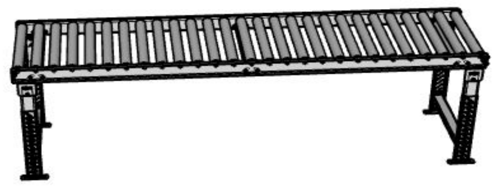


Figure 5. Conveyor belt.

c. Part hanging trolley pushing: Since it is a push-pull work, it is evaluated in the LMM-2 group of the BAUA. There are 20 parts in each trolley. For the 216 parts produced during the shift (216/20), 11 times full and 11 empty trolley, a total of 22 pulling operations are performed. The TWS is 2. The full trolley weight towed is 20pcs*3.3kgf (full) + 20*0.5kgf = 76kg. The auxiliary vehicle is wheeled and the corresponding weight score is 1. Since the trunk is upright and there is no rotational movement, the body position score is 1. Evaluation scores are given in Table 11. The risk score is 6 and the risk level is "1", it is in the low load group. REBA score is 6 and it was assessed as "medium load" ergonomic risk. There is no health threat.

Table 11. BAUA LMM-2 risk assessment.

Process	Process item	Method	Weight	Step 1	Step 2				Step 3	Risk level	Explanation
				TWS	A	B	C	D	Assessment		
Manual welding line	Part hanging trolley pushing	Current	50-100 kg	2	1	1	1	0	2*(1+1+1+0)=6	1	Low load
Arc welding line	Pallet push	Current	<10kg	2	3	1	2	1	2*(3+1+2+1)=7	2	Mid load
Pedal welding/ assembly line	Box push	Current	<10kg	2	1	1	1	1	2*(1+1+1+1)=8	1	Low load
Manual welding line with balancer gun	Manual welding with balancer gun	Current	35kg	10	0.5	1	2	1	10*(0.5+2+1+1) =45	3	High load
		Expected	-	-	-	-	-	-	-	-	-

Arc Welding Line

Arc welding is the process of joining sheet metal parts of metal melted between two parts with the heat generated by the electric arc. Arc welding is done with arc robots. Works evaluated in arc welding line; putting the part to the pallet, pallet push and cleaning the burrs remaining on the 19.8kg part after arc welding, tapping etc. are manual works. The employees' body postures during the process are shown in Figure 6.

a. Putting the part to the pallet: REBA evaluation of all works has been made at the line, the body posture while performing the work with the highest REBA score is shown in Figure 6a. The highest score occurs in the work where he takes the 19.8 kg part from the repair stand and places it to the pallet. REBA score is 10 (Table 8). It is assessed as a "high load" ergonomic risk.

Figure 6. Arc welding line. (a) putting the part to the pallet repairs, (b) pallet push, (c) arc welding.

a. Putting the part to the pallet: REBA evaluation of all works has been made at the line, the body posture while performing the work with the highest REBA score is shown in Figure 6a. The highest score occurs in the work where he takes the 19.8 kg part from the repair stand and places it to the pallet. REBA score is 10 (Table 8). It is assessed as a “high load” ergonomic risk.

According to the BAUA, 300 lifting times per shift are performed for the work of putting the part to the pallet evaluated in the LMM-1 group. TWS is 7. Evaluation scores are given in Table 10. The risk score is determined to be 56 and there is an overload.

In order to minimize the ergonomic risk level in the production station, a manipulator has been placed in the pallet placement area (Figure 7). Thanks to the manipulator system, direct contact with the part is eliminated and ergonomic handling is provided. Since the total holding time in a shift is 15 minutes, the TWS is 3. As a result, the risk level could be reduced to the medium load (Table 10). The REBA score was reduced to 3 " low load ".

Figure 7. Part placement to the pallet with the manipulator.

b. Pallet push: The evaluation scores of the pallet pushing work evaluated in the LMM-2 pushing works group according to the BAUA are given in Table 11. The risk score is 13.5 and the risk level is "2", physical overload is possible and health problems may occur. REBA score is 5. It is assessed as "medium load" ergonomic risk.

c. Arc welding repairs: Repairs are carried out by applying force with the help of a motorized hand gun. It is evaluated in the LMM-3 group according to the BAUA. Processing time per part is 21 seconds. The TWS is 1.5. Scoring details are given in Table 11. The risk score is "9", the risk level is in the low load. The REBA score is 3 and it is in the "low load”. Health risk is unlikely as the ergonomic workload is low.

Pedal Welding / Assembly Line

Pad mounting, tightening, robot arc welding works are performed in the pedal welding / assembly line according to the order of work. Among these, the works with a higher risk level compared to other works are box pushing and countersinking, shown in Figure 8.

Figure 8. Pedal welding / assembly line. (a) box push, (b) countersinking.

a. Box push: It is shown in Figure 8a. The employee puts the box with 6 pedals inside by pushing it onto the self. and pushes the 4 boxes by stacking them on top of each other. Part weight is 2 kg. REBA details are given in Table 8. The REBA score of the evaluation is 4. It is assessed as "medium load" ergonomic risk.

Box pushing work is evaluated in LMM-2 group according to BAUA. The TWS is 2. Evaluation scores are given in Table 11. The risk score is 8 and the risk level is "1", physical overload is unlikely. No health risks are expected.

b. Countersinking: It is the process of making conical or cylindrical slots in pre-drilled holes. While holding the part with the left hand, countersinking is performed with the right arm, moving from top to bottom. During the process, 103.6 N / 9.806 = 10kg load affects the right arm. The REBA score is 5 and the risk level is "medium load".

Countersinking process is evaluated in LMM-3 group according to BAUA since it is mostly manual work that creates workload in hand-arm-shoulder area. Since the total working time in a shift is less than 1 hour, TWS is 1. Other criteria are also evaluated in accordance with the tables and the risk level is "3", the load is high.

In order to reduce the risk, the countersink machine has been automated (Figure 9), and the process of performing the operation with arm power has been eliminated. After the part is placed in the machine, the process is completed by pushing the start button. Thus, the applied force weight point, which was 19 in the first case, was reduced to 3. Table 9 shows the LMM-3 risk assessment result after improvement. Risk level "1" is minimized as under load. The REBA score has also been reduced to 1.

Figure 9. Automatic countersinking machine.

Manual Welding Line with Balancer Gun

In the current station, the employee welds 13 spot with the balancer gun. After setting the part on the machine, the employee welds by pulling / pushing the 15-20 kg hanging guns. The process is performed while standing, holding the heavy gun at the appropriate distance and keeping the neck in front. Assessed works; welding with balancer gun, putting the part to the pallet and welding in pneumatic jig (Figure 10).

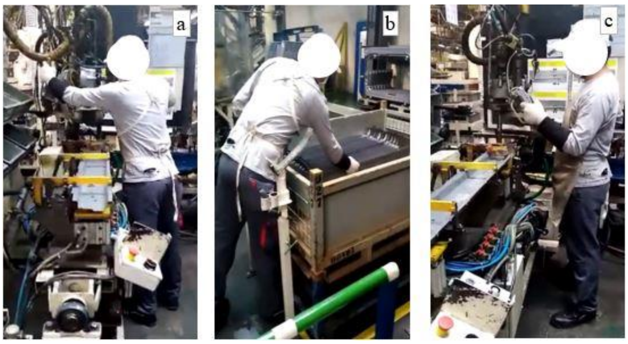


Figure 10. Manual welding line with balancer gun. (a) manual welding with balancer, (b) putting the part to the pallet, (c) welding in pneumatic jig.

a. Manual welding with balancer gun: The REBA score of the manual welding with gun (Figure 10a) is 10 (See Table 8). It is assessed as a “high level” ergonomic risk.

According to the BAUA, it is evaluated in the LMM-2 group as it is push-pull works. Gun movement has 15 times, 15 frequencies * single person average 120 pieces = 1800 frequency, total gun movement. Accordingly, the TWS is 10. The risk level is "3" against the risk score of 45, and the load during the process is high. In order to minimize the sudden loads during the welding process with the balancer gun, the use of heavy balancer and the push-pull works accordingly were completely removed by placing a robot in the line. As a result of the improvement suggestion, the REBA score was also reduced to 2 (low load).

b. Putting the part to the pallet: After the welding, the finished parts are placed in the pallet (Figure 10b). Since the pallet placement is mainly lifting and carrying, it is evaluated in LMM-1 group according to the BAUA. It takes 3 seconds to put each part to the pallet. (120pieces*3 / 60 = 6min / day) Accordingly, the TWS is 4. Risk score is 24, while the risk level is "2", ergonomic workload is medium. The REBA score is 4 (medium load).

c. Welding in pneumatic jig: It is the ergonomic workload that occurs during the spot welding after pulling the gun in line with the spot points. It is evaluated in the LMM-3 group according to the BAUA. Spot welding is 150 seconds / part. The processing time per shift is (150*120 / 3600 = 5) 5 hours. Accordingly, the TWS is 3. The risk score is 9 and the risk level is in the low load. The body posture of this procedure is shown in Figure 10c. REBA score is 2 for spot welding in pneumatic jig. The risk level is low.

Discussion

The results of this study approve that the risk output of both methods depends on the exposures considered and their greatness. The method used to detect the postures where employees find the most difficult, is of great importance. When the REBA and BAUA scores in Table 12 are examined, it is seen that BAUA scores are sometimes higher in most of the similar results. For example, if we look at the results of the pedal welding line in Table 12, the result was found to be medium load according to REBA. The risk assessment of this score is "Improvement may be required". BAUA LMM-3 score is determined as "high load" and according to this score, the risk assessment result is "Improvement is required". In this case, while the improvement work may not be done according to the REBA result, it has become necessary according to the BAUA result. Since the aim of ergonomics studies is to eliminate the risks of MSD, the results that will show where to start the improvement studies should be determined in the most accurate way and no factors should be overlooked.

Table 13 includes the comparison of REBA and BAUA. When we consider the BAUA as a whole as LMM-1, 2 and 3, it can be said that it analyzes more criteria than REBA. Both REBA and BAUA are used for work done using the whole body. The biggest difference between the REBA and BAUA is that the TWS evaluation is always used in the BAUA, and the time is not taken into account in the REBA. In the BAUA, the first thing is that it is necessary to decide whether it is lifting-displacement, holding or transportation work. In BAUA, application conditions according to REBA, force in the finger and hand, movement speed and work organization are also examined.

Table 12. REBA and BAUA scores of four welding lines with ergonomic risk assessment.

	1- Manual welding line with gun		2- Fixed spot welding line		3- Arc welding repair line		4- Pedal welding line	
	Risk Score	Level	Risk Score	Level	Risk Score	Level	Risk Score	Level
REBA	7	Medium load	10	High Load	5	Medium load	0	High Load
LMM-1	40	High Load	56	Very High Load	-	-	24	Medium load
LMM-2	6	Low load	7	Low load	8	Low load	45	High Load
LMM-3	46	High Load	9	Low load	26.5	High Load	9	Low load

Table 13. Comparison of REBA and BAUA

	Body Neck Leg	Upper arm Lower arm Wrist	Load	Coupling	Movement frequency	Time	Application conditions	Movement speed	Force in finger & hand	Work organization
REBA	√	√	√	√	√	X	X	√	X	X
LMM-1	√	X	√	√	√	√	√	X	X	X
LMM-2	√	X	√	X	√	√	√	√	X	X
LMM-3	√	√	√	√	√	√	√	X	√	√

Conclusion

In this study, ergonomic risk assessment is discussed by using REBA and BAUA in automotive supply industry welding lines. By examining all the production lines of the enterprise, risky working areas were determined in welding processes where the physical strains that employees are exposed to are the highest. The compatibility between REBA and BAUA risk assessment methods and the ability of the methods to correctly classify the risk level of four risky tasks were examined and significant differences were found in the ability to identify at-risk tasks as at risk between methods. In order to eliminate risky situations, improvement studies were carried out and post-improvement evaluations were made again.

In the REBA, the body is divided into two as upper and lower body for each posture and, evaluation is made according to the angles of the limb during posture. The total score is calculated by the combination of neck, body, and upper and lower limb positions. The angular postures that will occur in the limbs depending on the task done will vary according to the height of the employee and it varies according to the short or tall employees.

If different tasks are done consecutively, it is not easy and correct to evaluate them jointly. In such cases, a more detailed analysis of the task is required to make a risk assessment. The BAUA provides a multidimensional assessment that fulfills simple legal requirements in determining the strain limit according to scientific criteria of the task. This method is a helpful tool in determining the compliance of working conditions with social and labor laws as well as medical and scientific perspectives of the task. The most important factor that distinguishes this method from other methods is the determination of the TWS according to the frequency of repetition, duration or distance covered. In addition to the posture of the body limb while performing the task, the level of force applied to the finger and hand area as well as the hand-arm position, the evaluations in the loading according to other tasks and the application conditions such as the clarity of the task, noise, moisture and air flow, are also evaluated.

As can be seen in the comparison results of this application in welding lines in the automotive industry, the BAUA is thought to be more successful in a workstation where sequential tasks are performed, allowing more detailed analysis of the tasks performed by using more power and body. The BAUA allows the evaluation of neglected situations in the REBA as more criteria are taken into account.

Ethics committee approval and conflict of interest statement

There is no need to obtain permission from the ethics committee for the article prepared.

There is no conflict of interest with any person / institution in the article prepared.

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