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A NEW SCORING SYSTEM FOR THE RAPID ENTIRE BODY ASSESSMENT (REBA) BASED ON FUZZY LOGIC: A CASE STUDY

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Keywords

*Risk Assessment,
Work-Related Musculoskeletal Disorders,
REBA,
Fuzzy Logic REBA.*

Abstract

Work-related musculoskeletal disorders (MSDs) are among the most common occupational diseases encountered in today's working conditions. In order to prevent MSD, the strains occurring in employees must be identified. Ergonomic risk assessment methods have been developed in this context examine the physical and environmental factors affecting the employee and ensure that any discomfort that may occur is minimized with corrective suggestions. Therefore, it can be said that ergonomic risk assessment methods can play a major role in preventing MSDs. In traditional ergonomic risk assessment methods, angular deviations of the limbs from the normal posture are taken into consideration. Such methods are not sensitive enough to measure the effect of input variables on the result value, as they give the same risk score for different input variables. This study aims to develop Fuzzy-REBA (F-REBA) to a new scoring system for traditional REBA by using fuzzy sets approach to eliminate the disadvantages of traditional REBA. In order to perform risk analysis with the F-REBA method, the body, neck and foot posture positions considered for Table A and the upper arm, lower arm and wrist positions considered for Table B were converted into linguistic terms according to the flexion

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or extension conditions and a rule base was created with the MATLAB program. The purpose of obtaining more precise output values with the created rule base and the clarification process is to obtain more precise output values. When the obtained results are taken into consideration, it has been determined that the fuzzy REBA method gives more sensitive results to possible changes in input variables such as the changes of flexion or extension degrees.

BULANIK MANTIK TEMELLİ HIZLI TÜM VÜCUT DEĞERLENDİRMESİ (REBA) İÇİN YENİ BİR PUANLAMA SİSTEMİ: VAKA ÇALIŞMASI

Anahtar Kelimeler

Risk Değerlendirmesi, İşle İlgili Kas-İskelet Sistemi Bozuklukları, REBA, Bulanık-REBA.

Öz

Günümüz çalışma koşullarında karşılaşılan en yaygın mesleki hastalıklar arasında iş bağlı kas-iskelet sistemi rahatsızlıkları (KİSR) gelmektedir. KİSR 'nı önlemek için çalışanlarda oluşan zorlanmaların belirlenmesi gerekmektedir. Bu bağlamda geliştirilen ergonomik risk değerlendirme yöntemleri, çalışanı etkileyen fiziksel ve çevresel faktörleri inceleyerek oluşabilecek her türlü rahatsızlığın düzeltici önerilerle en aza indirilmesini sağlamaktadır. Ergonomik risk değerlendirme yöntemlerinin KİSR 'nı önlemede önemli rol oynayabileceği söylenebilir. Geleneksel ergonomik risk değerlendirme yöntemlerinde, çalışma esasında işe katılan uzuvların normal vücut duruşundan açısal sapmaları dikkate alınmaktadır. Bu tür yöntemler, farklı girdi değişkenleri için aynı risk puanını verdiğinden, girdi değişkenlerinin sonuç değeri üzerindeki etkisini ölçmek için yeterince hassas değildir. Bu çalışma, geleneksel REBA 'nın dezavantajlarını ortadan kaldırmak için bulanık kümeler yaklaşımını kullanarak geleneksel REBA için yeni bir puanlama sistemi olan Bulanık-REBA (F-REBA) ile daha hassas puanlamanın yapılması amaçlanmıştır. F-REBA yöntemi ile risk analizi gerçekleştirmek amacıyla Tablo A için dikkate alınan gövde, boyun ve ayak duruş poziyonları ve Tablo B için dikkate alınan üst kol, alt kol ve bilek pozisyonları ve oluşan esneme ya da gerilme durumlarına göre dilsel niteleyicilere dönüştürülerek MATLAB programı ile kural tabanı oluşturulmuştur. Oluşturulan kural tabanı ve durulaştırma işlemi ile daha hassas çıktı değerlerinin eldesi amaçlanmıştır. Elde edilen sonuçlar dikkate alındığında, bulanık REBA yönteminin çalışma esnasında oluşan esneme (fleksiyon) ve gerilme (ektansiyon) nedeniyle eklem yerlerinde oluşan açısal değişimlerin risk skorlarına olan etkisi daha hassas bir şekilde belirlenmiştir.

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1. Introduction

The rapid and intense mechanization process in production technologies creates more pressure and stress on employees. Ergonomics science is a great importance for eliminating or at least minimizing of these negative effects (Atasoy, Keskin, Başkesen and Tekingündüz, 2010). The first steps in the field of ergonomics were taken by applied psychology experts. Especially the work 'Psychology in Industrial Activities' published by Munsterberg has become an important study (Koçak, 2007). Ergonomics aims to ensure balance between employees, the tools they used and the work environments. In this respect, ergonomics is an interdisciplinary science that uses different subjects such as engineering, design, anatomy, psychology (Dizdar and Ünver, 2019). Arrange of work environments according to employees is very important for both the health of workers and productivity of business. Workers that are working in industrial are exposed to physical factors such as long-term repetitiand tasks and inappropriate working positions. Due to these such negative effects, employees may expose with work-related musculoskeletal disorders (WRMDs) and even injuries or disabilities. Work-related musculoskeletal disorders are a major problem for both employers and employees in occupational settings and must be managed properly (Stewart, Ricci, Chee, Margonstein and Lipton, 2003). Work-related musculoskeletal disorders are disorders in the muscles, nerves, tendons, cartilage, ligaments, joints and discs that occur due to frequently repeated body movements such as bending, holding, grasping and reaching (Atıcı, Gönen and Oral, 2015). Many methods have been developed to ergonomically evaluate risky situations that cause employees to have difficulty (Shin and Kim, 2007). These methods can be classified under 3 main headings as personal survey methods (Cornell MSD screening, Questionnaires and Body Disorder Map etc.), methods using direct measurement equipment's (goniometer, biomechanical analysis equipment and optical instruments etc.) and observation-based methods (NIOSH, RULA, REBA, OWAS etc.) (Çetin and Oğuz Kılıç, 2023). REBA analysis is a traditional ergonomic risk assessment method based on observation. In this method, the whole body is taken into account and the risk values resulting from working postures are expressed numerically (Hignett and McAtamney, 2000). With the REBA method, it is possible to easily assess business risks without the need for expensive equipment's (Kahraman, 2012).

When the literature is examined, it is seen that there are some academic studies on traditional methods based on observation. Sa, Nascimento, Melo, Santos & Adissi (2006) made risk analysis by comparing the postures and work positions of dentistry students with REBA and RULA analysis methods and made remedial suggestions. Sağıroğlu, Coşkun and Erginel (2015) conducted risk analysis on workstations using the REBA method in a company. They stated that the risk scores were reduced with the improvements they suggested with the REBA scores. Rud (2011) performed an ergonomic risk analysis on the handling of cargo boxes in a company. According to the REBA and RULA assessment results used in their study, it was determined that the employees were likely to develop work-related musculoskeletal disorders. Kocabaş (2009) examined that the postures of workers in metal manufacturing, construction and stone works by using OWAS and REBA methods. Delice, Ayık, Abidinoğlu, Çiftçi and Sezer (2018) conducted ergonomic risk analysis by using REBA, OWAS, QEC, and MANTRA methods at a tube manufacturing plant which is regarded as heavy and dangerous workgroup. Kahya and Gürleyen (2018) identified the risks in a combi boiler assembly line using the REBA method. Kaya and Özok (2018) examined the ergonomic risks in apparel firm and they stated that these identified risks could affect worker health. Ulutaş and Gündüz (2017) identified problems related to musculoskeletal disorders in a cable manufacturing factory with two different methods. One of the areas where work accidents and occupational diseases are most frequently experienced is undoubtedly the construction sector due to its irregular and intensive workforce (Ercan, 2010). Toktaş and Can (2018) determined the risk levels of construction sites with the KEMİRA-M method, which takes into account qualitative and quantitative criteria in the construction sector. Erdemir and Eldem (2019) performed ergonomic analysis of working postures in a casting workshop using the REBA method based on digital human modeling. Altunay (2025) performed ergonomic risk analysis in production processes using the REBA method with the help of a computer-aided program in a company that produced solid fuel heating systems and remedial suggestions were made for the high-risk scores identified. Koç and Testik (2016) analyzed that the risks of the musculoskeletal system in the furniture sector using REBA, OWAS, QEC and ManTRA methods. They made remedial suggestions for the high risks obtained. Ayvaz et al. (2023) conducted that ergonomics risks of nurses' working posture in a hospital by using questionnaire, Rapid Entire Body Assessment (REBA) and Rapid Upper Limb Assessment (RULA) methods. They identified the average of REBA and RULA scores in the stations of hospital. They emphasized that the operations performed in the emergency department and operation room should be improved ergonomically.

Liu (2014) performed work-related musculoskeletal system load analysis on workers using the LUBA, REBA, OWAS, KIM, OCRA, SI, ULRA, NIOSH and RULA methods. Mork and Choi (2015) evaluated the postures during sample preparation processes in the laboratory using REBA and Body-Map methods. Kahya and Söylemez (2019) determined the physical strain of workers working in a rim factory using REBA and QUEC methods. Erginel, Toptancı and Acar (2018) analyzed the postures of the employees with the Fuzzy REBA method in a furniture factory. In this direction, they developed two separate calculation methodologies for Fuzzy REBA analysis. They stated that they obtained different Fuzzy REBA scores as a result of the different methodologies they used in the study. Ghasemi and Mahdavi (2020) aimed to develop a new scoring system using fuzzy sets and Bayesian network (BN) approach to cover the returns of traditional REBA in their study. According to the results obtained, they found that fuzzy REBA results were more sensitive than traditional REBA results.

Although there are some national and international studies on Fuzzy-REBA in the literature, they are not sufficient. When the literature is examined, it can be seen that in the Fuzzy-REBA studies, certain intervals are used in converting the inputs used to determine the classical risk scores into linguistic terms and the output values are designed to be nearly the same as the classical REBA scores. But, in this study, it was aimed to determine more sensitive outputs by converting the joint angles measured during the work (taking into account the lower and upper limit values of joint angles) into appropriate linguistic terms in determining the risk values. The study consists of three steps. In the first step, REBA risk scores were determined based on observation in the press line of a company producing rubber. In the second step, fuzzy logic classifier model prepared by using determined data, input and output variables and rules of fuzzy logic classifiers in MATLAB. The last step, fuzzy-REBA scores were determined precisely with the prepared model and that results were compared with the classical REBA scores. This study presents original contributions to the literature and is expected to serve as a useful reference, particularly for young researchers conducting studies in this field.

2. Materials and Methods

2.1. Study area

This study was carried out on the hydraulic press assembly line of a company that produces rubber for commercial vehicles. It has been determined that operators working on the assembly line have to stand for long periods of time during production, make repetitive movements and handle raw materials. Possible strains on employees during the operations were detected by using REBA and Fuzzy REBA methods in this study. In this study, research and publication ethics were followed.

2.2. Methods

2.2.1. Observational analysis: REBA (Rapid Entire Body Assessment)

The Rapid Entire Body Assessment (REBA) method allows the body to be analyzed quickly and without the use of costly equipment by examining the working postures of employees. Classic REBA is a practical method that can be easily applied by the user in the industry, especially by using some computer programs. REBA method, first introduced by Hignett ve McAtamney (2000), divides the body into two main parts; the first part is composed of the neck, trunk, and legs. Their scores are combined using Table A in the REBA worksheet to obtain a single value. The second part is composed of upper arm, lower arm, and wrist, and their scores are aggregated using Table B in the REBA worksheet. After adding the scores associated with coupling and force, the scores of these tables are combined using Table C. Lastly, the score associated with the type of activity is added. The final REBA score has a range from one to greater than eleven. Risks that may occur as a result of the analysis are expressed with a numerical score between 1 and 11. These scores and associated action levels according to traditional REBA analysis is presented in Table 1.

Table 1.

The Final Risk Score in the REBA Method and Associated Action Levels.

Degrees of posture (°)	REBA Score	Risk Level	Precaution
0	1	Negligible	Not Necessary
1	2-3	Low	May Be Necessary
2	4-7	Medium	Necessary
3	8-10	High	Necessary Soon
4	11-12	Very High	Necessary Immediately

In the REBA method, which is one of the traditional ergonomic risk assessment methods, the risk score is calculated by taking into account the angular deviations of the limbs in the joints from the normal posture. The low sensitivity of traditional methods to changes in input variables stems from the fact that they commonly follow the principles of classical set theory. The effect of angular change in the input variable on the result score is not reflected precisely in the traditional methods based on observation. The effect of angular changes of joints on ergonomic risk score can be determined more quickly and completely with the prepared model. Also, with the model, possible risk scores can be estimated at different joint angle values that are not measured. For example, flexion or extension that occurs in the upper-arm between 0° and 20° is in the same score group according to traditional REBA worksheet. But, suppose that the angle ranges of upper-arm positions are defined by using fuzzy membership functions as shown in Figure 1

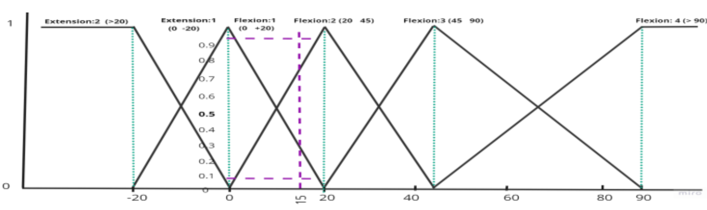

Figure 1. The Process of Translating the Angle Ranges of Traditional REBA into Fuzzy Membership Functions According to Upper Arm Segment of Body.

Let's assume that the upper arm is flexed at 15 degrees. When the using traditional REBA method, which is based on the classical set theory, the risk score associated with this body segment would be 1. On the other hand, when the fuzzy set theory is used, this angle of flexion belongs to two sets and consequently adopts two scores with 0.1 and 0.9 degrees of membership, respectively. That is, 15 degrees of flexion in the upper-arm can be both flexion 1and flexion 2. It can be said that it would be more useful to use fuzzy classifiers to the more sensitive and faster evaluation of the reflection of body posture change on the risk score.

2.2.2. Design of fuzzy logic classifier for fuzzy- REBA scores.

Fuzzy set theory was first developed by Zadeh in 1965. While in classical set theory the membership degrees can only be 0 and 1, but in fuzzy set theory the membership degrees can take any value in the range of [0,1]. This situation is contrary to the classical set view. For this reason, it can be said that fuzzy set theory is a computational technique that helps to eliminate the uncertainties that may occur in the solution of problems (Zadeh, 1965).

In the fuzzy logic classifier; x is the input value, μ(x) is the fuzzy output value, μ(u) is the result of the inference process and u is the output value of model. The fuzzification unit converts define data at the input of the controller to linguistic variables. The fuzzy knowledge base represents two basic data: database and rule base. The database contains the definition of each system variable and the rule base contains the rules necessary to obtain the real output. The inference unit is the unit that performs fuzzy inference on fuzzy rules. The defuzzification unit converts the fuzzy values obtained from the output of the inference unit to numerical values This operation is called as fuzzification (Zadeh, 1994). The fuzzy logic controller (classifier) is given in Figure 2.

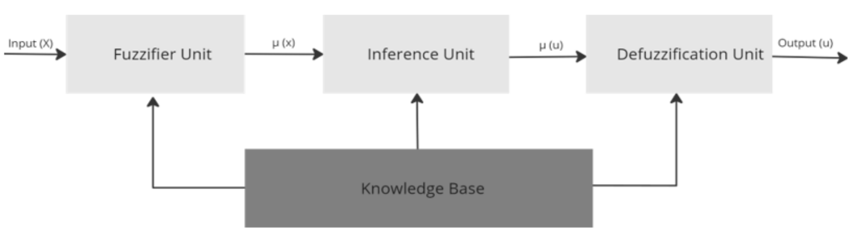

Figure 2: Fuzzy Logic Classifier.

When the input variables of REBA or any similar method are expressed in terms of fuzzy membership functions, the tables cannot be used to combine the scores of different body parts at the traditional REBA (such as Tables A, B and C). Instead, a fuzzy inference system (FIS) is used, which contains a set of rules that create relationships between the inputs and outputs (Jamshidi, Yazdani-chamzini and Haji, 2013).

3. Results and discussion

In this study, REBA risk scores were determined experimentally in the hydraulic press assembly line of a company that produces rubber for heavy commercial vehicles. Also, in order to determine the fuzzy REBA scores, the rule base of the fuzzy logic classifier was prepared in MATLAB by using the input (Table A, Table B and Table C) and output values (REBA score). While table-A has a total of 60 posture combinations for the trunk, neck and legs, and group B has a total of 36 posture combinations for the upper arms, lower arms and wrists. The limits of membership function were determined according to Table A values in the REBA method (Figure 3).

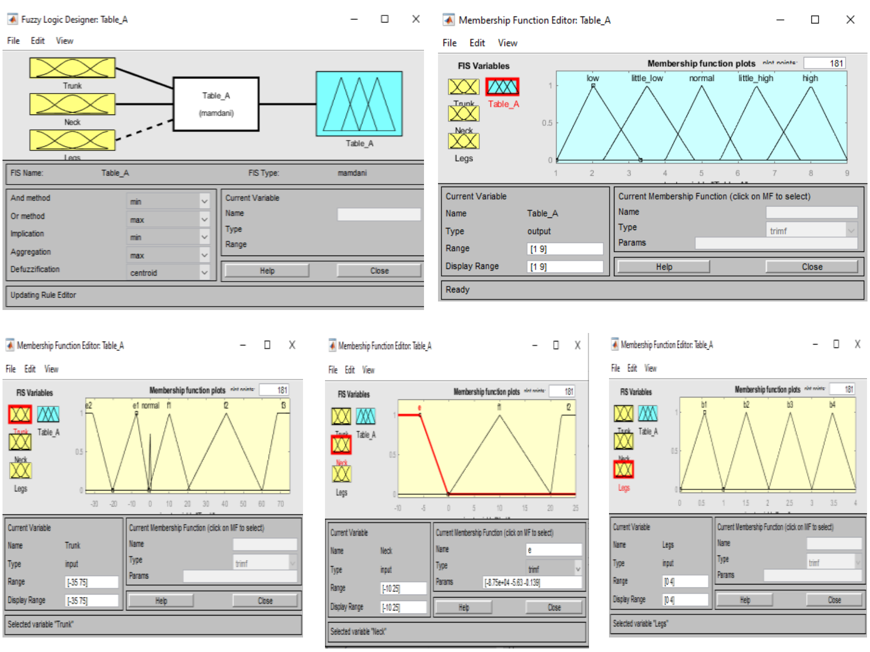

Figure 3. Input Variables of Fuzzy Logic Classifier for Table A (Trunk, Neck and Legs)

In the input and output variables with situation of body that extension and flexion are coded as "e" and "f" respectively. Input variables that related to table A and table B were called as low, little low, normal, little high and high. Leg posture evaluations were coded with "b1, b2, b3 and b4" take into account the traditional REBA values.

For the trunk score, e1 is the extension occurring between -20° and 0°, e2, extension occurring at an angle greater than -20°, normal, the body is at a right angle, f1 is the flexion that occurs between 0 and 20 degrees, f2 is the flexion that occurs between 20 and 60 degrees, and f3 shows flexion occurring at an angle greater than 60 degrees. For the neck score, e represents extension, f1 indicates flexion between 0 and 20 degrees, and f2 indicates that flexion at an angle greater than 20 degrees of neck. For the leg score, b1 is when the legs are bilaterally weight, and walking or sitting position, b2, when the legs are unilaterally weight and or unstable position, while b3 indicates 30-60 degrees of flexion in the knees, b4 indicates more than 60 degrees of flexion in the knees. That is, b3 and b4 represent an additional 1 point to be added to the b1 and b2 situations, depending on the flexion state that occurs in the knees. The limits of membership function were determined according to Table B values in the REBA method (Figure 4).

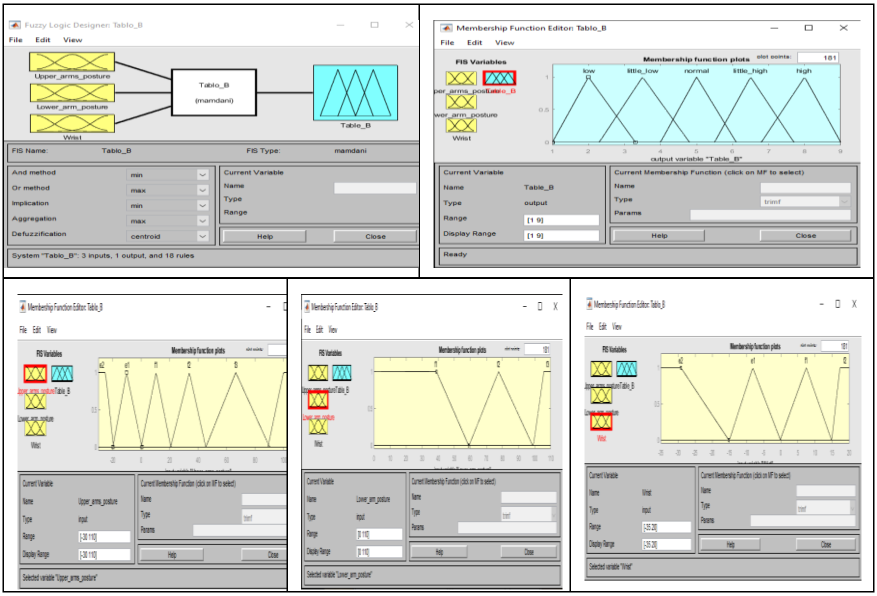

Figure 4. Input Variables of Fuzzy Logic Classifier for Table B (Upper Arm, Lower Arm and Wrists).

For the upper-arm score, e1 is the extension occurring between -20° and 0°, e2 is the extension occurring at an angle greater than 20°, f1 is the flexion that occurs between 0 and 20 degrees, f2 is the flexion that occurs between 20 and 45 degrees, f3 is the flexion that occurs between 45 and 90 degrees, and f4 shows flexion occurring at an angle greater than 90 degrees. The upper-arm is flexed or extended with opened to the side or above the shoulder of upper arm one is added to related score. For the lower arm score, f1 refers to flexion occurring at an angle less than 60°, and f2 refers to the flexion that occurs between 60 and 100 degrees. For wrist score, e2 refers to extension occurring at an angle greater than 15°; e1 refers to extension occurring between 0° and 15°, f1 refers to flexion occurring between 0° and 15°, and f2 refers to flexion occurring at an angle greater than 15°. Score A was obtained by adding the applied force to the Table a value. Score B was obtained by adding the easy of grip or coupling to the Table B value. Score C was obtained using Table A and Table B values. The values of A, B and C scores are defined as nine different data and are shown in figure 5.

There are 9 situations in the rule base, from extremely low to extremely high for score A, score B and Table C, respectively. There are three states for activity score as AS1, AS2 and AS3. The force or load values are used in determining the score A and the coupling values are used in determining the score B without the fuzzification process. Because, these values are fixed. So, these values have been used directly fuzzification process in this study as seen Table 2.

Table 2.

The Values of Load/Force, Coupling and Activity Score

Ease of grip (Coupling)			
0 (Good)	Well-fitting handle and a mid-range power grip		
1 (Fair)	Hand hold acceptable but not ideal or coupling is acceptable by another part of the body		
2 (Poor)	Hand hold not acceptable but is possible		
3 (Unacceptable)	Coupling is unacceptable by using other parts of the body, no handles or unsafe grip.		
Load or Force			
0	1	2	+1
<5 kg	5-10 kg	>10 kg	Shock or rapid up of force
Activity score			
AS1= +1: 1 or more body parts are static held for longer than 1 min.:			
AS2= +1: Repeated small range action, more than 4 times per min. (no walking)			
AS3= +1: 1 or more body parts are static held for longer than 1 min.			

The A and B scores are combined in Table C to give a total of 144 possible combinations, and finally an activity score (Table 2) without fuzzification process is added to give the final REBA score. Fuzzy logic classifier was observed to work in order to define risk score according to the prepared rule base. The basic rule of fuzzy logic system was determined according to the input and output variables and their functions. There are totally 120 rules (for Table A is 34, for Table B is 18, for Table C is 52, for final fuzzy REBA score is 16) in the fuzzy logic classifier (Figure 5.)

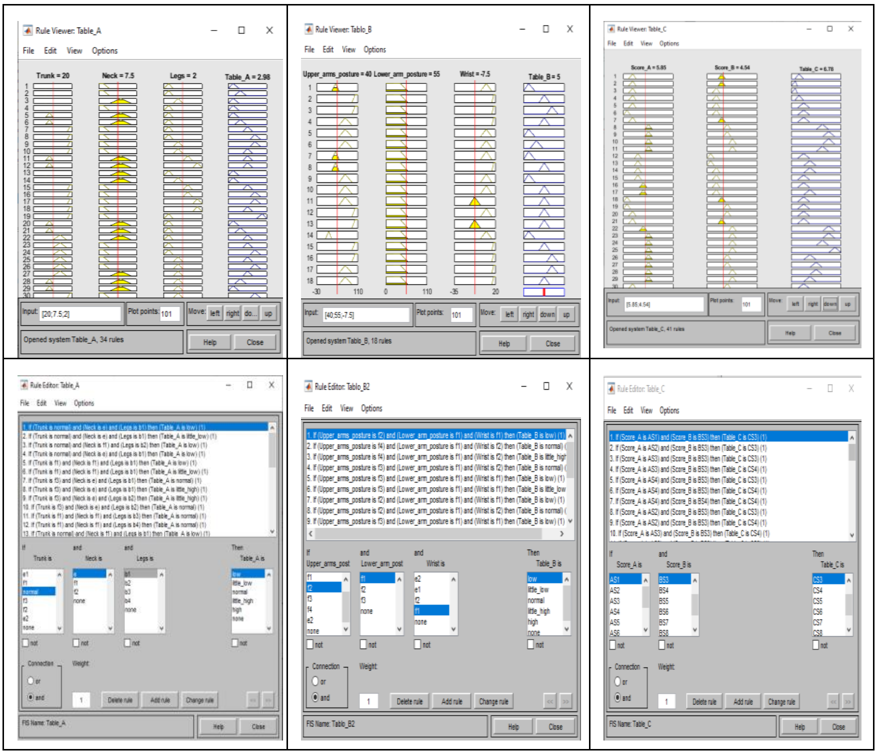

Figure 5. The Rule Base for Table A, B and C.

4. Conclusion and suggestions

People are exposed to various stresses, both physically and mentally in the long-term working conditions. Especially musculoskeletal disorders were occurred as a result of the constant repetition of inappropriate body postures. The most important way to prevent the occurrence of such diseases is to conduct an ergonomic risk assessment to identify ergonomic hazards. REBA (Rapid Entire

Body Assessment) is a method developed for this purpose. Traditional REBA is an observational method and has low sensitivity to input variables. Therefore, this study has been aimed to develop a new scoring methodology based on fuzzy set theory to determine the effect of input variables on the REBA score the more precisely. For comparison purposes, 12 different hypothetical postures were made and assessed using both traditional REBA and Fuzzy REBA (F-REBA). The two left most columns of this table demonstrate the results of these assessment (Table 3).

Table 3.

Characteristics of Twelve Postures used for Comparing REBA and F-REBA.

Process Number	Machine Type	Description of process	Angle of Trunk Position	Angle of Neck Position	Score of Legs	Force / Load Score	Angle of Upper Arm Position	Angle of Lower Arm Position	Angle of Wrist Position	Coupling Score	Activity Score	Final REBA Score	Final Fuzzy REBA Score
1	M -1	Removal of semi-finished products from the conveyor	0	6°e	1	0	28°	51°	11°e	0	2	4	4.7
2	M -1	Placing semi-finished products into the machine	0	10°	1	0	54°	69°	11e°	0	2	3	4.5
3	M -1	Starting the machine	0	4°e	1	0	48°	62°	8°e	0	1	4	5.1
4	M -1	Placing the finished product onto the product conveyor	16°	19°	1	0	11°	21°	9°e	0	2	5	5.4
5	M -2	Removal of semi-finished products from the conveyor	83°	18°e	1	0	86°	24°	16°e	0	1	9	9.0
6	M -2	Placing semi-finished products into the machine	5°	13°	1	0	22°	68°	21°e	0	1	5	5.4
7	M -2	Starting the machine	0°	11°	2	0	76°	24°	2°e	0	2	5	5.5
8	M -2	Placing the finished product onto the product conveyor	73°	9° e	2	0	99°	7°	25°e	0	1	1 0	11.8
9	M -3	Removal of semi-finished products from the conveyor	83°	18°e	1	0	86°	24°	16°e	0	1	1 0	11.7
10	M -3	Placing semi-finished products into the machine	3°	5°	2	0	47°	38°	21°e	0	1	5	5.5
11	M -3	Starting the machine	45°	15°	1	0	110°	10°	5°e	0	1	5	9.0
12	M -3	Placing the finished product onto the product conveyor	51°	9°	1	0	64°	65°	12°e	0	1	9	8.8

When the Table 3 is examined, it is seen that the REBA method and the F-REBA method give similar results. However, numerically small differences are quite important when it comes to employee health. Therefore, it can be said that the F-REBA method gives more sensitive results than the REBA method. When the REBA and F-REBA methods are examined, there are six processes (processes 1, 3, 4, 6, 7 and 10) with a 'medium' risk level and there are two types of the process (processes 5 and 12) with a 'high' risk level in the both methods. In some processes (processes 2, 8, 9, and 11) examined, it is seen that both methods give different results. The risk level of process number 2 was determined as 'low' according to the traditional REBA score, while it was determined as 'medium' according to the F-REBA score. The risk level of processes number 8 and 9 were determined as 'high' according to the traditional REBA score, while they were determined as 'very high' according to the F-REBA score. The risk level of process number 11 was determined as 'medium' according to the traditional REBA score, while it was determined as 'high' according to the F-REBA score. It can be said that the Fuzzy REBA method gives more precise results for each unit change occurring in the joints with the prepared model.

These changes in risk levels also affect the timing and necessity of measures to be taken. For example, in process number 2, the measure is 'may be necessary' according to REBA, but is 'necessary' according to F-REBA. This example shows that the necessity of the measure is affected by changes in risk levels. The part where the timing of the measure is affected can be explained with the following example: In process number 11, the measure is 'necessary' according to REBA, but is 'necessary in the near future' according to F-REBA. It can be said that the main reason for the change in the obtained risk scores is the response of the model to the input variables. The effects of change in each of the input values on the risk value can be calculated precisely with the model that prepared for fuzzy REBA. In other words, it can be said that the values of the risk scores obtained with the fuzzy REBA method can be determined dynamically and more precisely. The approach expressed within the scope of the study can be applied to other ergonomic risk assessment methods.

Authors' contributions

In this study; Fatih YAPICI contributed to the proposal of the article idea, its development, analysis and interpretation, and Esra OZTONGA contributed to the provision of data and transferring it to the computer environment.

Disclosure statement

The authors declare that they have no competing interests.

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