

# Effect of Higher Age on the Ergonomic Evaluation of Arc Welding Workstation

Md. Dilshad Alam<sup>\*</sup>, Shah Nawaz Mohsin<sup>\*\*</sup>, Imtiaz Ali Khan<sup>\*\*\*</sup>,

T. S. Rajput<sup>\*\*\*\*</sup> and Mohd. Parvez<sup>\*\*\*\*\*</sup>

dilshadalam8@gmail.com,<sup>\*</sup> shahmohsin1@rediffmail.com<sup>\*\*</sup> (Corresponding Author),  
fayaqnoor@yahoo.co.in,<sup>\*\*\*</sup> tsrajput60@gmail.com<sup>\*\*\*\*</sup>, parvez0527@gmail.com<sup>\*\*\*\*\*</sup>

**Abstract** – Present study aimed at reducing the musculoskeletal disorders and injuries in arc welding environment. Poor arm posture during various industrial applications, mainly results musculoskeletal disorders and injuries. It also affects the performance and effort (holding, lifting, and lowering) of the worker. Current study involves the ergonomic design of arc welding workstations. **Method:** Here, arc welding work height, working distance and angle of work has been considered as operator performance-affecting anthropometric factors. Twenty-seven right-handed males of age group (35 to 55 years) university students and employees participated in the experimental investigations. Grip force and welding time for a pre-assigned task were recorded as measures of subject performance. The collected experimental data were analysed through MANOVA using *Minitab* statistical software. **Results:** The results of this study indicated that work height, distance of worker, and angle of work have a significant effect on operator's performance in the arc welding environment for higher age group welding operators. It is further explored that interaction of work height and workers' distance has a significant effect on the performance of the subjects. Further analysis on the basis of the mean value comparison method revealed that 80 cm work height, 65 cm operator working distances and zero degree work angle resulted optimum grip force, and 80 cm work height, 65 cm operator working distances and 20 degree work angle resulted optimum welding time in case of 35 to 55 year age group workers.

**Keywords** – Arc-welding, Grip force, Load cell, Welding time, Higher age.

## I. INTRODUCTION

Ergonomics is the application of scientific information concerning human to the design of objects, systems, and environments for use. Ergonomics also involves the interaction of human factors, physical and mental capabilities and limitation of a worker with machine and equipment in the work environment. It requires an understanding of all aspects of how operators function and how they interact with the various tools and systems when performing tasks. With this understanding, various tasks can be performed in a safe and efficient manner.

Ergonomic also considers human reliability, psychomotor capabilities and human characteristic in equipment design, work quality and assessment of skill. The human factors approach involves the interaction of human abilities, expectation, and limitation of the work environment and system design. The goal of human factors engineering is to design devices that the users accept willingly and operate safely in realistic conditions. In industrial application, human factors engineering helps to

improve human performance and reduce the risks associated.

A poorly designed system can result in lost opportunities for productivity and quality. The principle of ergonomic design is to promote workers' health and safety. This makes economic sense because improving working conditions in the control room correspondingly can affect operator's performance, productivity, and overall job satisfaction. These factors translate into reduced absenteeism and higher plant productivity.

Anthropometry deals with the measurement of the dimensions and certain other physical characteristics of the body, such as volumes, centers of gravity, inertia properties and masses of body segments. There are many possible uses for anthropometrics data in designing things for people. One of the most important is in the design of the workplace.

Shielded metal arc welding is one of the world's most popular welding processes, accounting for over half of all welding in some countries. Because of its versatility and simplicity, it is particularly dominant in the maintenance and repair industry and is heavily used in the construction of steel structures and in industrial fabrication. In recent years its use has declined as flux-cored arc welding has expanded in the construction industry and gas metal arc welding has become more popular in industrial environments. However, because of the low equipment cost and wide applicability, the process will likely remain popular, especially among amateurs and small businesses where specialized welding processes are uneconomical and unnecessary [1]. Due to these advantages and wide use of arc welding, we have tried to design the welding environment ergonomically.

Based on the literature surveyed, it is observed that the main purpose of the ergonomists is to design workplaces that are suitable as well as comfortable to fit both body and the mind of the operators.

[2], have tested maximum grip force on cylindrical aluminum handles to evaluate the relationships between the handle diameter (25–50mm diameter handles), perceived comfort, finger and phalange force distribution, and electromyographic efficiency of finger flexor and extensor muscle activity. A force glove system containing 16 thin profile force sensors was developed to measure finger and phalangeal forces on the cylindrical handles. Participants rated the mid-sized handles (30, 35 and 40 mm) as the most comfortable for maximum grip force exertions. Total finger force capability was inversely related with handle diameter. They also found the average contribution of the middle finger to the total grip force was highest (34.8%),

followed by ring (26.5%), index (24.9%), and little (13.8%) finger in that order.

[3], find the Effect of Elbow Flexion, Forearm Rotation and Upper Arm Abduction on MVC (maximum voluntary contraction) Grip and Grip Endurance Time A full factorial design of experiment, i.e., 3 (0, 45, 90 degree an abduction angles of upper arm) × 3 (45, 90, 135 degree angle of elbow flexion) × 3 (0, 60 prone, +60 degree supine angles of forearm rotation) was used to find the effect of 27 combinations of postures on MVC grip strength and grip endurance time. The results showed that none of the main factors were significant on MVC grip, although there was a change in MVC grip. Grip endurance time significantly decreased with an increase in upper arm abduction. Also, grip endurance significantly increased with the elbow flexion angle and decreased with forearm rotation from neutral.

[4], conducted a study on CNC-EDM to evaluate the effect of abduction angle on time to enter the data, and effect of viewing angle on time to searching the error. Three levels of Angle of Abduction, namely 45, 55 and 60 degrees were considered. His study shows that the level of the angle of abduction has a significant effect on the performance of CNC-EDM Operators. It is also observed that CNC-EDM systems should be re-designed so as to achieve a 45 degree angle of abduction for optimal performance. Three levels of Viewing Angle, namely 15, 21 and 28 degrees above horizontal were considered. He concluded that the level of viewing angle has a significant effect on the performance of CNC-EDM operators. The Findings of this work indicate that CNC-EDM systems should be re-designed so as to achieve a 21 degree viewing angle for optimal performance.

[5], explores in their study that if the constant intramuscular IMP /EMG (improved medical physiology/ Electromyography) relationship with increased force may be extended to dynamic contractions and to fatigued muscle. IMP and EMG were recorded from the shoulder muscles in three sessions:

- (a) Brief static arm abductions at angles from 0-90 degree with and without 1 kg in the hands.
- (b) Dynamic arm abductions at velocities from 9-90 degree/s with and without 1 kg in the hands.
- (c) Prolonged static arm abduction at 30 degrees for 30 min followed by recovery.

[6], was conducted a case-control study in an automobile assembly plant. There were 79 workers who reported shoulder pain and met symptom criteria. More than one-half also had positive findings on a physical examination. Subjects were randomly selected which are free of shoulder disorders. 41% of the subjects flexed or abducted the right arm "severely" (above 90°) during the job cycle, and 35% did so with the left arm. Shoulder disorders were associated with severe flexion or abduction of the left (odds ratio (OR) 3.2) and the right (OR 2.3) shoulder. The risk increased as the proportion of the work cycle exposed increased. His findings support the conclusion that severe shoulder flexion or abduction, especially since 10% or more of the work cycle, is predictive of chronic or recurrent shoulder disorders.

[7], explored the influence of external factors such as arm posture, hand loading and dynamic exertion on shoulder muscle activity is needed to provide insight into the relationship between internal and external loading of the shoulder joint. The study collected surface electromyography from 8 upper extremity muscles on 16 participants who performed isometric and dynamic shoulder exertions in three shoulder planes (flexion, mid-abduction and abduction) covering four shoulder elevation angles (30, 60, 90 and 120 degree). Shoulder exertions were performed under three hand load conditions: no load, holding a 0.5 kg load and 30% grip. It was found that adding a 0.5 kg load to the hand increased shoulder muscle activity by 4% maximum voluntary excitation (MVE), across all postures and velocities.

[8], determined that the abduction of one arm preferentially activates erector spine muscles on the other side to stabilize the body. The study hypothesizes that the corti co-spinal drive to the arm abductors and the erector spinae may originate from the same hemisphere.

[9], explored that the shoulder is one of the most complex joints of the human body, mainly because of its large range of motion but also because of its active muscular stabilization. The study presented an algorithm to solve the indeterminate problem with a feedback control of muscle activation, allowing the natural humorous translation. In this study the abduction was considered in the scapular plane, accounting for the three deltoid parts and the rotator cuff muscles.

[10], performed an experiment to obtain electromyography (EMG) activity from a sample of healthy shoulders to allow a reference database to be developed and used for comparison with pathological shoulders. In this study temporal and intensity shoulder muscle activation characteristics during a coronal plane, abduction/adduction movement was evaluated in the dominant healthy shoulder of 24 subjects. The study concluded that the most reproducible patterns of activation arose from the more prime mover's muscle sites in all EMG variables analyzed and although variability was present, there emerged invariant characteristics that were considered normal for this group of non-pathological shoulders.

[11], explored that industrial jobs involving upper arm abduction have a strong association with musculoskeletal disorders and injury.

[12], reported large and statistically significant reductions in muscle activity by modifying a workstation arrangement of an ultrasound system's control panel. In this study, the right suprascapular fossa activity indicated a reduction of muscle activity by 46%, between a postural stance of 75 and 30 degrees abduction.

[13], explored in their study that the constant intramuscular (IMP) / EMG relationship with increased force may be extended to the dynamic contractions and to the fatigued muscles. In this study, IMP and EMG patterns were recorded through shoulder muscles in the three sessions. It was found in the study that during the brief static tasks the IMP and EMG patterns increased with the shoulder torque.

[14], determined the upward lifting motion involved at the scapula at various shoulder angles. In particular, 90 and 120 degrees of flexion, 30 degrees of adduction, and 90 degrees of abduction were found to be the most vulnerable angles based on the measured maximum voluntary contractions (MVCs). The average root mean square value of the EMG increased, most significantly at 90 to 150 degrees of flexion and at 30 and 60 degrees of abduction. The increasing demand of the anthropometric data for the design of the machines and personal protective equipment to prevent the occupational injuries has necessitated an understanding of the anthropometric differences among occupations.

[15], identified the differences in various body measurements between various occupational groups in the USA. The analysis of the data indicated that the body size or the body segment measurements of some occupational groups differ significantly.

[16], investigated the optimum height of the table of the operating room for the laparoscopic surgery. The study concluded that the optimum table height should position the handles of the laparoscopic instrument close to the surgeon's elbow level to minimize discomfort. The study determined the optimum table height as 64 to 77 centimeters above the floor level. In the retail supermarket industry where the cashiers perform repetitive light manual material-handling tasks during scanning and handling products, the cases of the musculoskeletal disorders and the discomfort are high.

[17], conducted a research to determine the effect of working position (sitting versus standing) and scanner type (bi-optic versus single window) on the muscle activity. Ten cashiers from a Dutch retailer environment participated in the study. Cashiers exhibited the lower muscle activity in the neck and shoulders when standing and using a bi-optic scanner. The shoulder abduction was also less for the standing conditions.

[18], this study represents an effective approach for the optimization of a higher age group operator-CNC machine interface environment with multi-performance characteristics. The findings of this work suggest that age is an important factor for ergonomic evaluation of the interfaces and for higher age group operators, the systems and corresponding interfaces should be designed separately.

## II. METHODS

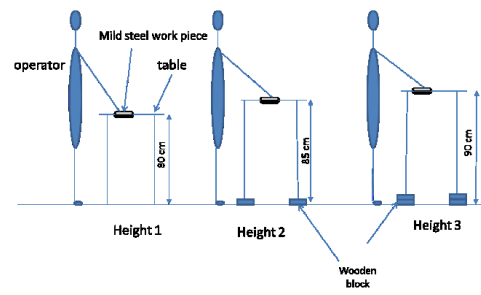
### 2.1 Problem Statement

It is found on the basis of a literature survey and various pilot studies carried out that the main purpose of the ergonomics is to design workplaces that are suitable as well as comfortable to fit both body and the mind of the operators. In an industrial environment, various factors play a significant role, which influences the operator's performance and results in injuries. These factors also affect the productivity of the system.

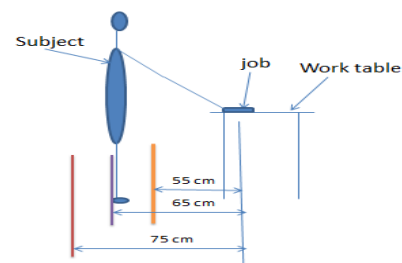
Also, anthropometric factors play an important role when the human working environment is designed. From an ergonomic point of view, by considering anthropometric factors, we can design better human working environment

in such a changing world. Various factors like body alignment (abduction angle), work position (height, working distance and inclination to work), repetition of the work, the machine and their interaction environment are the main causes which affect the productivity of a system and musculoskeletal disorders (MSDs) on the worker. Many other factors like pollution, incrimination lane, the posture of workers, noise, vibration, temperature etc. also affect the performance of the system. If these factors are considered, while designing the system, we can have a better working environment and increased productivity with limited resources.

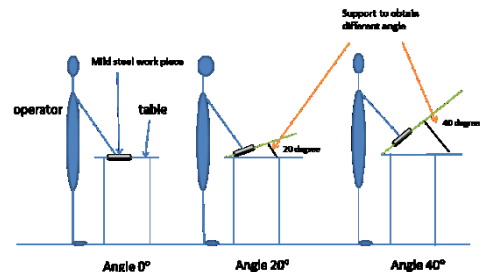
In this research work, study was conducted to evaluate the effect of welding work environment (in terms of height of the work table, angle of work table, and operator's working distance) on human performance, considering output measures as "grip force", and "productivity" (in terms of time) in an arc welding environment. The line diagram of the study is given in Fig. 2.1.



(a) Showing different height of work



(b) Showing different distance of work



(c) Showing different angle of the work table

Figure 2.1 Showing the line diagram of the experimental setup.

So, for developing the ergonomic database, study was carried out in a laboratory arc welding environment. The subject's selection was done on the basis of levels of input parameters (three levels of each three input parameters are selected for the experimental work). In this work, it is

considered that productivity of any system is directly affected by the posture and grip force. It is also considered that the higher grip force may cause MSD. Here we have tried to ergonomically design the workplace where the optimum grip force is applied to hold the electrode holder and minimum time to complete the job. It is also evident that the performance of an operator varies with the variation of the angle of the work table, the height of the work table, operator working distance.

In terms of statistical hypothesis, the problem could be expressed as follows:-

- Posture has a significant effect on human performance in an arc welding environment for age group (35 to 55) years.

In terms of null hypothesis, the problem could be expressed as follows:-

- Posture does not have a significant effect on human performance in an arc welding environment for the age group (35 to 55) years.

#### 4.2 Experimental Design

The experimental hypothesis stated above was tested through a set of experimental investigations. For conducting such investigations, an experimental setup is designed which is summarized as follows:

#### 4.3 Experimental Setup

The following system was used to conduct the experiment at “Workshop ZHCET, AMU, Aligarh”.

1. A designed welding table (height -80cm, width-95cm, breadth-65cm)
2. Wooden block to vary the height of the welding table of height 5cm
3. Welding machine
4. Electrode holder
5. Electrodes
6. Laptop and LabVIEW software
7. Arduino UNO, wires and breadboard
8. Flexi force sensor
9. Variable angle job platform (self-fabricated)
10. Stopwatch

Arc welding task is used to perform the experiment for the measurement of productivity through grip force. The work with table and operator distance can be adjusted considering three, heights (80, 85, 90 cm), work table angle (0, 20, and 40 degree), and distance of work (55, 65, and 75 cm).

To perform the experiment, a cylindrical electrode holder of 30-35 mm diameter is taken [2] as shown in Fig. 2.2. Grip force applied by the subject to the cylindrical electrode holder is measured by using the flexi force sensor as shown in Fig. 2.3. It needs to place the sensor at the middle finger of the subject [2]. It is also observed by conducting a pilot study by placing the sensor in a different position (i.e. hit and trial method) that the grip force at the middle finger was maximum.



Fig. 2.2 Electrode holders

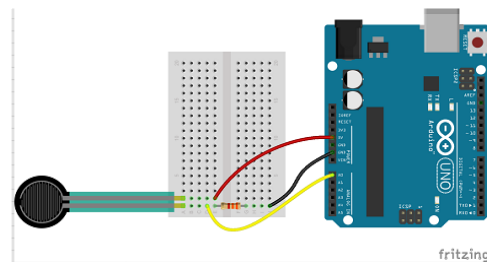


Fig. 2.3 Sensor attached to Arduino UNO

#### 4.4 Calibration of Sensor

The selected sensor works in collaboration with Arduino and LabVIEW program. Firstly, we prepare a program on LabVIEW for Arduino UNO as shown in Fig. 2.4.

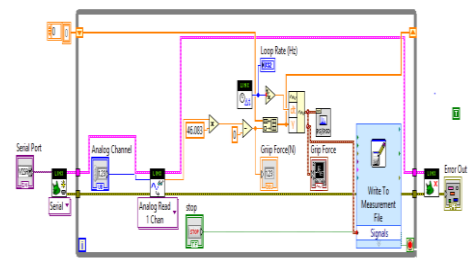


Fig. 2.4 Lab View program for grip force measurement

The sensor gives output in terms of the voltage generated in mv when force is applied. To change this voltage signal as an output in terms of force (in Newton) we need to calibrate it by using known weight. To calibrate the sensor we use the electronic weighing machine. After connecting the sensor to the laptop, some impression is given to the sensor after placing it on weighing machine. This impression gives outputs on the display of weighing machine in term of mass in kg and the display of the LabVIEW program gives the output in terms of voltage in mv. The output is given in Table I.

By using these outputs, we plot a graph of voltage (mv) Vs weight (N). The actual curve traced by data is linear in the initial stage, but as the force increases, the nature of the curve changes to non-linear as shown in Fig. 2.5. The graph indicates that an increase in force causes an increase in voltage in a less proportion. To avoid calculation complications, it is considered as linear.

The performance of each subject in this study was measured in term of time taken to perform pre-specified arc

welding task and grip force applied by subjects during holding the electrode holder.

In the present study three variables i.e. “height of work”, “work table angle”, and “distance of work” are independent variables and variables “grip force”, and “time of task” are the dependent variable. One of the important requirements for conducting the experimental investigation was the selection of appropriate number and type of subjects participating in the study. Generally, in the experiment related to the field of ergonomics, an investigator employed 15-20 subjects for their studies.

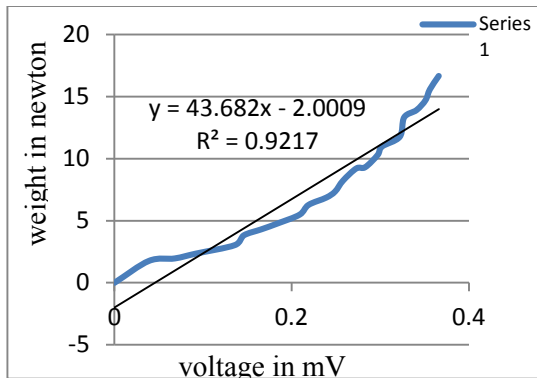


Fig. 2.5 Calibration graph of voltage output into force in Newton

Table I Calibration data

S. No.	VOLTAGE (mv)	WEIGHT (N)
1	0	0
2	0.039	1.7658
3	0.068	1.962
4	0.092	2.3544
5	0.136	3.0411
6	0.146	3.8259
7	0.166	4.3164
8	0.185	4.8069
9	0.209	5.4936
10	0.219	6.2784
11	0.239	6.867
12	0.249	7.3575
13	0.258	8.2404
14	0.273	9.2214
15	0.283	9.3195
16	0.297	10.3005
17	0.302	10.9872
18	0.322	11.772
19	0.327	13.3416
20	0.341	13.9302
21	0.351	14.715
22	0.356	15.5979
23	0.366	16.677

In the present study, an experimental investigation was carried out for age group (35 to 55 years) selecting 27 subjects. All the subjects were of the same sex (male). In this group, age varies from 35 to 55 years with mean age of 44.5 years (all were students and employee of ZHCET, AMU). Selected subjects were naive as far as the arc welding task is concerned. In this context, each subject was

imparted a basic training of arc welding task to synchronize the experiment with each subject.

#### 4.5 Experimental Procedure

The ergonomic design of “human performance” in the arc welding environment for age group (35 to 55 years) subjects, has been carried out. Before starting the experiment, the subjects were trained. To carry out the experiment, following steps was incorporated.

- i. Vary the height of the work table in the arc welding environment
- ii. Provide the job and place it within required space.
- iii. Instruct the subject to stand at a required distance from the work table. It was important that the toe of feet is kept on the line drawn to a different distance from the work table.
- iv. Ensure the subject to grip the electrode holder properly and keep the sensor at middle finger as shown in Fig. 2.6.
- v. Later on, the signal was given to each subject in term of voice message “start”.
- vi. As soon as the welding task is completed, the total time taken by the subject was recorded through stopwatch and the grip force was recorded on the laptop display.
- vii. The same procedure was repeated three times and the average is considered as a final output.
- viii. The performance of each subject was recorded at the time taken and grip force to complete the job.



Fig. 2.6 Sensor placed on the middle finger

## V. RESULTS

The experiment was carried out according to the procedural detail presented in section 2.5. Data were collected and thereafter analyzed through *Minitab* statistical software. The present work comprised of a study, based on the evaluation of the effect of work height, working distance and angle of work on the performances considering grip force and operation time. Grip force is the measure of effort required to keep the electrode holder. The time taken for arc welding task and grip force were taken as the measures of performance of each subject. Experimental data (grip force and welding time) are recorded at different levels of work height, working distance and angle of the work. After the data collected, the analysis of variance (ANOVA) with the repeated measure type of statistical design was performed.

### 3.1 Analysis

The experimental data of grip force and welding time are summarized in Table II.

### 3.1.1 General linear model for grip force vs. work height, working distance and angle of work

This study is done on the subject of age group 35 to 55 years. A General linear model for grip force vs height of the table, operator distance and angle of work is developed using *Minitab* software. The summary of analysis is given in Table III. The F-ratio was used in testing the statistical hypothesis and the level of significance for the test was set at 0.05.

Table II Observations of grip force and arc welding time

Height (cm)	Distance (cm)	Angle (degree)	Force (newton)	Time (second)
80	55	0	7.3001	20.55
80	55	20	7.7706	19.86
80	55	40	9.9991	21.15
80	65	0	7.1358	22.82
80	65	20	6.449	19.74
80	65	40	9.4343	20.34
80	75	0	8.6324	23.95
80	75	20	6.6501	22.24
80	75	40	10.6466	23.22
85	55	0	8.925	22.84
85	55	20	9.314	20.76
85	55	40	10.567	21.34
85	65	0	8.365	22.35
85	65	20	9.453	21.32
85	65	40	10.13	20.85
85	75	0	9.765	24.95
85	75	20	10.342	23.52
85	75	40	11.957	21.98
90	55	0	9.852	24.56
90	55	20	9.873	22.86
90	55	40	10.753	24.1
90	65	0	8.356	23.35
90	65	20	9.854	23.54
90	65	40	11.652	22.27
90	75	0	12.354	25.15
90	75	20	12.854	24.26
90	75	40	13.682	24.95

On the basis of results indicated in Table III in reference to the height of the work table, we reject the null hypothesis, since observed  $F_{ob} = 55.23$  is greater  $F_{cr}$  value  $(F(2,8)_{.05}) = 4.459$  and  $(P\text{-value})_{ob} = 0.00$  (approximately) is lesser than the set significance level of  $[P\text{-value}]_{cr} = 0.05$ . Hence it indicates that the height of the table has a significant effect. Therefore, it can be concluded that the variable height of work table will have important bearing on human performance as far as human-arc welding interface is concerned. Furthermore, in case of workers' distance, it can be observed from Table III that the null hypothesis rejected because  $F_{cr}$  value  $(F(2,8)_{.05}) = 4.459$  is less than the observed  $F_{ob} = 24.49$  and P-value is found  $P_{ob} = 0.00$  is lesser than set significance level i.e.  $\alpha = 0.05$ . It indicates that the workers' distance has strongly significant effect. Therefore, it can be concluded that the variability workers' distance will have important bearing on human performance as far as human-arc welding interface is concerned. Moreover, in case of work table angle, it can be observed from Table III that the null hypothesis rejected because  $F_{cr}$  value  $(F(2,8)_{.05}) = 4.459$  is less than the observed  $F_{ob} = 34.22$  and P-value is found  $P_{ob} = 0.00$  is lesser than set significance level i.e.  $\alpha = 0.05$ . It shows that the angle of work table effects significantly. Therefore, it can

be concluded that the variable angle of work table will have important bearing on human performance as far as human-arc welding interface is concerned. Moreover, in case of interaction of worker distance and work table angle, it can be observed from Table III that the Null hypothesis accepted because  $F_{cr}$  value  $(F(4,8)_{.05}) = 3.8379$  is greater than the observed  $F_{ob} = .759$  and P-value is found 0.58, which is greater than set significance level i.e.  $\alpha = 0.05$ . As null hypothesis accepted it means there is no significant effect of interaction of worker distance and work table angle. Therefore, it can be concluded that the interaction of worker distance and work table angle will not have important bearing on human performance as far as human-arc welding interface is concerned. Furthermore, in case of interaction of work table height and work table angle, it can be observed from

Table III Summary of Analysis of Variance for grip force

Source	DF	Adj SS	Adj MS	F-Value	P-Value	%age contribution
Height (cm)	2	35.6702	17.8351	55.23	0.000	41.08
Distance (cm)	2	15.8199	7.9100	24.49	0.000	18.22
Angle (degree)	2	22.1054	11.0527	34.23	0.000	25.46
Height (cm) x Distance (cm)	4	5.7745	1.4436	4.47	0.034	6.64
Height (cm) x Angle (degree)	4	3.8786	0.9696	3.00	0.087	4.46
Distance (cm) x Angle (degree)	4	0.9806	0.2452	0.76	0.580	1.12
Error	8	2.5835	0.3229			2.97
Total	26	86.8128				

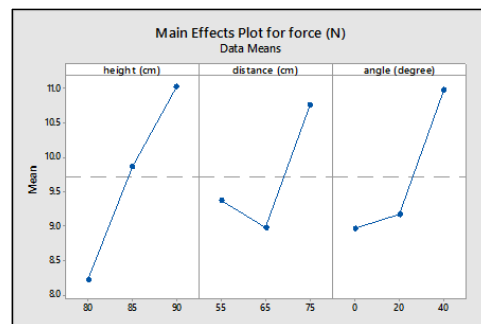


Fig. 3.1 Graph of the main effect for grip force

Table III that the Null hypothesis accepted because  $F_{cr}$  value  $(F(4,8)_{.05}) = 3.8379$  is greater than the observed  $F_{ob} = 3.00$  and P-value is found 0.087, which is greater than set significance level i.e.  $\alpha = 0.05$ . As null hypothesis accepted it means no significant effect of interaction of work table height and work table angle. Therefore, it can be concluded that the interaction of work table height and work table angle will not have important bearing on human performance as far as human-arc welding interface is concerned. Moreover, in case of interaction of work table height and workers' distance, it can be observed from Table III that the Null hypothesis rejected because  $F_{cr}$  value  $(F(4,8)_{.05}) = 3.8379$  is less than the observed  $F_{ob} = 4.47$  and P-value is found 0.034, which is lesser than set significance level i.e.  $\alpha = 0.05$  as we know that the rejection of null hypothesis shows that the interaction of height and distance of work table has a significant effect. Therefore, it can be concluded that the interaction of work table height and workers' distance will have important bearing on human

performance as far as human-arc welding interface is concerned.

On taking average percentage contribution for each performance characteristic of each factor in the arc welding, working environment, it is observed from Table III that height of work table has a maximum contribution (41.08%) followed by work table angle (25.46%), workers' distance (18.22%), interaction of work table height and workers' distance (6.64%), interaction of work table height and work table angle (4.46%) and interaction of workers' distance and work table angle (1.12%). It is also observed that the average error percentage contribution in performance measure in the arc welding environment is 2.97%.

From the analysis, we obtained the graph by using average values of outputs as shown in Fig. 3.1. These plots show the trend of variation of the output factor with a variation of input factors. The plot of height vs. grip force shows that as height increases the grip force also increases. Therefore, a particular height of work table should be maintained to have optimum grip force. Distance vs. grip force plot indicates that grip force decreases up to 65 cm working distance and after that, it increases. The grip force is minimum at the distance of worker 65 cm from the work table. The plot obtained from the angle of table vs. grip force shows that as the angle of work table increases the grip force also increases. Hence, a particular angle of work table should be maintained to have optimum grip force.



Fig. 3.2 Interaction plot for grip force

In Fig. 3.2, the interactions of the height of the work table, worker distance and angle of the worktable are shown. It is interesting to see that the interaction effect of height and distance is significant. But the result Table III indicates that there is a significant effect of interaction between the work height and operator distance. It is also observed from the Fig. 3.2, that the other interactions do not have any significant effect.

### 3.1.2 General linear model for welding time vs. height of work table, worker distance and angle of work

A General linear model for welding time vs height of the table, distance of table and angle of work is developed using *Minitab* software. The summary of analysis is given below in Table IV. The F-ratio was used for testing the statistical hypothesis and the level of significance for the test was set at 0.05.

Considering the results shown in Table IV, in reference to the height of the work table, the null hypothesis rejected because  $F_{cr}$  value ( $F(2,8)_{.05}$ ) = 4.459 is less than the

observed f-value  $F_{ob} = 25.976$  and  $(p\text{-value})_{ob} = 0.00$  is lesser than  $[p\text{-value}]_{cr} = 0.05$  taken as significance level. It indicates that the height of work table has a significant effect on arc.

Table IV Summary of Analysis of Variance for time

Source	DF	Adj SS	Adj MS	F-Value	P-Value	%age Contribution
Height (cm)	2	26.428	13.2142	25.98	0.000	38.60
Distance (cm)	2	21.322	10.6608	20.96	0.001	31.14
Angle (degree)	2	9.821	4.9105	9.65	0.007	14.36
Height (cm) x Distance (cm)	4	2.253	0.5633	1.11	0.416	3.29
Height (cm) x Angle (degree)	4	2.690	0.6725	1.32	0.341	3.92
Distance (cm) x Angle (degree)	4	1.872	0.4681	0.92	0.497	2.73
Error	8	4.070	0.5087			5.94
Total	26	68.456				

welding time. Therefore, it can be concluded that the variable height of work table will have an important bearing on human performance as far as human-arc welding interface is concerned. Furthermore, in case of workers' distance, it can be observed from Table IV that the null hypothesis rejected because  $F_{cr}$  value ( $F(2,8)_{.05}$ ) = 4.459 is less than the observed F-value ( $F_{ob}$ ) = 20.956 and p-value is found 0.001, which is lesser than set significance level i.e.  $\alpha = 0.05$ . It indicates that the distance of worker from work affects significantly the performance of the operator. Therefore, it can be explored that the variable workers' distance has important consideration in human performance. Moreover, in case of work table angle, it can be observed from Table IV that the null hypothesis rejected because  $F_{cr}$  value ( $F(2,8)_{.05}$ ) = 4.459 is less than the observed F-value ( $F_{ob}$ ) = 9.65 and p-value is found  $P_{ob} = 0.007$ , which is lesser than significance level i.e.  $\alpha = 0.05$ . It indicates that the angle of work table affects significantly the performance of a worker as the null hypothesis is rejected. Therefore, it can be concluded that the variability workers' distance has an important impact on human performance. Furthermore, in case of interaction of worker distance and work table angle, it can be observed from Table IV, that the null hypothesis accepted because  $F_{cr}$  value ( $F(4,8)_{.05}$ ) = 4.459 is less than the observed  $F_{ob} = 9.65$  and p-value is found  $P_{ob} = 0.007$ , which is less than significant level i.e.  $\alpha = 0.05$ . It indicates that the angle of work table effects significantly as null hypothesis is rejected. Therefore, it can be concluded that the variable work table angle will have important bearing on human performance as far as human-arc welding interface is concerned. Moreover, in case of interaction of worker distance and work table angle, it can be observed from Table IV that the null hypothesis accepted because  $F_{cr}$  value ( $F(4,8)_{.05}$ ) = 3.8379 is greater than the observed  $F_{ob} = 0.92$ , and P-value is found  $P_{ob} = 0.497$ , which is greater than set significance level i.e.  $\alpha = 0.05$ . It indicates that the interaction of distance and angle of work table does not affect significantly the performance of operators. Therefore, it can be concluded that the interaction of work table height and work angle have an important bearing on human performance as far as human-arc welding interface is concerned. Furthermore, in case of interaction of work table height and work table angle, it can be observed from Table IV that the null hypothesis accepted because  $F_{cr}$  value

$(F(4,8).05) = 3.8379$  is greater than the observed  $F_{ob} = 1.322$ , and P-value is found  $P_{ob} = 0.341$ , which is greater than set significance level i.e.  $\alpha = 0.05$ . It shows that the interaction of height of table and angle of work table does not affect significantly the performance of the worker. Moreover, in case of interaction of work table height and working distance, it can be observed from Table IV that the null hypothesis accepted because  $F_{cr}$  value  $(F(4,8).05) = 3.8379$  is greater than the observed  $F_{ob} = 1.11$ , and P-value is found  $P_{ob} = 0.416$ , which is greater than set significance level i.e.  $\alpha = 0.05$ . It shows that the interaction of the height of the table and working distance does not affect significantly the performance of the worker.

On the basis of the average percentage contribution of each factor's performance characteristic of the arc welding environment, it is observed from Table IV that height of work table has a maximum contribution (38.60%) followed by workers' distance (31.14%), work table angle (14.36%), interaction of work table height and work table angle (3.92%), interaction of work table height and worker distance (3.29%), interaction of worker distance and work table angle (2.73%). It is also observed that the average error percentage contribution in performance measure in the arc welding environment is 5.94%.

From the graph height of table vs welding-time is shown in Fig. 3.3, it is evident that as height increases the time to complete the arc welding work also increases. In the same graph, the variation between the distance of worker and welding time indicates that firstly, the time decrease as the distance increases up to 65 cm and a further increase in working distance results increase in time to complete the welding job. It is also observed from the graph (Fig. 3.3), the angle of work table vs time that the increase in work table angle from zero to 20 degrees causes a decrease in welding time, while as increased welding time resulted when the work table angle is increased from 20 to 40 degrees.

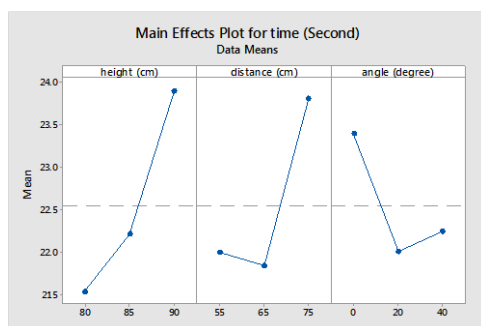


Fig. 3.3 Graph of the main effect for welding time

### 3.1.3 Statistical conclusion

On the basis of above results following conclusions may be drawn:

- (i) The height of the work table, working distance and the angle of work have a predominant significant effect on the grip force as well as on the arc welding time (i.e. P-value < 0.1) as we reject the null hypothesis.
- (ii) On the basis of analysis of collected experimental data, it can further be concluded that the

interaction of height and distance has a significant effect on grip force.

## VI. DISCUSSION

Nowadays, efforts in health promotion programs have increased. Notwithstanding, work related musculoskeletal disorders (WMSDs) remain a widespread and growing issue of concern in the manufacturing industry. In the coming years, WMSDs leading to absence and reduced employment ability along with an aging workforce with comparatively high wages will become an even greater challenge for these manufacturing companies facing worldwide competition. The prevention of WMSDs is achieved through improvements in the design of working conditions and tasks as well as through influencing the health promoting behavior of individuals. What is needed, nowadays, is a systematic approach, that enables manufacturing industries to identify and control physical stress at work that leads to WMSDs in a comprehensive manner.

The world health organization considers the cause of work-related musculoskeletal disorder to be multifactorial. The work environment and the work performed are important, but are not the only factors to be considered. The preferred term for conditions that may be subjectively or objectively influenced or caused by work is a work-related musculoskeletal disorder. Certain occupations are associated with a high risk for neck and arm pain. Some risk factors can be identified, but the interaction between different risk factor is not understood. It is important to reorganize that the personal characteristics and other environmental and sociocultural factors usually play a role in these disorders. Working with the hand at or above shoulder level may be one determinant of rotator cuff tendinitis. Industrial workers exposed to tasks that require working over shoulder level include shipyard welders, car assemblers, and house painters. Generally, rotator cuff tendinitis was found more among shipyard welders as compared to male office. Pain in neck and arm has been related to gripping an instrument and awkward posture. Neck flexion while working in welding environment may be associated with non-specific neck and shoulder symptoms. There are several factors that are considered to influence static activity in the neck and shoulder muscles such as the horizontal distance between worker and working place, the position of the task, height of work table surface, the weight of the tool, shoulder joint flexion/Inflexion, abduction/adduction, and posture.

Several studies have been conducted on anthropometry. The increasing demands for anthropometric information for the design of machinery and personal protective equipment to prevent occupational injuries have necessitated an understanding of the anthropometric differences to be found among occupations.

On the basis of the literature surveyed the present study was taken to develop a better understanding of the effect of the height of work, distance of the worker from the work, and angle of the work table considering arc welding environment.

In this work experimental investigations were carried out to develop a better understanding of anthropometric factors like; height of the work table, working distance and angle of work table during performing an arc welding task. Analysis of result shown that for the higher age group (35 to 55 years) subjects, the height of the welding work table, distance of operator from work, and the angle of work, significantly affects the grip force and operation time of subject in an arc welding environment. It was found that “grip force” was minimum at the work height 80 cm, distance of worker 65 cm and zero degree work angle. As the height of work table increases, the grip force increases. From the result, it is observed that the slope of the increment of grip force between heights 85 to 90 cm is less as compared to the slope between heights 80 to 85 cm. The result also shows that for subjects of 35 to 55 years age, the arc welding operation time is optimum at a work table height 80 cm, working distance 65 cm and work angle 20 degrees. In case of welding time, as work height increases, the time taken to complete the welding job increases. The time resulted is more at the 55 cm working distance, but decreases up to the increase of working distance to 65 cm and again with the increase in working distance from 65 cm, the operation time increases. While as, the welding time is low at higher angle of work i.e. 20 and 30 degrees (Fig. 3.3). In case of grip force, as work height increases the exerted grip force increases. Moreover, at 55 cm operator working distance the grip force is high, but it decreases up to 65cm working distance and again the grip force increases with the increase in working distance. While as, with the increase in angle of work, the grip fore increases.

Increase in work height results in the larger abduction angle, therefore, the welding operation time increases with the increase in work height. It is explored in this study that the welding operation time is minimum at work height 80 cm, working distance 65 cm and angle of work 20 degrees. It is further concluded that the grip force is optimum at work height 80 cm, working distance 65 cm and angle of work zero degree.

It is further explored that, the interaction effect of work height and working distance is significant in case of grip force only. It is also observed that the interaction of work height and working distance has non-significant effect in case of arc welding operation time. Moreover, other interactions, namely work height versus work angle and working distance versus work angle effects are non-significant in case of grip force as well as welding operation time.

In order to minimize musculoskeletal disorders, we have to work in an environment where less force in holding and lifting is required. So, on the basis of the above results, it can be explored that, at 80 cm work height, 65 cm working distance and zero degree angle of work, results in less grip force to keep the electrode holder. In order to increase the productivity in an arc welding environment, the grip force and operation time should be minimum.

## VII. CONCLUSIONS AND FUTURE SCOPE

Through the set of present experimental investigations, an attempt has been made to develop a better understanding of human performance in the context of the arc welding environment.

On the basis of results obtained, following concluding remark is drawn:

- (i) The level of work height, working distance and angle of work has a significant effect on operator performance as far as the grip force and arc welding operation time are concerned.
- (ii) The interaction of work height and working distance affects operator performance significantly in case of grip force. Other interactions indicate a non-significant performance effect in case of both grip force and the arc welding time.
- (iii) Analysis of the results indicates that arc welding work environment should be designed so as to achieve welding work height 80 cm, the welder working distance 65 cm and work angle zero degrees.
- (iv) On the basis of experimental investigation carried out, it was explored that the height of the work, working distance and angle of work on the arc welding environment plays a significant role as far as designing of better systems and generation of the ergonomic database is concerned.

Nowadays, the following aspects of welding system are being considered.

- (i) The aspect of the workplace design.
- (ii) Skilled operator health complaint.
- (iii) Ergonomic studies related to other welding environment-, namely gas welding, TIG welding and MIG welding etc.

The above-mentioned areas represent just a trend on which researches are being conducted. But still, a lot of problems with the welding environment appeared to have remained unexplored. In the welding system, such aspects are expected to be explored in future under varying conditions of age, sex, task structure, anthropometric characteristics and environmental variables. Someone may go for further study by considering factors such as quality of weld within a specified time. Grip force may be estimated at different angles of abduction. Grip force study may be performed by placing more sensors on the palm at different points.

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graduate levels, such as Machine Design, CAD etc. He has supervised a number of Projects. He has attended several refresher Courses, Conferences & Seminars. He has visited several countries and taught in Sultanate of Oman. He has published one edited book chapters and several research papers.

## AUTHORS' PROFILES



Dr. Imtiaz Ali Khan currently working as a Professor in the Department of Mechanical Engineering, Aligarh Muslim University, Aligarh, India and has more than 28 years of teaching, research, and administrative experience. He is a Gold Medalist in M.Tech. He has worked as Director, Centre for Robotics, Artificial Intelligence, and Flexible Manufacturing Systems

(CRAIF), a government of India project. He has published one book, two edited book chapters and 27 research papers.



Shahnawaz Mohsin is an Associate Professor in the Mechanical Engineering Section at University Polytechnic, Aligarh Muslim University, Aligarh. He graduated with a B. Tech degree in Mechanical Engineering followed by M. Tech. (Machine Design) from Zakir Husain College of Engg. & Tech., Aligarh

Muslim University, Aligarh, India. He joined University Polytechnic in 1994. He has not only taught courses at under-graduate level, but also at