RESEARCH ARTICLE OPEN ACCESS

Ergonomic Design of Arc Welding Workstation Using Younger Age Group Operators

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ABSTRACT
Industrial jobs involving arm posture have a strong association with musculoskeletal disorders and injuries. It also affects the performance and effort (i.e. effort in holding, lifting, and lowering, etc.) of the worker. The current study is an attempt in that direction. This study involves the ergonomic design of arc welding workstations. Here work height, working distance and angle of work have been considered as anthropometric factors. Twenty-seven right-handed males of age group (18 to 30 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 indicated that the work height, distance of worker, and angle of work have a significant effect on operator's performance in the arc welding environment for younger age group subjects. It is further explored that interaction of work table height and workers distance has a significant effect on the performance of worker for these subjects. Further analysis according to the mean value comparison method revealed that 80 cm work height, 65 cm operator working distances and zero degree work angle resulted in optimum grip force, and 80 cm work height, 65 cm operator working distances and 40-degree work angle resulted in optimum welding time in case of 18-30 year age group workers.

Keywords- Arc-welding environment, Grip force, Load cell, Welding time, Younger age

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Date of Submission:03-05-2018 Date of acceptance: 19-05-2018

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, varioustasks 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 ofthework 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 40mm) 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 finger 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 degreean 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 degree 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 for 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 cospinal 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 coral 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.

Another anthropometric measurement of the isometric muscle strength of Chinese young males in Taiwan aged from 16 to 20 years was studied by [18], they used a sample of 120 male students and measured four types of muscle strength:

(a) Right arm strength in exerting a pull, push, adduction, abduction, lift, and press directions with five elbow angles (60, 90, 120, 150 and 180 degree) in seated posture;
(b) Grip strength of both hands;
(c) Back lift strength, and
(d) Chest expanding strength.

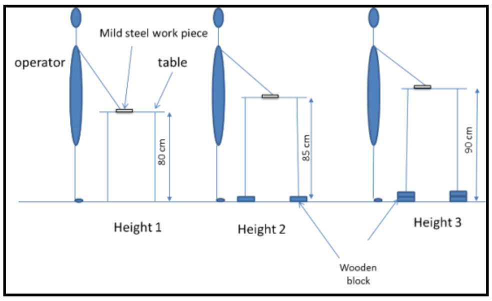
II. METHODS

2.1. Problem Statement

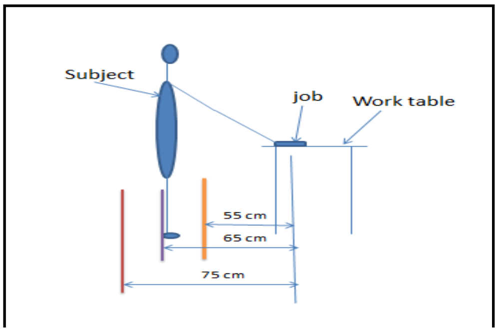
It is found on the basis of a literature survey and various pilot studies carried out that the main purpose of the ergonomics is to design workplaces that are suitable as well as comfortable to fit both body and the mind of the operators. In an industrial environment, various factors play a significant 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, the height of work), work position (height, distance and inclination to work), repetition of the work, the machine and their interaction environment are the main causes which affect the productivity of any system and musculoskeletal disorder MSD's 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.

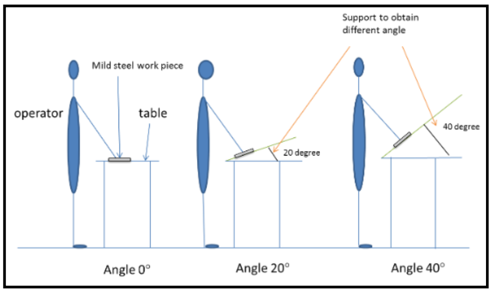
In this experimental work, study was conducted to evaluate the effect of welding work environment (in terms of height of the work table, angle of work table, and operator's working distance) on human performance, considering output measures as "grip force", and "productivity" (in terms of time) in an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

So, for developing the ergonomic database, studywascarried 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 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 havetried 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, height of the work table, operator working distance etc.

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 (18 to 30) 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 (18 to 30) years.

2.2. 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:

2.3. 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 and grip force. The work is placed on the work table,consideringthree, 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 tothe cylindrical electrode holder is measured by using 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 at a different position (i.e. hit and trial method) that the grip force at the middle finger was maximum.

Figure 2.2Electrode holders

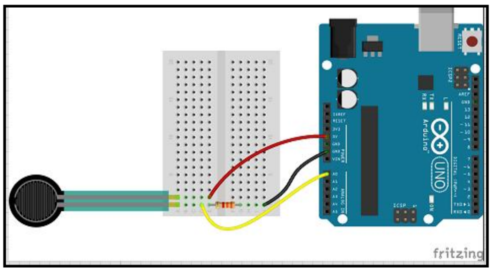


Figure 2.3Sensor attached to Arduino UNO

2.4. 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.

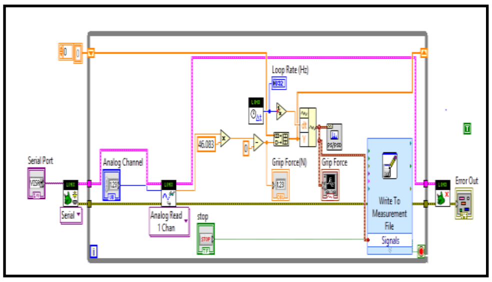


Figure 2.4LabVIEW program for grip force measurement

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 outputson 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 2.1.

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 increase in voltage in a less proportion. To avoid calculation complications, it is considered as linear.

Table 2.1Calibration 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

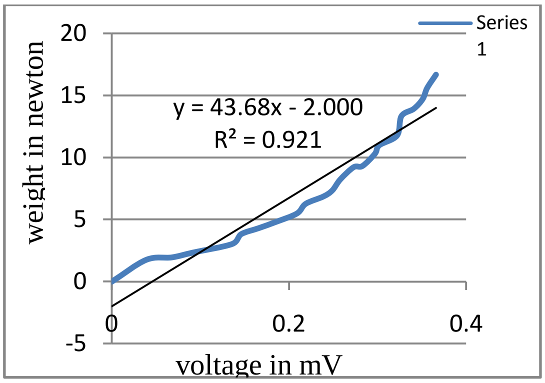


Figure 2.5Calibration graph of voltage output into force in Newton

The performance of each subject in this study was measured in term of time taken in 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.

In the present study, an experimental investigation was carried out for age group (18 to 30 years)selecting 27 subjects. All the subjects were of the same sex (male). In this group, age varies from 18 to 30 years with mean age of 24.7 years (all were students and employee of ZHCET, AMU). Selected subjects werenaive 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.

2.5. Experimental Procedure

The ergonomic design of "human performance" in the arc welding environment for age group (18 to30 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 required 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 atthe time taken and grip force to complete the job.

Figure 2.6Sensor placed on the middle finger

III. RESULTS

The experiment was carried out according to the procedural detail presented in section 2.5. Data were collected and thereafter analyzedthroughMinitab 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 as grip force and operation time is taken by the worker. Grip force is the measure of effort required to keep the electrode holder. The time taken for arc welding task and grip force was 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 3.1.

Table 3.1Observations of grip force and arc welding time

Height (cm)	Distance (cm)	Angle (degree)	Force (N)	Welding time (second)
80	55	0	10.08	17.25

80	55	20	10.321	16.7
80	55	40	11.205	15.35
80	65	0	9.535	17.35
80	65	20	10.09	17.05
80	65	40	10.955	15.46
80	75	0	12.325	18.91
80	75	20	11.913	17.55
80	75	40	12.875	16.33
85	55	0	11.545	21.3
85	55	20	12.054	17.85
85	55	40	12.973	18.43
85	65	0	11.258	18.91
85	65	20	11.985	16.5
85	65	40	12.247	17.1
85	75	0	12.876	19.55
85	75	20	12.849	19
85	75	40	13.342	17.82
90	55	0	12.84	20.8
90	55	20	13.256	18.1
90	55	40	13.543	20.13
90	65	0	12.15	20.2
90	65	20	12.872	19.65
90	65	40	12.987	18.83
90	75	0	13.338	22.67
90	75	20	13.85	20.13
90	75	40	14.851	21.35

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 18 to 30 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 3.2. The F-ratio was used in testing the statistical hypothesis and the level of significance for the test was set at 0.05.

Table 3.2Summary of Analysis of Variance for grip force

Source	DF	Adj SS	Adj MS	F-Value	p-Value	Percentage contribution
Height (cm)	2	23.2911	11.6455	160.75	0.000	55.1
Distance (cm)	2	11.9301	5.9651	82.34	0.000	28.22
Angle (degree)	2	4.6510	2.3255	32.10	0.000	11.00
Height (cm) x Distance (cm)	4	1.2819	0.3205	4.42	0.035	3.03
Height (cm) x Angle (degree)	4	0.2005	0.0501	0.69	0.618	0.47
Distance (cm) x Angle (degree)	4	0.3332	0.0833	1.15	0.400	0.788
Error	8	0.5796	0.0724			1.37
Total	26	42.2673				

On the basis of results indicated in Table 3.2 in reference to the height of the work table, we reject the null hypothesis, since observed F_{ob} = 160.752 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 work height 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 3.2 that the null hypothesis rejected because F_{cr} value $(F(2,8)_{.05})$ = 4.459 is less than the observed F_{ob} = 82.34 and also p-value approximately p_{ob} =0.00 is lesser than significance level i.e. α = 0.05. It indicates that the workers' distance has a strong significant effect, therefore it can be concluded that the variable workers' distance will have important consideration on human performance as far as human-arc welding interface is concerned. Moreover, in case of the angle of the work table, it can be observed from result Table 3.2, null hypothesis rejected because F_{cr} value $(F(2,8)_{.05})$ = 4.459 is less than the observed F_{ob}= 32.1 p-value is found P_{ob}= 0.00 is lesser than set significance level i.e. α = 0.05. It shows that the angle of work table affects the work environment,significantly. Therefore, it can be explored that the variable work table angle will have an important bearing on human performance as far as human-arc welding interface is concerned. Furthermore, in case of interaction of the work table angle and workers' distance, it can be observed from Table 3.2 that the null hypothesis accepted because F_{cr} value $(F(4,8)_{.05})$ = 3.8379 is greater than the observed F_{ob} = 1.15 and p-value is found 0.4, which is greater than setting significance level i.e. α = 0.05. As null hypothesis accepted it means there is no significant effect of the interaction of worker distance and work table angle. Therefore, it can be concluded that the interaction of work table angle and workers' distance will have not important consideration on human performance as far as human-arc welding interface is concerned. Moreover, in case of interaction of work table height and work table angle, it can be observed from Table 3.2 that the null hypothesis accepted because F_{cr} value $(F(4,8)_{.05})$ = 3.8379 is greater than the observed F_{ob} = 0.692 and p-value is found 0.618, which is greater than set significance level i.e. α = 0.05. As null hypothesis accepted it means no significant effect of interaction of work table height and angle of the work. Therefore, it can be stated that the interaction of work table height and angle will have no important impact on human performance as far as human-arc welding interface is concerned. Furthermore, in case of interaction of work table height and workers' distance, it can be observed from Table 3.2 that the null hypothesis rejected, because F_{cr} value $(F(4,8)_{.05})$ = 3.8379 is less than the observed F_{ob} = 4.424 and p-value is found

0.035, which is lesser than set significance level i.e. α = 0.05. As we know that the rejection of null hypothesis shows that the interaction of work height and operator distance has a significant effect. Therefore, it can be concluded that the interaction of work table height and workers' distance will have important consideration on human performance as far as human-arc welding interface is concerned.

On the basis of average percentage contribution determined for each performance characteristic of each factor in the arc welding environment, it is observed from Table 3.2 that height of work table has a maximum contribution (55.1%) followed by workers' distance (28.22%), work table angle (11%), interaction of work table height and workers' distance (3.03%), interaction of work table height and angle (0.788%) and interaction of worker distance and work table angle (0.47%), respectively. It is also observed that the average error percentage contribution in performance measure in the arc welding environment is 1.37%.

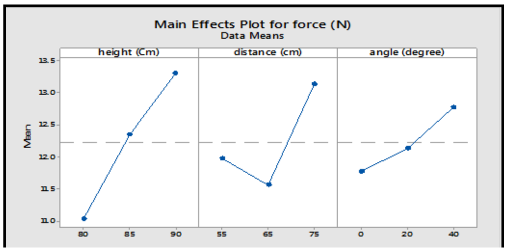


Figure 3.1Graph of the main effect for grip force

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 fromthe 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.

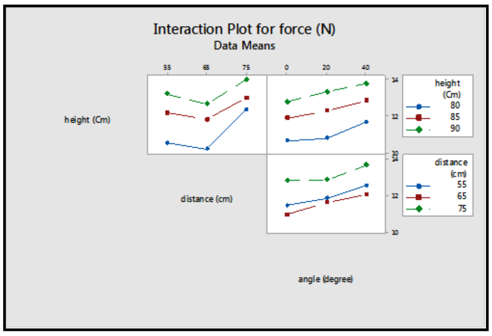


Figure 3.2Interaction plot for grip force

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 resultTable 3.2 indicates that there is a significant effect of interaction betweenthe 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. heightof 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 3.3. The F-ratio was used for testing the statistical hypothesis and the level of significance for the test was set at 0.05.

Table 3.3Summary of Analysis of Variance for time

Source	DF	Adj SS	Adj MS	F-Value	p-Value	Percentage contribution
Height (cm)	2	49.715	24.8576	50.30	0.000	55.26
Distance (cm)	2	8.470	4.2349	8.57	0.010	9.41
Angle (degree)	2	17.450	8.7248	17.66	0.001	19.39
Height (cm) x Distance (cm)	4	4.797	1.1993	2.43	0.133	5.33
Height (cm) x Angle (degree)	4	4.291	1.0726	2.17	0.163	4.77
Distance (cm) x Angle (degree)	4	1.281	0.3201	0.65	0.644	1.42
Error	8	3.953	0.4941			4.39
Total	26	89.956				

Considering the results shown in Table 3.3,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}= 50.30 and $(p\text{-value})_{ob}$ = 0.00 is lesser than [p-value]cr = 0.05 taken as significance level. It indicates that the height of work table has a significant effect on arc 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 3.3 that the null hypothesis rejected because F_{cr} value $(F(2,8)_{.05})$ = 4.459 is less than the observed F-value (F_{ob}) = 8.57 and p-value is found 0.01, which is lesser than set significance level i.e. α = 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 on human performance. Moreover, in case of work table angle, it can be observed from Table 3.3 that the null hypothesis rejected because F_{cr} value $(F(2,8)_{.05})$ = 4.459 is less than the observed F-value (F_{ob}) = 17.65and p-value is found P_{ob} = 0.001, which is lesser than significance level i.e. α = 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 3.3, that the null hypothesis accepted because F_{cr} value $(F(4,8)_{.05})$ = 3.8379 is greater than the observed F_{ob}=.648 and p-value is found P_{ob}= 0.644, which is greater than significance level i.e. α=0.05. It indicates that the interaction of distance and angle of work table does not affect significantly the performance of workers. Moreover, in case of interaction of work height and angle, it can be observed from Table 3.3 that the null hypothesis accepted because F_{cr} value $(F(4,8)_{.05})$ = 3.8379 is greater than the observed F_{ob} = 2.171, and p-value is found P_{ob}= 0.163, which is greater than set significance level i.e. α=0.05. It indicates that the interaction of work table height and angle does not affect significantly the performance of operators. Therefore, it can be concluded that the interaction of work table height and work angle do not 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 working distance, it can be observed from Table 3.3 that the null hypothesis accepted because F_{cr} value $(F(4,8)_{.05})$ = 3.8379 is greater than the observed F_{ob} = 2.427 and p-value is found 0.133, which is greater than set significance level i.e. α = 0.05. It shows that the interaction of height and distance do not affect significantly the performance of the worker.

On the basis of the average percentage contributionof each factor's performance characteristic ofthe arc welding environment, it is observed from Table 3.3that height of work table has a maximum contribution (55.26%) followed by work table angle (19.39%), working distance (9.41%), interaction of work table height and working distance (5.33%), interaction of work table height and angle (4.77%) and interaction of working distance and work table angle (1.42%), respectively. It is also observed that the average error percentage contribution in performance measure in the arc welding environment is 4.39%.

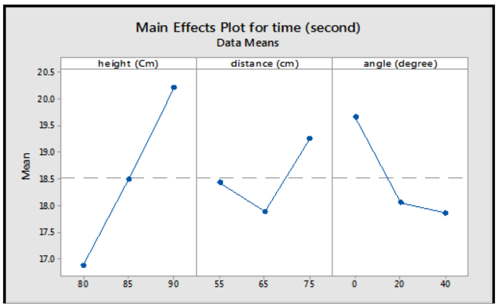


Figure 3.3Graph of the main effect for welding time

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 upto 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.3.4),the angle of work table vs time that the increase in work table angle causesa decrease in 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) The interaction of work height and working distance has a significant effect on grip force and arc welding operation time.

IV. DISCUSSION

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, 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 younger age group(18 to 30 years) subjects, the height of the welding work table, distance of operator from work, andthe 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 workangle. 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 18 to 30 years age, the arc welding operation time is optimum at a work height 80 cm, working distance 65 cm and work angle 40 degree. As for height increase the time taken to complete the welding job increases, and increasing or decreasing work height from 80 cm and working distance from 65 cm, results in an increase in arc welding operation time. Whereas,with the increase in angle of the work table,the time taken to complete the welding job decreases. Increase in work height resultsin 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 working distance 65 cm.

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 effectin case of arc welding operation time. Moreover, other interactions, namely workheight 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. Therefore, on the basis of the results obtained through this study, it can be explored that, at work height (80 cm), working distance (65 cm) and work angle (20 degree), the productivity of the 18-30 year age group operators arehighest in an arc welding environment. Therefore, it can be concluded that the above parameter combination will have an important bearing on human performance as far as human-arc welding interface is concerned.

V. 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 as well as arc welding operation time is concerned.
(ii) The interaction of work height and working distance affects operator performance significantly in case of grip force. Other interactions indicate 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 20 degrees.

(iv) On the basis of an experimental investigation carried out, it was explored that the height of the work, working distance and angle of work in 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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Shahnawaz Mohsin "Ergonomic Design of Arc Welding Workstation Using Younger Age Group Operators"International Journal of Engineering Research and Applications (IJERA), vol. 8, no.5, 2018,