AN EXPERIMENTAL STUDY ON ASSEMBLY WORKSTATION CONSIDERING ERGONOMICALLY ISSUES

Ibrahim H. Garbie

Department of Mechanical and Industrial Engineering, Sultan Qaboos University
P.O.Box 33, Al-Khoud 123, Muscat, Sultanate of Oman, Email: garbie@squ.edu.om

ABSTRACT

This paper describes the results of an experimental study conducted to investigate the effects of assembly of a product on operator performance. A fully adjustable ergonomically designed assembly workstation (smart workstation) was used for the experiment. Ten college students (five boys group and five girls group) randomly assigned into three experimental conditions (table adjustable, chair adjustable, and gender) performed the assembly task. Performances of the participants assembling a product are: operator production rate representing in how many assembly products per unit time (units/hour). The regression model to measure the operator performance was built based on the experimental work using Minitab Statistical Software package. The results shows that female are more productive than male.

Keywords: Ergonomic design, flexible workstation, experimental design

1. INTRODUCTION

Ergonomics is concerned with making the workplace as efficient, safe and comfortable as possible. Effective application of ergonomics in work system design can achieve a balance between worker characteristics and task demands. This can enhance operator productivity, provide worker safety and physical and mental well-being and job satisfaction. Many research studies have shown positive effects of applying ergonomic principles in workplace design, machine and tool design, environment and facilities design [1-9].

Research studies in ergonomics have also produced data and guidelines for industrial applications. The features of ergonomic design of machines, workstations, and facilities are well known [10-17]. However, there is still a low level of acceptance and limited application in industries, especially in developing countries. The main concern of work system design is usually the improvement of machines and tools. Inadequate or no consideration is given to the work system design as a whole. Therefore, poorly designed work systems are a common place in industry [4 and 11]. Neglect of ergonomic principles brings inefficiency and pain to the workforce. An ergonomically deficient workplace can cause physical and emotional stress, low productivity and poor quality of work [18-19].

Workstation should be laid out such that it minimizes the working area so that while carrying out the operations the worker could use shorter motions and expend less energy and thus reduce fatigue. Das and Grady [12] reviewed the concept of workspace design and the application of anthropometric data. It indicated that an adjustable chair and a workbench of standard size were highly desirable at the workplace. However, the standard height of the workbench could not be defined without the anthropometric data of the user population. Many of the user population do not have anthropometric data. It is therefore, desirable also to have the worktable adjustable [20-21].

A study by Yeow [22] concentrated on improving productivity as well as health and safety of workers in a printed circuit assembly (PCA) factory. The improvement involved the use of an ergonomically designed workstation with other ergonomic intervention such as clear segregation of tested and untested boards to prevent mix-up and retraining of operators by more qualified trainers. This had resulted in an improvement in quality and productivity of the workers, reduction in rejection rate as well as an increase in the revenue. The use of an ergonomically designed workstation and better structured processes along with other features, such as improved lighting, shelves and containers for parts and display boards, had helped and solved the problems of assembly processes at a German company [23]. The objective of this research was to study the productivity of operator by assembly a product on the smart workstation for a repetitive industrial assembly task taken into consideration table, chair adjustable and type of gender.

2. METHODOLOGY

The experimental study was conducted in the Ergonomics Lab of the Department following a sound methodology. Details of the study elements are described in the following sections.

2.1 The Task

The selected task was an assembly task from a local electrical company, assembly of fused electrical switch that consisted of eight parts. Usually, simulated tasks are chosen for research purposes that do not represent real life industrial tasks. Manual assembly of switches is a common task in electrical industry. The selected task was a highly repetitive task and it was performed on workstations that were not designed ergonomically. Also, the task method was not designed following ergonomic principles. The assembly task involved picking up the switch base and cover from the bins, assembling all the inside parts in the base, putting the cover, tightening the assembly using a screwdriver and placing it in the outgoing bin. The steps of the assembly task were modified in the new design considering motion study and ergonomic principles. A jig was designed and used in the performance of the task on the smart workstation. A power screwdriver was used for tightening the cover in the modified task method.

2.2. Participants

Ten college students (five boys group and five girls group) participated in the experimental study on a voluntary basis. The average age of the participants was 21.5 yrs with a standard deviation of 1.11 yrs. Mean stature was 1850 mm with a standard deviation of 101 mm. This indicated a significant size difference among the participants. The participants had no prior experience on the assembly task. They were given instructions on the assembly workstations and task and trained for 15 minutes on the task, as required based on their experimental conditions. Fifteen minutes training was considered adequate as the assembly task was not a complex task according to the learning rate. Environmental condition (light, temperature, humidity and noise) was comfortable and kept constant. The participants wore light and comfortable clothes.

2.3. The Experimental Study

Experiments were conducted using an ergonomically designed smart assembly workstation. Details of the ergonomically designed smart assembly workstation were reported in [11].

2.3.1. The Smart Assembly Workstation

The smart assembly workstation was designed and developed considering ergonomics in all aspects of design and layout with full adjustability. The size of the tabletop (work surface) was calculated based on the mean reach of the user population with an allowance. A special table frame was designed for the vertical and angular movements of the tabletop using small motors. The frame mechanism was designed for precise movements of the tabletop. Push-button switches were provided for the control of these movements. Operators could adjust the tabletop to their most preferred work heights. The table could be used for sit, stand, and sit-stand assembly workstations. Attachments were provided to the frame for bins and tools holders for adjustments. A fully adjustable ergonomic chair was provided to the operators. Major features of the ergonomic adjustable chair were: adjustable seat height by gas suction, adjustable and titled back support, tilted seat pan covered with porous and breath-able material, removable and adjustable arm rests, footrest and a foot ring.

An adjustable hydraulic footrest was provided for the operators. The existing hand tools were replaced with a power screwdriver that was supported by a balancer in front of the operator. The workplace layout was made according to the calculated normal and maximum work areas. Squire's method was adopted in the calculation. The bins were laid out based on this calculation and in a logical work sequence and a systematic method. Figures (1-2) show the isometric view and the schematic layout of the ergonomically designed smart assembly workstation, respectively. An improved work method following the assembly of parts sequence was developed for the task performance on this workstation. A jig was designed for ease of holding the base of the switch.

2.3.2 Experimental Setup

The ergonomically designed smart workstation was installed and set up in the Ergonomics Lab. Tables 1 shows the experimental conditions. Experiments were conducted at random times but not in the same week on both groups. Boys group was implementing their tasks in different time than girls group. Three factors are considered in the experimental work: table adjustable; chair adjustable and gender. With respect to table adjustable, there are five levels of experimental to adjust the table taking into consideration the ground floor as a reference point: 23.5, 27.5, 31.5, 35.5, and 39.5 cm. Also with respect to chair adjustable, there are five levels: 18.5, 19.75, 21, 22.25 and 23.50 cm. Regarding the gender, the conducted experimental includes two levels (male and female). Each experimental was conducted twice (number of replicates = 2) and the performance measurements are recorded based on performance measure: operator output (e.g., production rate). Participants were given a demonstration and then trained for 15 minutes the smart workstations and methods before starting the experimental sessions. Each participant had assembled electrical switches for one hour duration under his experimental condition randomly and the operator performance was recorded in terms of number of switches assembled (units/hr), operator satisfaction and operator health. A complete factorial design for different levels of independent variables is planned in 100 experimental (50 setups) with two replicates for each response. Tables 2 is used to display the observed data from the conducted experimental.

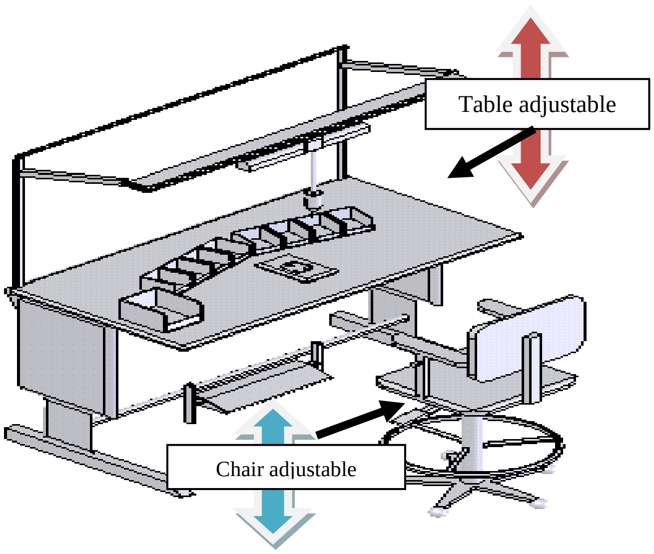
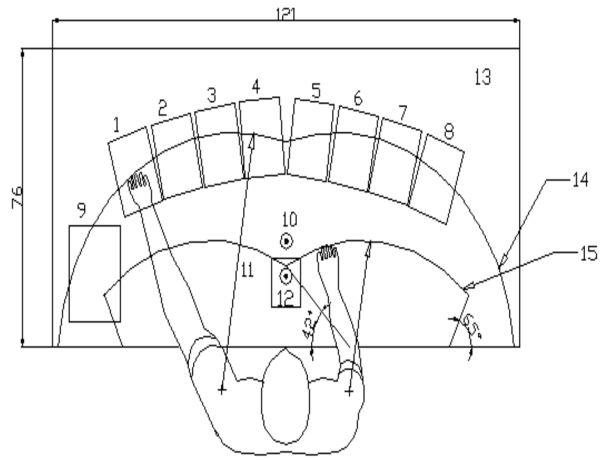


Figure 1: Isometric view of the workstation [21]



All dimensions are in cm

Legend: 1. Pin 1 bin; 2. Pin 2 bin; 3. Connector bin; 4. Screw bin; 5. Cover 2 bin; 6. Fuse bin; 7. Pin 3 bin; 8. Cover 2 bin; 9. Outgoing bin; 10. Power screwdriver; 11. Assembly area; 12. Fixture; 13. Assembly table; 14. Maximum reach; 15. Normal area proposed by Squires.

Figure 2: Schematic layout of the workstation [21]

Table 1: Experimental conditions with different factors and levels

Factors	**Levels**
Table adjustable (cm), (***T***)	23.5, 27.5, 31.5, 35.5, 39.5
Chair adjustable (cm), (***C***)	18.5, 19.75, 21.0, 22.25, 23.50
Gender (type), (***G***)	Male (***M***), Female (***F***)

Table 2: Data from experimental conditions with Operator output (Units/hour)

		Gender (*G*)									
		Male (*M*)					**Female (*F*)**				
		Table adjustable (cm), (*T*)					**Table adjustable (cm), (*T*)**				
		23.50	**27.50**	**31.50**	**35.50**	**39.50**	**23.50**	**27.50**	**31.50**	**35.50**	**39.50**
Chair Adjustable (cm), (*C*)	**18.50**	116	80	90	72	72	146	148	182	211	173
		119	83	83	87	76	157	163	178	226	224
	19.75	105	108	108	76*	65	131	146	189	169	137
		109	105	117	87	94	132	119	208	137	154
	21.00	98	94	98	98	76	134	152	135	170	187
		72	87	98	87	54	138	184	112	103	193
	22.25	83	76	108	105	87	115	179	127	160	154
		65	105	108	80	101	109	124	143	154	175
	23.50	69	69	83	83	98	165	158	223	165	156
		58	80	83	137	98	143	198	297	158	171

(*) is the measured value of production rate (units per hour)

3. RESULTS AND DISCUSSION

The operator performance data were summarized in Table 2 and analyzed using Minitab Statistical Software Package for analysis of variance (ANOVA) and regression models for each performance measure sequentially. The data presented in Table 3 are analyzed with the analysis of variance (ANOVA) technique. It seems from Table 3 that the main effects of the three factors (*T*, *C* and *G*) and the interactions effects (*TC*, *TG*, *CG* and *TCG*) are significant on production rate based on p-values which are less than 0.05. For this reason, they have been included in a regression model to build a mathematical formulation between these factors and production rate. It can be observed from Figure 3 that table adjustable with third level (31.50 cm) is the highest on production rate among all levels and there is no difference between fourth and fifth levels. This means that it is not needed to raise a table up to 39.50 cm (fifth level). With respect to chair adjustable, the first level (18.50 cm) and the fifth level (23.50 cm) are representing the highest values on production rate and there is no difference between third and fourth levels in the chair adjustable. This means it does not matter to raise a chair up to 21.00 cm (third level) or 22.25 cm (fourth level). Regarding gender, female are more productive than male in the assembly stations. With respect to interaction effect between table adjustable and chair adjustable, it can be noticed from Figure 4 that third level of table adjustable (31.50 cm) with fifth level of chair adjustable (23.50 cm) is representing the highest value of production rate. Regarding interaction effect of table with gender, it can be observed from Figure 5 that table adjustable with third level (31.50 cm) with female represents the highest values in production rate among all levels. Also, the interaction effect between chair adjustable and gender is producing the highest value in production rate with first level and/or fifth level of chair adjustable with gender (female) (see Figure 6). It is recommended hiring female in assembly workstation especially which has adjustable chair and table. It can be concluded from this analysis that third level of table adjustable; fifth level of chair adjustable with female will give high productivity of operator performance.

Table 3: Analysis of variance for production rate

Source	DF	SS	MS	F	P-value
Table adjustable	4	6628.7	1657.2	5.91	0.001
Chair adjustable	4	5810.2	1452.5	5.18	0.001
Gender	1	129024.6	129024.6	460.08	0.000
Table adj*Chair adj	16	13595.3	849.7	3.03	0.001
Table adj*Gender	4	5199.7	1299.9	4.64	0.003
Chair adj*Gender	4	9461.4	2365.3	8.43	0.000
Table adj*Chair adj*Gender	16	22572.3	1410.8	5.03	0.000
Error	50	14022.0	280.4		
Total	99	206314.2			

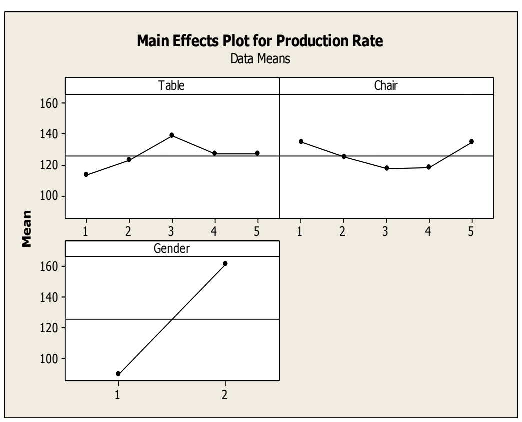


Figure 3: Main effects of table adjustable, chair adjustable and gender on production rate

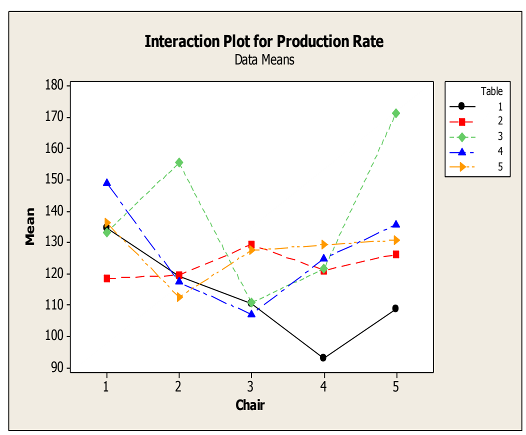


Figure 4: Interaction effect of table and chair on production rate

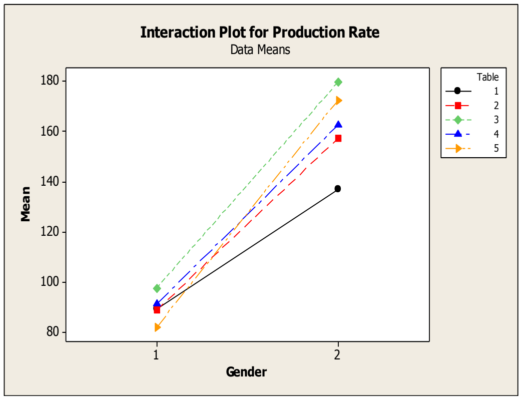


Figure 5: Interaction effect of table and gender on production rate

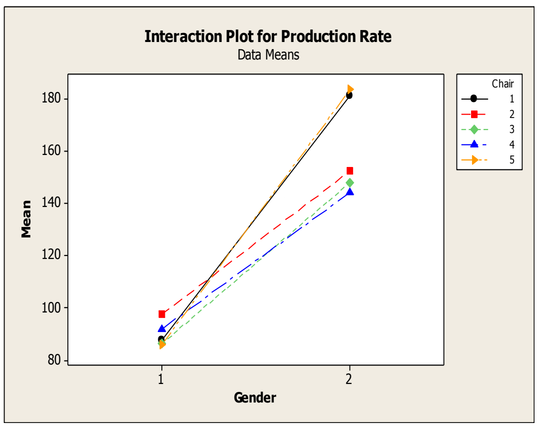


Figure 6: Interaction effect of chair and gender on production rate

The response function representing the production rate (P) is expressed as the following equation (1):

$$P = f(T, C, G) \qquad (1)$$

Where:
P: the production rate (response) or yield (units/hour),
T: table adjustable,
C: chair adjustable,
G: gender

A regression model is used to present the results of a designed experiment in a quantitative form. The second-order polynomial is capable of assuming a wide variety of shapes and it is a very flexible regression model [24-25]. The second order polynomial (regression) equation is used to represent the response (production rate) for K factors by using the following equation (2):

$$P = B_o + \sum_{i=1}^{K=3} B_i X_I + \sum_{i,j=1}^{K=3} B_{ij} X_i X_j + \sum_{i=1}^{K=3} B_{ii} X_i^2 \qquad (2)$$

Where:
B_o is the free term of the regression model, $B_i\,(B_1, B_2, \ldots\ldots, B_K)$ are the linear terms, $B_{ij}\,(B_{12}, B_{13}, \ldots\ldots, B_{K-1})$ are the interaction terms, $B_{ii}\,(B_{11}, B_{22}, \ldots\ldots, B_{KK})$ are the quadratic terms

The values of the coefficients of the polynomial of equation (2) are calculated by the regression model. The Minitab Statistical Software Package has also been used to calculate the values of these coefficients. The mathematical model as determined by above analysis is given as the following equation (3) and it is considered as a full initial regression model representing the production rate (units/hour) of assembly smart workstation.

$$\left.\begin{array}{l} P_{Inital} = 72.3 + 5.7T - 31.7C + 43.4G + 1.31TC + \\ \quad 8.81TG + 0.66CG - 3.27T^2 + 4.36C^2 \end{array}\right\} \quad (3)$$

The G^2 term (gender) has been removed from the equation through the Minitab Statistical Software Package because it has highly correlated with other variables. Summary of initial full regression model for production rate estimation is shown in Table 4. It can be noticed from Table 4 that C, G, T^2, C^2 and TG interaction were found to have significance on production rate although C and T^2 have negative effects but T, TC and CG have no significance effect based on p-values ($p < 0.05$). Testing of significance of regression model is evaluated through p-value equals 0.00 less than 0.05 (95.00% confidence level) although the determination of coefficient of initial regression model (R^2) was 69.8 % and the associated adjusted determination of coefficient (R^2-adj) was 67.2%.

Table 4: Summary of initial full regression model of production rate

Predictor	Coefficient	SE Coef	T-test	P-values
Constant	72.35	32.59	2.22	0.029
Table	5.66	11.73	0.48	0.631
Chair	- 31.74	11.73	- 2.71	0.008
Gender	43.43	16.54	2.63	0.010
Table*Chair	1.310	1.308	1.00	0.319
Table*Gender	8.810	3.699	2.38	0.019
Chair*Gender	0.660	3.699	0.18	0.859
Table^2	-3.268	1.563	-2.09	0.039
Chair^2	4.364	1.563	2.79	0.006

S = 26.1560   R-Sq = 69.8%   R-Sq(adj) = 67.2%

ANOVA for testing significance of initial regression model

Source	DF	SS	MS	F	P-value
Regression	8	144058	18007	26.32	0.000
Residual Error	91	62256	684		
Total	99	206314			

When R^2 and R^2-adj are not different dramatically, there is a good chance that significant terms have been included in the regression model [24-25] although R^2 and R^2-adj are not large enough. However, as it has noted in Table 4 that a large value of R^2 and R^2-adj does not necessarily imply the regression model is a good one and provide accurate predictions of future observations. R^2 is a measure of the amount of reduction in the variability of production rate by using the regressor variables. It is recommended to drop the insignificant terms (*T, TC* and *CG*) in the initial full regression model to let it more accurate, easy manipulate and consistency [26]. These data are presented in Table 5 and are considered a modified regression model. The new modified mathematical model of production rate determined by the modified regression model is given as the following Equation (4). It can be observed from Table 5 that all independent variables (*C, G,* T^2, C^2 and *TG* interaction) were found to have significance on the production rate with little bit changes in R^2 and R^2-adj although *C* and T^2 still have negative effects on production rate. The final summary of the experimental work is presented in Table 6.

$$P_{Modified} = 73.7 - 26.8C + 40.6G + 10.4TG - 2.12T^2 + 4.36C^2 \tag{4}$$

Table 5: Summary of modified regression model of production rate

Predictor	Coefficient	SE Coef	T	P-values
Constant	73.69	17.26	4.27	0.000
Chair	-26.816	9.497	- 2.82	0.006
Gender	40.58	10.86	3.74	0.000
Table*Gender	10.421	3.178	3.28	0.001
Table^2	-2.1174	0.8218	- 2.58	0.012
Chair^2	4.364	1.553	2.81	0.006

S = 25.9867   R-Sq = 69.2%   R-Sq(adj) = 67.6%

ANOVA for testing significance of modified regression model

Source	DF	SS	MS	F	P-value
Regression	5	142835	28567	42.30	0.000
Residual Error	94	63479	675		
Total	99	206314			

Table 6: Summary of Experimental work

Performance measure		Table adjustable (T)	Chair adjustable (C)	Gender (G)	
				Male	Female
Productivity (P)	Factors	3rd level	5th level		Significant
	Model	$P = 73.7 - 26.8C + 40.6G + 10.4TG - 2.12T^2 + 4.36C^2$			

4. CONCLUSIONS AND RECOMMENDATION

The following conclusions were drawn from this experimental study:

1. Operators' performance with regard to productivity with the ergonomically smart assembly workstation condition is studied and investigated.
2. The fully adjustable ergonomically designed smart assembly workstation was preferred by the operators and they adjusted and organized the workstation to their comfort.
3. Workstations for assembly tasks should be designed so that any operator can adjust to his/her comfort to relieve stress and improve performance. The ergonomically designed smart assembly workstation is a solution to ergonomic and productivity problems in the workplace.
4. Female (women) are more productive than male (men).
5. Creating a regression model representing operator performance (productivity) was built based on the experimental work.

The main contribution of this work is how to measure the production rate of manual assembly lines based on design ergonomically assembly workstation. The author plans to conduct the future research in real life case studies through validation this research in different sectors of industries (manufacturing parts, food industry and so on) and presented a new performance measure for each specified operator in these sectors.

REFERENCES

[1] Hasselquist, R.J., 1981. Increasing manufacturing productivity using human factors principles. Proceedings of the Human Factors Society – 25th Annual Meeting, pp. 204-206.

[2] Schnauber, H., 1986. Ergonomics and productivity as reflected in a new factory. Trends in Ergonomics/Human Factors III, Karwowski Ed., Elsevier Science Publishers, pp. 459-465.

[3] Ryan, J.P., 1989. A study of selected ergonomic factors in occupational safety. Advances in Industrial Ergonomics and Safety I, Anil Mital Ed., Taylor and Francis, pp. 359-364.

[4] Das, B., 1987. An ergonomic approach to designing a manufacturing work system. Int. J. of Industrial Ergonomics. 1(3), 231-240.

[5] Resnik, M.L., Zanotti, A., 1997. Using ergonomics to target productivity improvements. Computers and Industrial Engineering. 33(1/2), 185-188.

[6] Burri, G.J., Helander, M.G., 1991. A field study of productivity improvements in the manufacturing of circuit boards. Int. J. of Industrial Ergonomics. 7, 207-215.

[7] Shikdar, A., Das, B., 1995. A field study of worker productivity improvements. Applied Ergonomics. 26(1), 21-27.

[8] Das, B., Sengupta, A., 1996. Industrial workstation design: A systematic ergonomic approach. Applied Ergonomics, 27(2), 157-163.

[9] Das, B., Shikdar, A., 1999. Participative versus assigned production standard setting in a repetitive industrial task: a strategy for improving worker productivity. Int. J. of Occupational Safety and Ergonomics. 5(3), 417-430.

[10] Grandjean, E., 1988. Fitting the task to the man: An ergonomic approach, Taylor and Francis, London.

[11] Konz, S., 1995. Work design: Industrial Ergonomics, 2nd edn, Grid Columbus, Ohio.

[12] Das, B., Grady, R.M. 1983. Industrial workplace layout design: An application of engineering anthropometry. Ergonomics. 26(5), 433-443.

[13] Salvendy, G., 1987. Handbook of Human Factors. John Wiley, New York.

[14] Melamed, S., Luz, J., Najenson, T., Jucha, E., Green, M., 1989. Ergonomic stress levels, personal characteristics, accident occurrence and sickness absence among factory workers. Ergonomics. 9, 1101-1110.

[15] Sanders, M.S., McCormic, E.J. 1992. Human Factors in Engineering and Design, 6th edn, McGraw Hill, New York.

[16] Wilson, J.R., Corlett, E.N., 1992. Evaluation of Human Work: A Practical Ergonomics Methodology. Taylor and Francis, Philadelphia.

[17] McLeod, D., 1995. The Ergonomics Edge: Improving Safety, Quality and Productivity, John Wiley, New York.

[18] Ayoub, M.A., 1990a. Ergonomic deficiencies: I. Pain at work. J. of Occupational Medicine. 32(1), 52-57.

[19] Ayoub, M.A.1990b. Ergonomic deficiencies: II. Probable causes. J. of Occupational Medicine. 32(2), 131-136.

[20] Shikdar, A., Al-Hadhrami, M., 2007. Smart workstation design: an ergonomics and methods engineering approach. Int. J. of Industrial and Systems Engineering. 2(4), 363-374.

[21] Shikdar, A., Garbie, I., Khadem, M., 2011. Development of a smart workstation for an assembly task. Proceedings of the 2011 International Conference on Industrial Engineering and Operations Management (IEOM), Kula Lumpur, Malaysia, January 22-24, 2011.

[22] Yeow, P.H.P., 2003. Quality, productivity, occupational health and safety and cost effectiveness of ergonomic improvements in the test workstations of an electronic factory. Int. J. of Industrial Ergonomics 32(3), 147-163.

[23] Anon, A., 2005. Workstations, track system smooth assembly. Assembly. 48(4), 32-35.

[24] Montgomery, D.C., 2009. Design and Analysis of Experiments. 7th Edition, John Wiley and Sons, Inc., Hobaken, NJ, USA.

[25] Montgomery, D.C., and Runger, G.C., 2011. Applied Statistics and Probability for Engineers. 5th Edition, John Wiley and Sons, Inc., Hobaken, NJ, USA.

[26] Navidi, W., 2008. Statistics for Engineers and Scientists. 2nd Edition, Mc Graw Hill, New York, NY, USA.