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Operator Performance and Satisfaction in an Ergonomically Designed Assembly Workstation

A.A. Shikdar* and M.A. Al-Hadhrami

Department of Mechanical and Industrial Engineering, Sultan Qaboos University, P.O. Box 33, Al-Khod 123, Muscat, Sultanate of Oman

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أداء ورضاء العامل في استخدام محطة التجميع ذو التصميم الأورغونومي

االمستخلص: تهدف هذة الدراسة في البحث عن المؤثرات في اداء ورضا العمال باستخدام محطة عمل ذو تصميم إرغونومي لأعمال التجميع المتكررة في المصانع. حيث تم عمل التجارب باستخدام محطة العمل الحالية و الجديدة ذو التصميم الاورغونومي في المصنع الذي تم اختياره لهذه الدراسة باستخدام عمال ممن يقومون بنفس العمل.

من خلال التجارب اظهرت النتائج تطوراً في الانتاجية لدى العمال بنسبة ٢٧٪ باستخدام محطة العمل الجديدة مقارنة بمحطة العمل الحالية. كما أظهرت نتائج الاستبيان بان رضا العمال زادت بنسبة ٤١٪ باستخدام محطة العمل الجديدة. ان محطة العمل الجديدة ذو التصميم الاورغونومي المستخدمة للتجميع المتكرر كان لها الأثر الايجابي في زيادة الانتاجية والرضا لدى العمال. أهم ما يميز محطة العمل الجديدة هو ضبط ارتفاع الطاولة ووجود مساحة كافية للعمل. كرسي بميزات اورغونومية، أدوات يدوية بتصميم أورغونومي وتوزيع منظم لأجزاء محطة العمل.

المفردات المفتاحية: زمن الدورة، اداء ورضا العامل ، محطة عمل بتصميم عادي، محطة عمل بتصميم اورغونومي، عمل التجميع.

Abstract: The objective of this study was to investigate the effects on operator performance and satisfaction of an ergonomically designed workstation for performing a repetitive industrial assembly task. Experiments were conducted in a company with industrial workers using existing and newly developed workstations. Operator performance on the ergonomically designed workstation was 27% higher compared to the existing non-ergonomically designed workstation. Worker satisfaction score was also improved by 41% in the ergonomically designed workstation condition. The new workstation for a repetitive assembly task had highly significant positive effect on worker performance and satisfaction. Special features of the ergonomically designed assembly workstation were an adjustable and adequate worktable, an adjustable and ergonomically designed chair, ergonomically designed hand tools and a systematic layout of the workstation components.

Keywords: Cycle time, Operator performance and satisfaction, Ergonomically designed workstation, Assembly task

1. Introduction

Worker productivity and satisfaction improvements are a major concern in industry, especially for repetitive tasks such as short-cycled assembly. These tasks are considered boring, monotonous, fatiguing and de-motivating. This, in turn, results in reduced worker productivity, poor work quality, higher absenteeism and causes detrimental effects on worker physical and mental well being Shikdar and Das, (1995). Improving worker productivity in such tasks is, therefore, a major challenge, especially for the management.

Ergonomics is concerned with making the workplace as efficient, safe and comfortable as possible. Effective application of ergonomics in work system design must achieve a balance between worker characteristics and task demands. This can enhance worker productivity, provide worker safety as well as physical and mental well-being and job satisfaction. Many research studies have shown the positive effects of applying ergonomic principles in workplace design, machine and tool design, and environment and facilities design (Hasselquist, 1981; Schnauber, 1986; Ryan, 1989; Das, 1997; Resnik and Zanotti, 1997; Burri and Helander, 1991; Shikdar and Das, 1995; Das and Sengupta, 1996; Das and Shikdar, 1999).

Research studies in ergonomics have produced data and guidelines for industrial applications. The features of ergonomic design of machines, workstations, and facilities are well known (Grandjean, 1988; Konz, 1995; Das and Grady, 1983; Salvendy, 1987; Melamed *et al*. 1989; Sanders and McCormick, 1992; Wilson and Corlett, 1992;

*Corresponding authors E-mail: ashraf1@squ.edu.om

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McLeod, 1995). However, there is still a low level of acceptance and limited application of ergonomics in industry, especially in developing countries. The main concern of work system design is the improvement of machines and tools. Inadequate or no consideration is given to the design of the work system as a whole. Therefore, poorly designed systems are a common place in industry (Konz, 1995; Das, 1987). 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 (Ayoub, 1990a, 1990b).

A workstation should be laid out such that it minimizes the working area so that while carrying out the operations the worker uses shorter motions and expends less energy. This will reduce fatigue. The concept of workspace design and the application of anthropometric data had been reviewed by Das and Grady (1983). It was established that an adjustable chair was highly desirable for the workplace as well as a standard size workbench. However, the standard height of the workbench cannot be defined without the anthropometric data of the user population.

It was believed that application of ergonomics in the design of repetitive assembly tasks, including redesigning workstations and tasks, would not only improve worker safety and work quality, but it would also reduce cycle time and thus improve worker productivity significantly. An earlier study conducted in the laboratory with a simulated repetitive manufacturing task showed significant improvement in operator performance Shikdar *et al.* (1997). However, this study did not consider a fully adjustable workstation and a real life task situation. The objective of this research was to study the effects on operator performance and satisfaction of an ergonomically designed workstation for a repetitive industrial assembly task.

2. Methodology

The methodology adopted in the conduct of this study was to select a representative real life industrial assembly task, study the workstation thoroughly and task performance on the workstation, redesign the workstation ergonomically and conduct experiments to assess the effects on operator performance (measured in terms of work cycle time) and satisfaction.

2.1. Assembly Task

The selected task was an assembly of an electrical switch (molded case circuit breaker, MCCB) that consisted of 14 parts. Usually, simulated tasks chosen for research purpose does not represent real life industrial tasks. Manual assembly of switches is a common task in the electrical industry. The selected assembly task was a highly repetitive task. 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 base and cover from the incoming bins, assembling all the inside parts in the base, putting the cover on, tightening the assembly using a power screwdriver and placing it in the outgoing bin. Considerable maneuvering and correcting motions were required for the task performance. The assembly steps were modified in the new design by incorporating motion study and ergonomic principles.

2.2. Participants

The participants were ten assembly operators from a local electrical manufacturing company. They were selected based on their experience in the selected and similar tasks, adequate training in the selected task, education and commitment to complete the study. All the participants were Omani and Indian male and their average age was 25.2 yrs, with a standard deviation of 6.18 yrs. The mean stature of the sample was 1679 mm with a standard deviation of 55.47 mm. Education of the participants ranged from primary to trade diplomas. The average experience of the participants in this and similar tasks was 2.5 yrs. This was considered adequate for this study. The participants had full support from the management.

2.3. Existing Workstation

An existing workstation was provided by the company and brought to our Ergonomics Laboratory. The workstation was thoroughly analyzed to identify ergonomic deficiencies with respect to work height, work areas, seating, posture, clearances, hand tools and layout. In general, it was found that no ergonomic consideration was given to the existing workstation. The task was performed in a sitting posture using a chair which did not have an adjustable back support, tilt mechanism and appropriate cushioning. The table height was too low and fixed (h=740 mm) with inadequate work area for laying out components. The operators were unable to maintain a natural work posture. Working under such conditions for prolonged period could lead to shoulder stress and back pain (Grandjean, 1988). The hand tools were poorly designed and not suitable for operator's ease of use and comfort. These were not ergonomically designed, including no handle for the file and an inadequate handle for the screwdriver. Environment was not given adequate consideration as noise level was high and lighting was poor.

The layout of the workplace did not consider any systematic guidelines. The components were placed on the worktable without considering functional use and normal and maximum work areas. The incoming bin was placed on a side table and outgoing bin was placed on the floor on the same side. Figure 1 shows the layout of the existing workstation with the normal and maximum work areas superimposed. It can be seen that the bins were laid outside the maximum reach area.

2.4. Ergonomically Designed Workstation

The workstation was then redesigned using ergonomic

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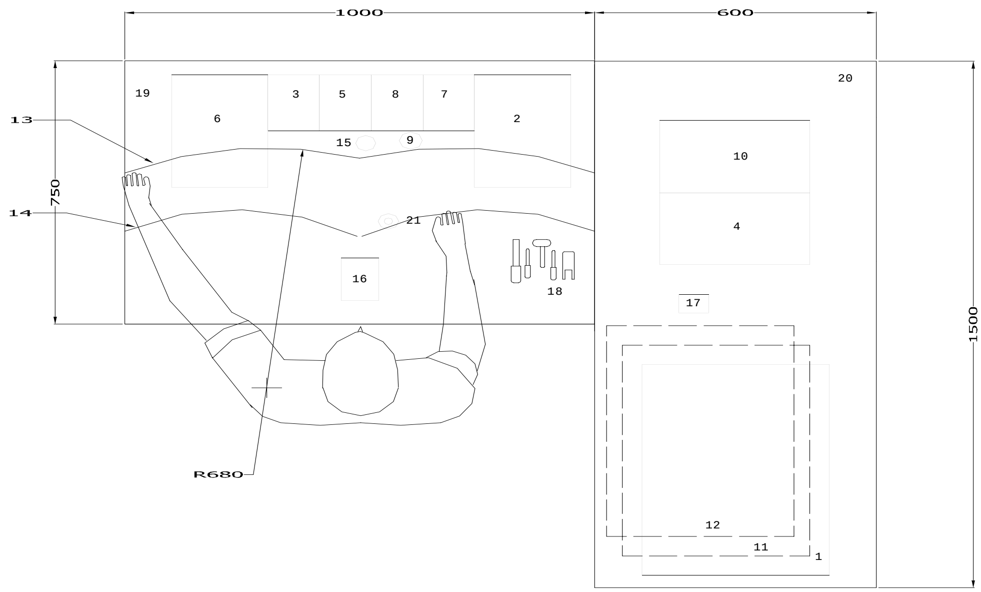


Legend: 1. Incoming bin (600x400); 2. Terminal lever bin (320x205); 3. Terminal clamp bin (140x110); 4. 3-pole body bin; 5. Handle base bin; 6. Handle springs, long screws, cover parts bin; 7. Handles bin; 8. Tripping lever bin; 9. Tripping lever springs bin; 10. Chutes; 11. Covers bin; 12. Outgoing bin; 13. Maximum reach; 14. Normal reach; 15. Grease container; 16. Assembly area; 17. Fixture; 18. Tool area; 19. Assembly table; 20. Side table; 21. Power screwdriver.

Figure 1. Plan view of the existing workstation with normal and maximum reach superimposed. All dimensions are in mm.

Figure 2. A conceptual ERGOMAS model of the workstation

principles and data. A conceptual design was developed using Ergonomic Layout and Optimization of Manufacturing Systems (ERGOMAS) software package. The software is capable of developing workstation designs using a population anthropometry. Workstation components could be selected from a wide range of products in the database. The conceptual model is shown in Fig. 2. The model used 90 percentile anthropometric dimensions of the US military male population as local anthropometric data is not available and it closely matches the dimensions of the user population sample in the company (ERGOMAS, 2001).

Considering the nature of the complexity of the assembly task it was decided to provide the worker with a fully adjustable ergonomic chair and an adjustable table so that the work could be performed in a posture that relieved the operator from unnecessary motions and fatigue. A footrest was provided for the worker. The existing hand tools were either modified or replaced with ergonomically designed ones. The workplace layout was made according to recommended dimensions for table height, seat height, thigh clearance, and reach envelopes of normal and maximum work areas for a male population Al-Haboubi (1992). However, the worker had the flexibility to adjust the table height or the chair to his comfort. Figure 3 shows some of the specific features of the ergonomically designed workstation. An improved work method was developed for the task performance.

2.5. The Experiments

A Methods-Time Measurement (MTM) analysis was conducted to establish the cycle time for the performance of the task on both workstations. They varied considerably. Experiments were conducted in the company using existing non-ergonomically designed workstation and new ergonomically designed workstation. Data on ten cycle times per participant (100 cycle times) were collected at random times using the existing non-ergonomic workstation condition before the intervention.

The ergonomically designed workstation was taken to the company and installed on the shopfloor. Participants were trained on the new workstation for two weeks and then allowed them to familiarize with the new method. The second set of experiments were scheduled three months later. Ten cycle times (in minutes) of each participant to assemble the product were collected under the new condition. A total of 200 cycle times were collected in two experimental conditions (100 cycle times for each condition).

2.6. Satisfaction Questionnaire

Satisfaction questionnaire was conducted at the end of both experimental conditions in order to measure worker satisfaction in using the existing and the ergonomically designed workstations. It consisted of 23 questions in three areas: satisfaction with regard to workstation, satisfaction with regard to task method, and satisfaction with regard to health attributes. The Human Factor Satisfaction Questionnaire was modified to suit this particular study Carlopio, (1991). The specific questions measured actual worker perception in the attributes using a Likert-type scale of 1 to 5, with 1 being very dissatisfied to 5 very satisfied. An example of satisfaction question with regard to workstation was 'How satisfied are you with the work space on the table?'. The data were summarized and analyzed using Statistical Package for Social Sciences (SPSS) software. The analyses were conducted with the cycle times and worker satisfaction scores.

3. Analysis of Results

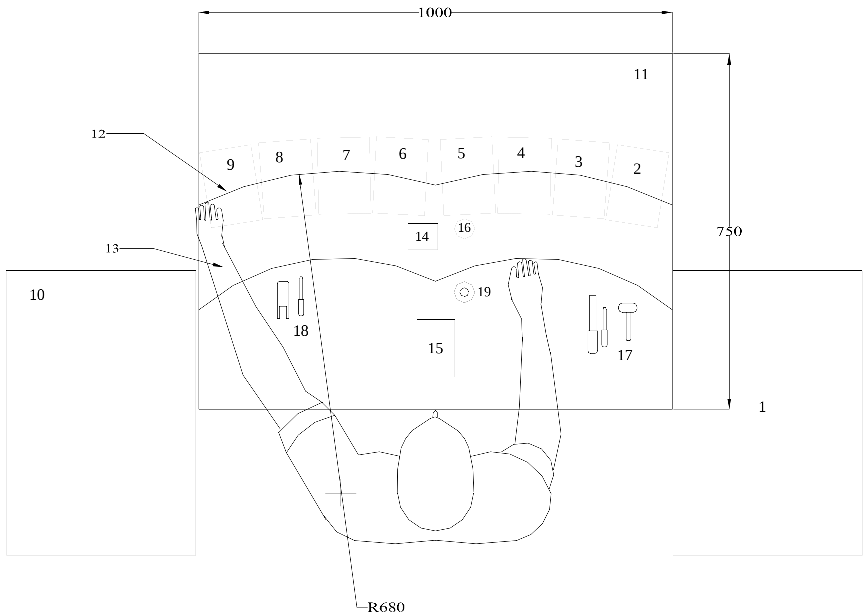
3.1. Operator Performance

Operator performance was measured in terms of work cycle time, converted to operator performance. A work cycle is defined as the time taken by an operator to complete one unit of the product. The mean cycle times of task performance in the two experimental conditions are presented in Fig. 4. The mean cycle time under the existing workstation design was 13.38 min. with a standard deviation of 5.23 min. In contrast, the mean cycle time under the ergonomically designed workstation condition was 9.73 min with a standard deviation of 3.79 min.

An analysis of variance (ANOVA) on the cycle time data showed that the difference between the two conditions was highly significant ($F=334.72$, $p<0.01$) in terms of cycle time (Table 1). A comparison between Condition 2 (Ergonomically designed workstation) and Condition 1 (Existing non-ergonomically designed workstation) showed that the mean cycle time of the participants working on the ergonomically designed workstation condition was significantly less compared to the mean cycle time of the participants working on the non-ergonomic workstation condition. The operator performance of the ergonomically design workstation condition (Condition 2) was 27% higher compared to worker performance in the non-ergonomically designed system. The higher worker performance was due to incorporating ergonomic principles and data in the design of the workstation and the task.

Participants consistently performed better in the ergonomically designed workstation. Figure 5 shows the performance of participants on the two workstations.

Major changes that were incorporated in the redesigned workstation and the task were: adequate table surface area with height adjustment mechanism, fully ergonomically designed chair with a comfortable seat pan, height adjustment, adjustable armrests, and an adjustable back rest with tilt mechanism, workspace layout in the normal and maximum work areas, ergonomically designed hand tools, and an improved work method. Since the worktable was adjustable, a flexible posture in the task performance was possible by the operators. The ergonomic changes incorporated to the design of the repetitive assembly task and the workplace made the work more comfortable, less fatiguing and more efficient. This is evident from the results of the satisfaction questions in Section 3.2. An example of these questions was ' How satisfied are you



Legend: 1. Incoming bin (600x400); 2. Arc chutes bin (140x110); 3. Terminal clamp bin; 4. Tripping lever bin; 5. Cover parts bin; 6. Handle springs and long screws bin; 7. Handle and handle base bin; 8. Line terminal bin; 9. 3-pole body bin; 10. Outgoing bin (600x400); 11. Assembly table; 12. Maximum reach; 13. Normal reach; 14. Fixture; 15. Assembly area; 16. Grease container; 17. Tool area 1; 18. Tool area 2; 19. Power screwdriver.

Figure 3. Plan view of the ergonomically designed workstation. All dimensions are in mm.

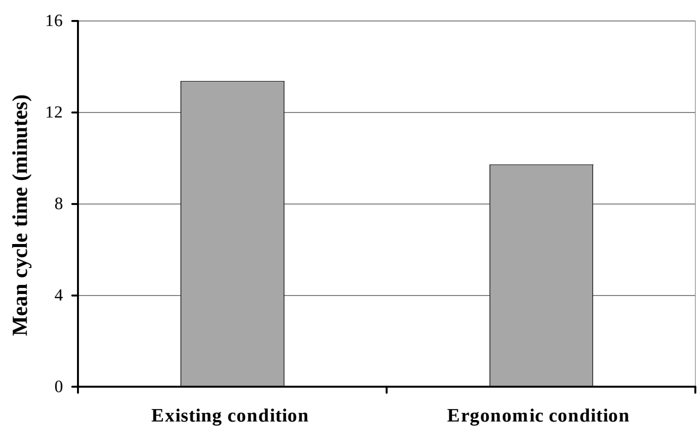


Figure 4. Mean cycle time for two conditions (minutes)

Table 1. Analysis of variance (ANOVA) of cycle time data

Source	df	Ms	F	PR>F*	r^2**
Model	20	1559.33	783.08	0.01	0.99
Conditions	1	666.53	334.72		
Subjects	9	397.71	199.73		
Conditions x Subjects	9	21.65	10.87		
Errors	180	1.99			
Total	200				

df – degrees of freedom; Ms – mean square; F – F value; *PR>F = Probability that a random F value would be greater than or equal to the observed value; **r^2 = coefficient of determination.

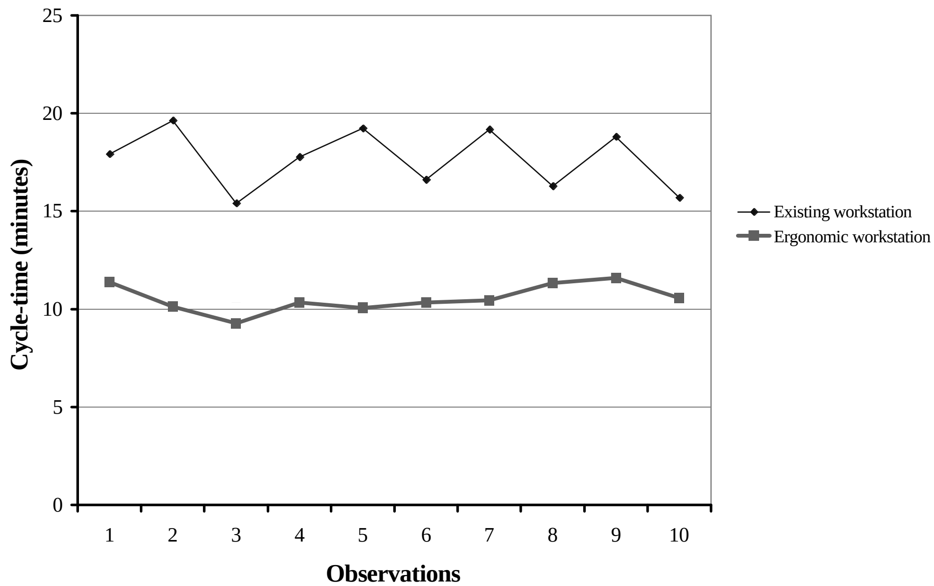


Figure 5. Observed cycle times of typical participant on workstations

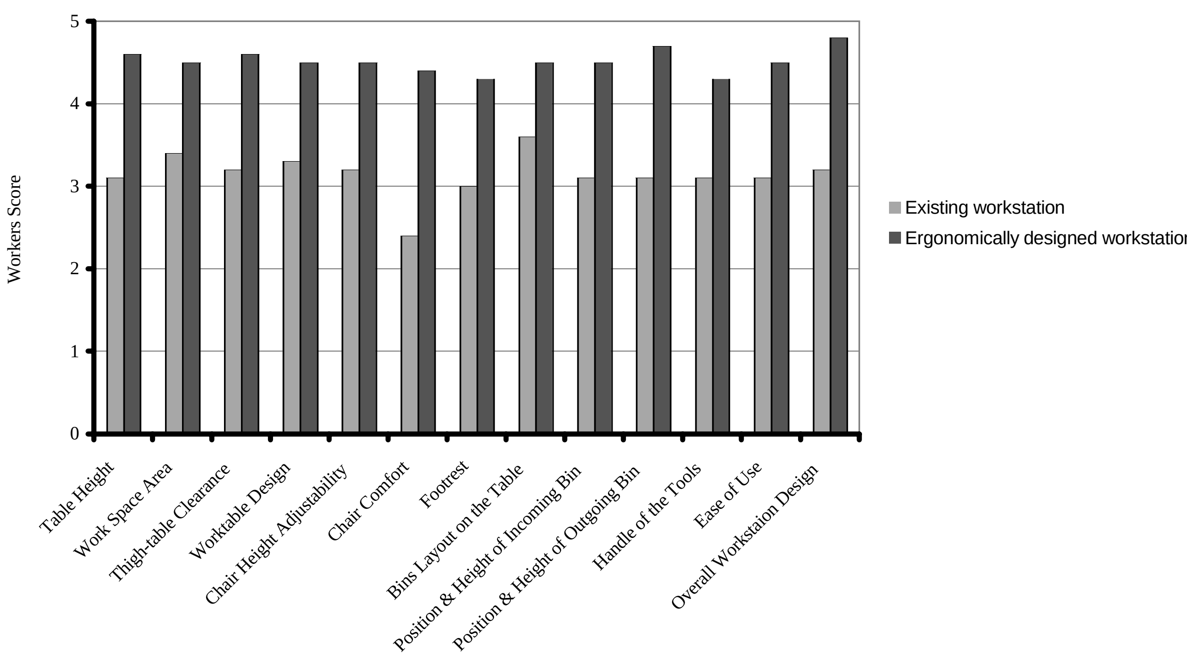


Figure 6. Operator satisfaction with design attributes on two workstations

Table 2. Mean operator satisfaction scores

Satisfaction attribute areas	Mean satisfaction scores*	
	Non-ergonomically designed workstation	**Ergonomically designed workstation**
Workstation design	3.14	4.52
Task method	3.03	4.35
Health related issues	3.03	3.95
* max possible score = 5.0		

Table 3. ANOVA of operator satisfaction scores with workstation design attributes

Source	df	MS	F	PR>F*	r^2 **
Model	20	200.70	496.98	0.01	0.98
Conditions	1	123.24	305.15	0.01	
Subjects	9	4.15	10.27	0.01	
Conditions x Subjects	9	5.08	12.58	0.01	
Error	240	0.40			
Total	260				

Variables are same as in Table 1.

with the posture you have to adopt in the task performance?'.

3.2. Operator Satisfaction

The mean operator satisfaction scores for the workstation, task method and health attributes are presented in Table 2. It can be seen that the mean scores for the ergonomically designed workstation were higher compared to the mean scores for the non-ergonomically designed workstation condition. Results of ANOVA in Table 3, showed that the difference between the conditions was highly significant with regard to worker satisfaction ($F=305.15$, $p<0.01$). The improvement in worker satisfaction with regard to workstation design attributes is 45% (Fig. 6).

A similar analysis of the satisfaction scores with regards to the task method and health attributes showed significant improvements in the ergonomically designed workstation. Worker satisfaction scores with regard to task attributes improved by 46%, while health attributes improved by 33%. Overall worker satisfaction improved by 41%. The improvement was due to incorporation of ergonomics in the workstation design and task method that was well perceived by the workers.

4. Conclusions

The ergonomically designed workstation for performing an assembly task had a highly significant positive effect on reducing the cycle time. The reduction in the mean cycle time was 27% in using ergonomically designed workstation. Worker satisfaction scores also improved significantly (*i.e*. 41%) on the newly designed workstation.

A fully adjustable ergonomically designed system for assembly task was possible by using an adjustable worktable, an adjustable chair and a systematic layout. The new workstation could be used as a sit-stand workstation. The major changes made in the original workstation were in providing an ergonomic seat (*i.e*. an adjustable chair) an adjustable and adequate worktable, proper layout of bins and tools within the normal working area, ergonomically designed hand tools and an appropriate work method. Ergonomic principles and data should be applied systematically in the design of repetitive assembly tasks to improve worker performance and satisfaction by making the tasks more comfortable, less fatiguing and more interesting.

In closing, the current research was conducted for a short period, taking random cycles of assembly time for each operator. Future research should focus on validation using a longer time period. To maximize operator performance, the optimum number of units that could be handled by the operator in a cycle should be investigated. Worker satisfaction with regards to safety, health and satisfaction with the ergonomically designed workstation condition should also be investigated.

Acknowledgments

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