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Development of a Smart Workstation for an Assembly Task

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Abstract

Fixed workstation can pose limitations on anthropometric dimensions of assembly operators. It can impose stress on musculoskeletal system of the operator resulting in health problems. Most populations, especially in developing countries, do not have anthropometric data. Therefore, it is of utmost importance that the workstation be designed with flexibility to adjust by the operators. A fully adjustable ergonomically designed assembly workstation was developed with special features such as a motorized table with upward, downward and angular movements, ergonomic chair with adjustable seat pan, arm and back supports, and a mechanism for bins and tools adjustments. The workstation could be used as sit, stand or sit-stand workstation. An experiment was conducted using college students who worked on both existing and the smart assembly workstations. There was a significant difference in workstation set-up parameters of smart assembly workstation by the participants and fixed parameters of the existing assembly workstation. Performance of the participants was about 43% higher on the smart assembly workstation compared to the existing assembly workstation. Flexibility in workstation design and set up can eliminate anthropometric and ergonomic problems of fixed workstation and thus boost operators' performance and reduce occupational health and safety problems.

Keywords
Adjustable workstation, ergonomic design, smart workstation, assembly task, worker productivity

1. Introduction

Worker productivity improvement is a major concern in industries, especially with repetitive industrial tasks. These tasks are considered boring, monotonous, fatiguing and de-motivating. This in turn results in reduced worker productivity, poor work quality, and high absenteeism and causes detrimental effects on worker physical and mental well being. Improving worker productivity in such tasks, therefore, is a challenge for the industrial managers.

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 worker productivity, provide worker safety, 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 [1-12].

Research studies in ergonomics have also produced data and guidelines for industrial applications. The features of ergonomic design of machines, workstations, facilities are well known [13-20]. However, it is still not widely accepted and there is a limited application in industries, especially in developing countries. The main concern of work system design is usually the improvement of the machines and tools. Inadequate or no consideration is given to

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the work system design as a whole, including the operator, the workstation and the environment. Therefore, poorly designed work systems are a common place in industry [4,14]. Neglect of ergonomic principles brings inefficiency and injury to the workforce. An ergonomically deficient workplace can cause physical and emotional stress, low productivity and poor quality of work [21-23]. Implementation of ergonomic intervention could result in a big savings and improved productivity, quality and occupational health and safety (OHS) of workers as well as job satisfaction [11].

For optimum design of workstation, anthropometric data is required. Das and Grady (1983) reviewed the concept of workspace design and the application of anthropometric data. It reported that an adjustable chair was highly desirable at the workplace and a workbench of standard size. However, the standard height of the workbench could not be defined without the anthropometric data of the user population.

Most of the studies did not consider a fully adjustable workstation. An adjustable chair is not sufficient to adjust work height. A standard table is limited to a fixed height. Moreover, anthropometric data of all user population is not available, especially in developing countries. It is therefore, desirable also to have the worktable adjustable to accommodate most of the user population. An earlier study undertaken in the laboratory with a simulated repetitive manufacturing task showed significant improvement in operators' performance, measured in terms of production output per hour [24]. This study did not consider a fully adjustable workstation and a real life task situation. Study considering full adjustability of both the worktable and the chair as well as task method under ergonomic conditions in real life industrial task situations needs to be conducted.

Fixed workstations can pose limitations on anthropometric dimensions of assembly operators. It can impose stress on musculoskeletal system of the operator. Moreover, flexibility to adjust his/her workstation is highly desirable. Existing anthropometric data are unsuitable for individual workstation design as most of the data were developed from military population in terms of percentiles and needs to be adjusted for civilian population.

Therefore, the objectives of this research were to (i) design and develop a smart workstation for repetitive industrial assembly tasks that is flexible and fully adjustable and eliminates constraints of fixed workstation and (ii) evaluate the workstation in terms of operator performance.

2. Existing Assembly Workstation

A large number of assembly workstations from local manufacturing companies were surveyed and a representative workstation was selected for the study. This type of workstation was used to assemble electrical switches. A workstation was provided by a company and brought to the Ergonomics Lab in the department. Figure 1 shows an isometric view of the existing assembly workstation. The workstation was thoroughly analyzed in terms of ergonomics.

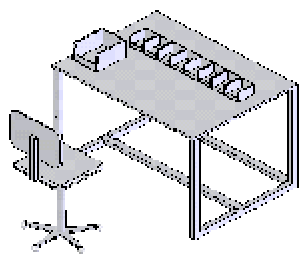

Figure 1: Isometric view of the existing workstation

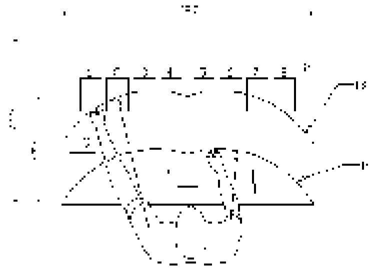

Figure 2. Layout of the existing workstation

Legend: 1. Cover 1 bin; 2. Screw bin; 3. Cover 2 bin; 4. Fuse bin; 5. Connector bin; 6. Pin 3 bin; 7. Pin 2 bin; 8. Pin 1 bin; 9. Outgoing bin; 10. Assembly area; 11. Tool area; 12. Assembly table; 13. Maximum reach; 14. Normal reach.
(All dimensions are in cm)

No ergonomic consideration was given to the workstation and layout. The task was performed in a sitting position. The table height was fixed and too low (h=740 mm) with inadequate table surface (100 x 750 mm). The chair was not ergonomically designed and it was not adjustable. There was no footrest. The attached bar along the middle of the table frame at the bottom of the table was used as the footrest by the operators. The seat pan was small and unsuitable for large people. Working under such conditions for prolonged period could lead to shoulder stress and back pain [13].

The hand tools were poorly designed and not suitable for operator's ease of use and comfort. These were not ergonomically designed, including inappropriate handle for the screwdriver. Using non-ergonomic tools could cause cumulative trauma disorders. Environment was not given adequate consideration. No fixture and power screwdriver were used for the task performance.

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. Component bins were placed in a straight line. Figure 2 shows the layout of the existing workstation with the normal and maximum work areas superimposed.

3 Design and Development of the Smart Assembly Workstation

The workstation was then redesigned using ergonomic principles and data. The term 'smart workstation' was used as the objective was to design an assembly workstation that could be used by any individual and in any posture. Basic anthropometric data were taken from 50 student subjects to identify the range of movements that were necessary to design the smart workstation. Table 1 shows these parameters. Considering the nature 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. The required ranges were accommodated in the new design.

Table 1: Some of the anthropometric characteristics

	Min	Max	Range
Sitting height	66.00	96.00	30.00
Sitting elbow height	18.90	30.90	12.00
Forearm length	33.10	50.9	17.80
Forward grip reach	55.30	83.50	28.20

The size of the tabletop (work surface) was calculated based on the mean reach of the user population with an allowance of 30mm (720 mm + 30 mm=750 mm). A special table frame was designed for the vertical and angular movements of the tabletop using small (0.5hp) motors. The frame mechanism was designed for precise movements (0.1 mm accuracy) 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 ranges of the vertical and angular movements were 700 - 1050 mm and 45^0, respectively. The table was designed for use in sit, stand, and sit-stand workstation. Attachments were provided to the frame for bins and tool holders for adjustments (Figure 3).

A fully adjustable ergonomic chair was provided to the operators. Major features of the adjustable chair were, adjustable seat height by gas suction (430 mm – 560 mm), adjustable and titled back support (30^0), tilted seat pan (15^0) covered with porous and breath-able material, adjustable arm rests (230 mm – 330 mm) 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 areas [15]. Squire's method was adopted in the calculation. The bins were laid out based on this calculation and in logical work sequence and systematic method. However, the worker had the flexibility to adjust the table height or the chair to his comfort.

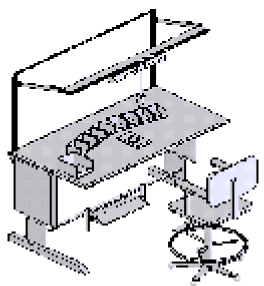

Figure 3. Orthographic views of the smart workstation

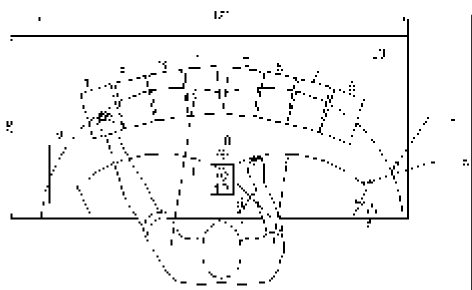

Figure 4. Layout of the smart workstation

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.
(All dimensions are in cm)

Figure 4 shows the layout of the smart workstation with the normal and maximum work areas superimposed. An improved work method following the assembly of parts sequence was developed for the task performance on this workstation. A fixture was designed for ease of holding the experimental part. The workstation was installed in the Ergonomics Lab for evaluation.

4 Evaluation of the Smart Workstation

An experiment was designed and conducted on both the existing and the smart assembly workstations to evaluate the smart workstation in terms of worker productivity. Details of the experimentation are provided in sections below.

4.1 The Task

The selected task was assembling fused electrical switches that consisted of eight parts. The 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 and methods.

The assembly task involved picking up the switch base and the cover from the bins, assemble all the inside parts in the base, put the cover, tighten the assembly using a screwdriver and place it in the outgoing bin. The steps of the assembly task were modified in the new design considering motion study and ergonomic principles.

4.2 Participants

Thirteen university students volunteered in the study. The average age of the participants was 21 yrs, with a standard deviation of 3 yrs. All the participants were male students. They had no prior experience in the assembly task.

4.3 The Experiment

The two experimental conditions were: (1) assembling electrical switches on the existing workstation following the usual method and (2) assembling the electrical switches on the smart workstation following a modified method that incorporated ergonomic principles. Experiments were conducted at random times but not in the same week on both the workstations.

Participants were given a demonstration and then trained for one hour in both the existing and the smart workstations following relevant methods before starting the experimental sessions. Each participant had assembled electrical switches for duration of one hour under each experimental condition randomly and the output was recorded.

The data were summarized and analyzed using SPSS. The mean assembled units in one hour in the two experimental conditions were 84.80 (SD 9.40) and 121.10 (SD 11.90) units per hour, respectively.

An analysis of variance (ANOVA) on the number of units assembled in one hour showed the difference among the two conditions was highly significant ($F=318.181$, $p<0.01$) in terms of units assembled (Table 2).

A comparison between Condition 2 (smart workstation and modified method) and Condition 1 (Existing workstation and usual method) showed that the mean of assembled switches per hour of the participants working on the smart workstation condition was significantly higher compared to the mean of assembled switches per hour of the participants working on the non-ergonomic workstation condition. The increase in the output (number of parts assembled) was 42.8%.

Stated otherwise, worker productivity on the ergonomically designed (smart) workstation condition was 42.8% higher compared to the worker productivity in the non-ergonomically designed workstation condition. The higher worker performance in the assembly task on the ergonomically designed smart workstation condition was due to incorporating flexibility and ergonomic and methods engineering principles in the design of the smart workstation and the task

Major changes incorporated in the redesigned workstation and the task were: (1) adequate table surface area with height and angle adjustment mechanisms, (2) fully ergonomically designed chair with a comfortable seat pan, height adjustment, and a proper back rest with tilt mechanism, (3) workspace layout in the normal and maximum work areas with adjustable bins mechanism, (4) ergonomically designed hand tools, and (5) an improved method of assembly. Since the workstation was fully adjustable, a flexible posture in the task performance was possible by the operators. All the operators made changes to adjust in the set up of the smart workstation. The ergonomics and methods changes incorporated to the design of the repetitive assembly task and the workstation made the work more comfortable, less fatiguing and more efficient.

Table 2. ANOVA of the output in two conditions

Source	*df*	*MS*	*F*	*p>F **	*r2***
Model	14	20426.8	318.18	0.00	0.99
Conditions	1	8568.60	133.47	0.00	
Subjects	12	165.40	2.58	0.05	
Error	12	64.19			
Total	39				

p*>F – probability that an *F* value would be greater than the observed value
**r2 – coefficient of determination

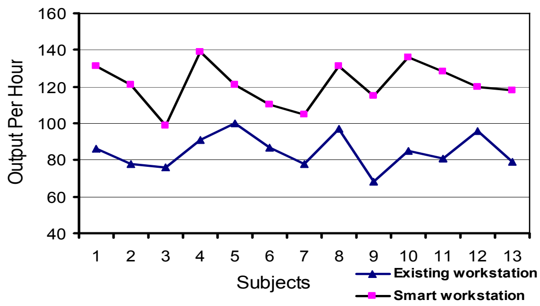

Figure 5. Observed output of the participants on the workstations

Figure 5 shows the performance of the participants in the two workstation conditions. Participants consistently performed significantly better in the ergonomically designed (smart) workstation condition.

5 Conclusions and Future Research

The following conclusions were drawn from this study:

1. A smart assembly workstation was developed that could be fully adjusted by the individual operator to his/her requirements and comfort and could be used as sit, stand or sit-stand workstations.
2. Major elements of the smart assembly workstation were a motorized (powered) table frame to adjust the height and angle of the tabletop (work surface), a fully adjustable and ergonomic chair with an adjustable back support, an adjustable footrest, a mechanism for bins and tools support and ergonomically designed hand tools.
3. The smart assembly workstation for performing an assembly task had a highly significant positive effect on increasing the operator performance. The increase in the output was 42.8% in the ergonomically designed smart workstation compared to the existing workstation condition. Stated otherwise, operator performance was improved 42.8% in the ergonomically designed smart assembly workstation.
4. Workstations for assembly tasks should be designed so that any operator can adjust to his/her comfort to relieve stress and improve performance. The smart assembly workstation is a solution to ergonomic and productivity problems in the workplace.

The following future research is in order to accomplish the benefits from this research:

1. The research was conducted using college students and for a short period, one hour. It should be validated using industrial operators and for longer times taking for a half or a full day's work.

2. To maximize operator performance in such a condition, the optimum number of units that could be handled by the operator in a cycle (batch assembly) should be investigated.
3. Operators' perceptions with regard to safety, health and satisfaction with the smart assembly workstation condition should be investigated.

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