Investigating the Effects of Assembly Order on the Performance in Relation to Cognitive and Physical Demands Under Takt Time

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ABSTRACT

Assembly line operations generally involve physical and cognitive demanding tasks. Simultaneous performance under physical and cognitive demanding tasks may create physical and mental stresses. A within subjects study was carried out to determine the effects of assembly levels (variable assembly and consistent assembly) on working conditions. Nine participants participated in the study and performed 8 conditions. The objective of the study was to determine the relation between physical and cognitive demands in a simulated task involving simultaneous performance of physical (fastening nuts and bolts) and cognitive (code matching with secondary task of memorizing the code) demanding task. Results showed the significant effects of assembly order (consisted of the concurrent performance of physically and cognitively demanding task) on the working conditions. Quality of performance was affected by variable assembly order, high mental demand and above shoulder height.

Keywords: **Variable Assembly, Consistent Assembly, Memory Load, Assembly Work, Performance.**

1. INTRODUCTION

Assembly line is a link of work stations in sequence order, through which the product passes successively by means of transportation or conveyer belt [1-2]. The worker has a major role in producing a product in an assembly line. He is responsible to maintain the productivity and quality of the product in assembly line. Operations of an operator assembling automotive products have been categorized into value adding (direct work) and non-value adding (indirect work). Pure assembly work is categorized as value addition. The remaining operations (e.g. fetching materials and tools, walking, handling packaging, inspection, adjustments, reporting, consulting and waiting) are considered as losses and thus classified as non-value adding [3]. Bicheno [4] and Cooney [5] discussed the importance in lean manufacturing, of compact workstations to reduce non value adding time. It was pointed out by Walker and Guest [6] that assembly line work included mechanical pacing, repetitiveness, low skill requirements, performance of tiny fractions of the product, limited social interactions and predetermination of tools and techniques. These factors are the major issues for the industries and assembly line workers who face the problems of fatigue and discomfort that eventually result in musculoskeletal disorders.

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Workstation operations involve both physically and cognitively demanding tasks. The simultaneous performance of such tasks may impose physical and mental stresses. Examples of work station tasks at moving assembly line include tasks related to reduced cycle time, awkward postures, information processing, and decision making [7-8]. Lot of work has been done on assessing the impacts of physical demands and cognitive demands on working conditions separately. However, very few researchers have focused on the complex tasks, which involve simultaneous performance of physical and cognitive demanding tasks [9-11].

This paper focuses on investigating the effects of assembly order (variable and consistent assembly) on working conditions under Takt time, a lean manufacturing tool [12]. Takt time is fundamental to lean manufacturing and is defined as the maximum time allowed for producing a product in order to meet customer demands. It can therefore vary with the level of the company's order book [13]. Within an assembly line, everything in the production cell operation is based on the Takt time. The complexity at variable assembly was set higher than the consistent assembly. Therefore, it was hypothesized that performance would be slower at variable assembly as compared to consistent assembly order. It was hypothesized that the levels of pacing, working height and memory load may be affected by takt time. It was also hypothesized that the physical performance may be reduced by high memory load.

2. METHODOLOGY

2.1 Participants

Nine (9) participants, with the mean age SD (Standard Deviation) of 27.5(3.4) years, were recruited from the university. Participants signed the consent form, which was approved by local committee of ethics. Participants were given proper instructions regarding the performance of task. Practice session was also provided to each participant in order to completely familiarize with the task.

2.2 Experimental Design

Two simulated assemblies were designed in the laboratory, which were followed by a real assembly task observed in an automobile industry.

The previous study [14] showed the significant effects of different levels of pacing (no pacing, low pacing and high pacing) on the quality of performance and also showed the significant interaction between physical and cognitive demands on objective measures and perceived responses. However, the findings from the previous study were not high physically and cognitively demanding and showed the ceiling effects between variables. The current study has been designed more demanding and modified with some changes as shown in Table 1. This paper discusses the performance and analysis of study 2.

2.3 Independent Variables

The independent variables in the present study were pacing as a time demand with two levels (low pacing with the Takt time of 90 seconds per assembly task and high pacing with Takt time of 60 seconds per assembly). Work height as a physical demand with two levels (elbow height with lower arm parallel to the ground and above shoulder height with upper arm parallel to the ground). Cognitive load as a cognitive demand with two levels (variable assembly order with the secondary task of code memory and consistent assembly order with the secondary task of code memory). Example of variable assembly order and consistent assembly order is shown in **Fig. 1(a-b).**

TABLE 1. INDEPENDENT VARIABLE AND THEIR LEVELS

Independent Variables	Levels
Pacing	Low pacing (90 seconds to finish code matching assembly of 6 nuts and bolts)
	High pacing (60 seconds to finish code matching assembly of 6 nuts and bolts)
Work height	Elbow height (lower arm parallel to the ground)
	Above shoulder height (upper arm parallel to the ground)
Memory	Memorizing the code of 8 during the assembly both heights.
Task	**Performance**
Physical	Code matching assembly of fastening 6 nuts and bolts in two different ways Each assembly is coded in random order Each assembly is coded in consistent order
Cognitive	Memorizing the 8-digits code during each assembly.

2.4 Dependent Variables

Both objective and subjective measures were used to investigate the effects of Takt time on the working conditions in single model assembly line and mixed model assembly line. The objective measures were time to complete the assembly task at low pacing and high pacing, number of completed assemblies, number of correct code responses, walk time and number of dropped nuts and bolts. The subjective measure were to determine the mental workload using NASA TLX [15-16], stress and arousal score using stress and arousal checklist [17] and fatigue and discomfort using physical well being checklist [18].

3. PROCEDURE

Simulated tasks consisted of concurrent performance of physical and cognitive demanding task. The physical demanding task was to pick the nuts and bolts from the line bin (fixed at 10cm below each assembly) and fasten the six nuts and bolts on a L-shaped metallic plate attached on a wooden bar at elbow height and above shoulder height. The wooden bar consisted of 6 L-shaped metallic plates, which were 10cm apart from each other. The cognitive demanding task was fastening of nuts and bolts in variable order and random order. The six holes on the L-shaped metallic plate were numbered in random order for all the six assemblies in a row which represented the variable assembly. Similarly, the assemblies were numbered in consistent order, which represented consistent assembly. The nuts were also numbered in order to perform the code matching task. The consistent assembly order represented the single model assembly line, whereas the variable assembly order represented the mixed model assembly line. Another cognitive demanding task was to memorize the 8-digit code during the performance of each assembly.

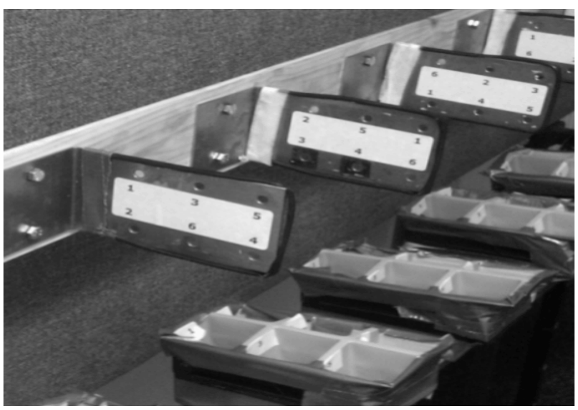

FIG. 1(a). CODE MATCHING ASSEMBLY TASK IN VARIABLE ORDER

FIG. 1(b). CODE MATCHING IN THE ASSEMBLY TASK IN CONSISTENT ORDER

The experiment lasted for 2 hours 30 minutes per participant. Experiment consisted of 8 conditions (four conditions of low pacing and four conditions of high pacing). The time for low pacing condition and high pacing conditions was 60 minutes and 45 minutes respectively. The conditions were selected in random order. There was a 5 minutes break after each condition. Participant filled the subjective responses during the break.

Experiment was performed in standing position. Participant was asked to get the code on the computer display and memorize the code during the assembly task. The code was entered before and after the assembly. Assembly task was performed either at elbow height or above shoulder height, depending upon the randomly selected conditions of low pacing or high pacing. Each condition consisted of six assembly tasks and separate code was memorized for each assembly task. After each condition, a five minute break was given.

4. RESULTS

A repeated measure 3 way (2x2x2) ANOVA (Analysis of Variance) was conducted to investigate the effects of takt time on working conditions in single model assembly line and mixed model assembly line. Three independent variables were analyzed, which were considered as time demand, physical demand and cognitive demand. The time demand was the two levels of pacing (low pacing at 90 seconds and high pacing at 60 seconds). The physical demand was the two levels of work height (elbow height and above shoulder height). The cognitive demand was the two levels of code matching (variable code matching task with secondary task of memorizing the 8 digit code and consistent assembly with the secondary task of memory the 8 digit code). The analysis was carried out on both objective and subjective measures. ANOVA F test is used to test significance between all factor means and/or between their variances equality in ANOVA procedure at the significance level of $p<0.05$. DoF (Degree of Freedom) is used to compare the same group in two conditions.

4.1 Objective Measure

Data was collected on 4 objective measures, which are:

(i) Actual assembly time in each condition (measuring the time while performing the assembly task).

(ii) Number of fully completed assemblies in each condition (Total number of fully fastened nuts and bolts during the task performance).

(iii) Number of correct code responses.

(iv) Number of dropped nuts and bolts during the assembly task performance.

The mean and standard error of each of the objective measure are shown in Fig. 2, which are further discussed.

4.2 Actual Assembly Time

Takt time was set as 90 seconds for low pacing and 60 seconds for high pacing. Each condition involved 6 tasks for low pacing and six tasks was high pacing. Actual time was measured for each task through computer generated program. A three way (2x2x2) ANOVA showed significant difference between two levels of takt time, two levels of work height and two levels of mental processing assembly. Mean assembly time for takt time at low pacing and high pacing was 393.722 and 350.16 seconds respectively. Mean assembly time for physical demand at elbow height and above shoulder height was 366.94 and 376.94 second respectively. Mean assembly time for cognitive demand at variable assembly and consistent assembly was 377.58 and 366.30 seconds respectively.

4.2.1 Number of Fully Completed Assembly

Each assembly task consisted of fastening six nuts and bolts. There were six assembly tasks in a row, which

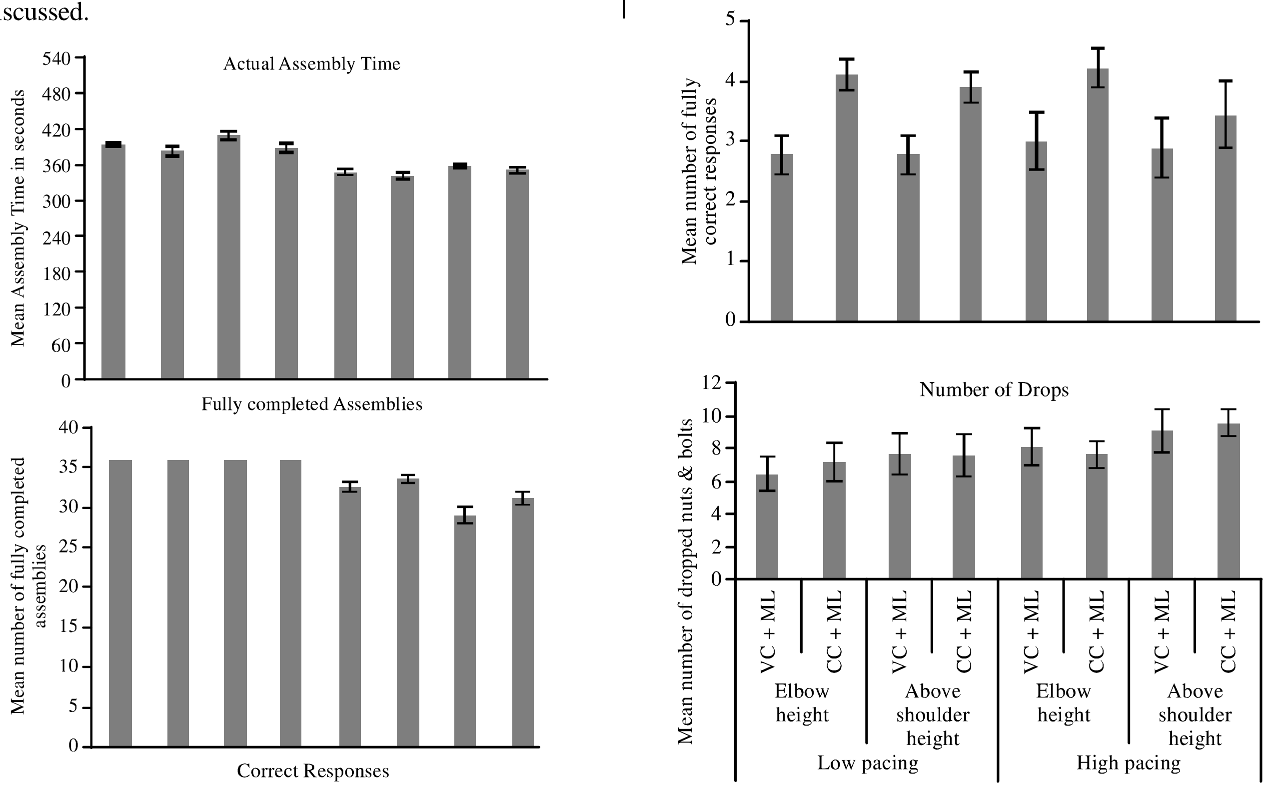

FIG. 2. MEAN AND STANDARD ERROR OF 8 CONDITIONS OF EACH OF THE OBJECTIVE MEASURE

represented 6 workstations tasks in an assembly line. Number of correctly fastened nuts and bolts out of 36 assemblies was recorded in each condition.

A three way (2x2x2) repeated measure ANOVA showed significant difference between two levels of takt time, two levels of work height and two levels of cognitive demand. Mean number of completed assemblies for takt times at low pacing high pacing were 36 and 31 numbers of correctly fastened assemblies respectively. Mean number of completed assemblies for elbow height and above shoulder height were 34.55 and 33 respectively. Mean number of completed assemblies for variable assembly and consistent assembly were 33.389 and 34.22 respectively.

ANOVA also showed the significant interaction between two levels of takt time and two levels of work height, between two levels of takt time and two levels of cognitive demand.

4.2.2 Correct Code Responses

Memorizing the code during the assembly task, was taken as cognitive demand. Participants received the code from the computer and moved to perform the assembly. Data was collected for the correct code response for each task. ANOVA showed significant difference between two levels of takt time, two levels of work height and two levels of cognitive demand. Mean number of completed assemblies for takt times at low pacing high pacing were 36 and 31 number of correctly fastened assemblies respectively. Mean number of completed assemblies for elbow height and above shoulder height were 34.55 and 33 respectively. Mean number of completed assemblies for variable assembly and consistent assembly were 33.389 and 34.22 respectively.

ANOVA also showed the significant interaction between two levels of takt time and two levels of work height, between two levels of takt time and two levels of cognitive demand.

4.2.3 Dropped Nuts and Bolts

Number of dropped nuts and bolts was recorded out of 36 assemblies. ANOVA showed significant difference between two levels of physical demand. Mean number of dropped nuts and bolts at elbow height and above shoulder height were 0.361 and 1.11 respectively.

4.2.4 Subjective Measure

Data was collected on three subjective measures. Raw NASA TLX score, Stress and Arousal level and Physical well being checklist.

5. NASA TLX

The work load was measured using 5 dimension of NASA TLX. The dimensions were mental demand, physical demand, temporal demand, performance and effort. Raw NASA TLX rating scale was used to collect data. The bar charts with mean and standard error are shown in Fig. 3. The analysis of each dimension is discussed as below:

5.1 Mental Demand

Mental workload data was collected on the raw NASA TLX scale ranging from 0 as low and 20 as high. The data was collected after each condition. A three way (2x2x2) repeated measure ANOVA was performed to analyze the effects of time demand (two levels of pacing), physical demand (two levels of work height) and cognitive demand (assembly order + code memory) on mental workload and to determine whether there was an interaction between physical and cognitive demands. ANOVA showed significant difference between two levels of takt time, and two levels of cognitive demand. Mean mental demand for takt times at low pacing and high pacing were 14.94 and 15.55 respectively. Mean mental demand for cognitive demand at variable assembly and consistent assembly were 15.91 and 14.583.

5.2 Physical Demand

Physical workload data was collected on the raw NASA TLX scale ranging from 0 as low and 20 as high. The data was collected after each condition. A three way (2x2x2) repeated measure ANOVA was performed to analyze the effects of time demand (two levels of pacing), physical demand (two levels of work height) and cognitive demand (assembly order + code memory) on Physical workload and to determine whether there was an interaction between physical and cognitive demands. ANOVA showed significant difference between two levels of physical demand.

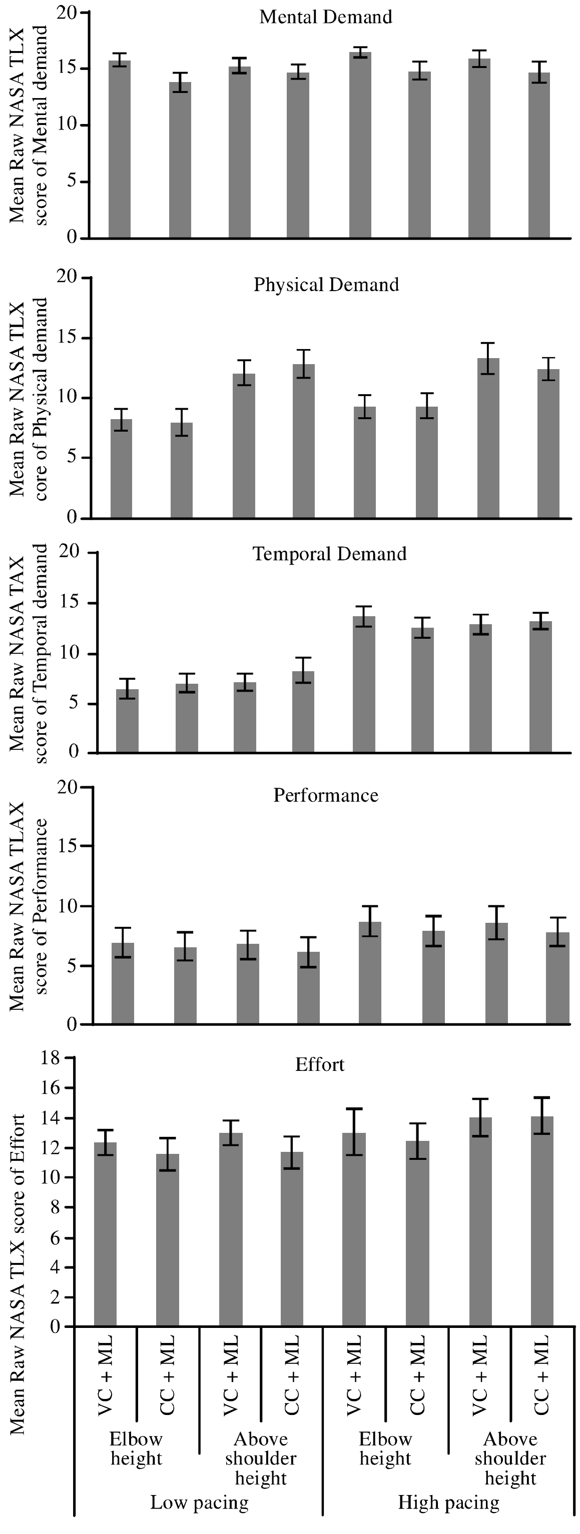

FIG. 3. MEAN AND STANDARD ERROR OF RAW NASA TLX SCORE OF 5 DIMENSION OF NASA TLX, RANGING FROM 0 AS LOW AND 20 AS HIGH; EXCEPT PERFORMANCE RANGING FROM 0 AS PERFECT AND 20 AS FAILURE

Mean physical workload for physical demand at elbow height and above shoulder height were 8.722 and 12.694.

5.3 Temporal Demand

Temporal demand data was collected on the raw NASA TLX scale ranging from 0 as low and 20 as high. The data was collected after each condition. A three way (2x2x2) repeated measure ANOVA was performed to analyze the effects of time demand (two levels of pacing), physical demand (two levels of work height) and cognitive demand (assembly order + code memory) on time pressure and to determine whether there was an interaction between physical and cognitive demands. ANOVA showed significant difference between two levels of takt time ($F=29.051$, $df= 1, 8$, $p<0.05$). Mean temporal demand for takt times at low pacing and high pacing were 7.22 and 13.083 respectively.

5.4 Performance

ANOVA was performed to analyze the effects of time demand (two levels of pacing), physical demand (two levels of work height) and cognitive demand (assembly order + code memory) on performance and to determine whether there was an interaction between physical and cognitive demands. ANOVA showed significant difference between two levels of takt time. Mean performance for takt times at low pacing and high pacing were 6.58 and 8.22 respectively.

5.5 Effort

Data on performance dimension was collected on the raw NASA TLX scale ranging from 0 as perfect and 20 as failure. The data was collected after each condition. A three way (2x2x2) repeated measure ANOVA was performed to analyze the effects of time demand (two levels of pacing), physical demand (two levels of work height) and cognitive demand (assembly order + code memory) on effort and to determine whether there was an interaction between physical and cognitive demands. ANOVA showed significant difference between two levels of takt time ($F=5.960$, $df= 1, 8$, $p<0.05$), two levels of physical demand ($F=5.612$, $df= 1, 8$, $p<0.05$) and two levels of cognitive demand ($F= 7.808$, df 1, 8, $p<0.05$). Mean effort for takt time at low pacing and high pacing were 12.13 and 13.38

respectively. Mean effort for physical demand at elbow height and above shoulder height were 12.33 and 13.19 respectively. Mean effort for cognitive demand at variable assembly and consistent assembly were 13.08 and 12.44 respectively.

6. STRESS AND AROUSAL

Data on stress and arousal was collected using stress and arousal checklist. The checklists consisted of 30 adjectives that described the feeling of the mood. Data was collected after each condition as shown in Fig. 4.

6.1 Stress

Participants were asked to show their feeling after each condition by marking on the list consisted of 30 adjectives. A three (2x2x2) repeated measure ANOVA showed significant difference between two levels of pacing and two levels of cognitive demand. Mean stress level for takt time at low pacing and high pacing were 12.13 and 13.38 respectively. Mean stress level for cognitive demand at variable assembly and consistent assembly were 13.08 and 12.44 respectively.

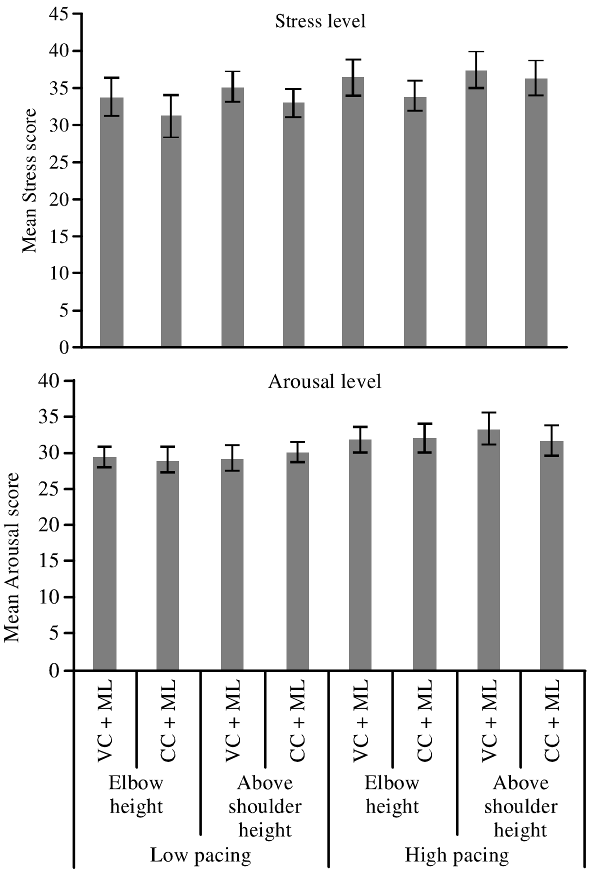

FIG. 4. MEAN AND STANDARD ERROR OF 8 CONDITIONS OF STRESS AND AROUSAL SCORE

6.2 Arousal

A three way (2x2x2) repeated measure ANOVA was performed to analyze the effects of time demand (two levels of pacing), physical demand (two levels of work height) and cognitive demand (assembly order + code memory) on arousal level and to determine whether there was an interaction between physical and cognitive demands. ANOVA showed significant difference between two levels of takt time. Mean arousal level for takt time at low pacing and high pacing were 29.33 and 32.19 respectively.

7. DISCUSSION

The simulated study was a part of the real assembly task observed in an automobile industry. The task consisted of concurrent performance of physical and cognitive demand in a paced assembly line. Similar type of study was designed in a laboratory. The experiment consisted of 8 conditions, which were performed by 9 participants. A three way ANOVA showed significant effects of time demand, physical and cognitive demands on objective measures (performance time, number of completed assemblies, correct code responses, walk time and dropped nuts and bolts) and subjective measures (mental workload, stress and arousal and fatigue). Variable assembly and consistent memory load in each condition were the two main aspects of the cognitive load that caused increased mental workload and stress. Furthermore, resulting in slightly decrease in physical performance. This accepted the hypothesis that the performance was slower in mixed model assembly (variable assembly order) than single model assembly line (consistent assembly order). Results showed that participants forgot the code during the performance of variable assembly. However, in the post study questionnaire, all participants pointed that task was high mentally demanding due to memorizing 8 digits code. In another question regarding the physical performance, participant showed that the above shoulder height was a bit physically demanding. Regarding the difference between variable and consistent, participants pointed out no difference between these two assembly orders. However, statistical analysis showed the difference between these two levels of assembly order with respect to time, code responses and height.

Participants took more time in low pacing than in high pacing. This further interprets that takt time at low pacing was quite comfortable for the participant to finish their assembly task in time as compared to the takt time at high pacing [19]. However, waiting time during low pacing may create the situation of under load, which further results in decrease in attentional resources [20].

The present study also showed some interactions at objective measures. However, no interaction found through subjective responses. Interaction between time damand and physical demand illustrates that the number of assemblies was higher at high pacing and elbow height as compared to the number of assemblies was lower at high pacing and above shoulder height. Interaction between time damand and cognitive load illustrates that the number of assemblies was lower at high pacing and variable assembly as compared to the number of assemblies was higher at high pacing and consistent assembly.

Post-hoc analysis showed the effect of time demand, physical demand and cognitive demand on the NASA TLX workload and stress and arousal checklist. Participant showed the task high mentally demanding at high pacing as compared to low pacing, resulted in high temporal demand in high pacing, lower performance in high pacing and also high effort in high pacing.

The cofusing part of the present study was the aspects of cogntive load, which were assembly order (variable assembly and consistent assembly) as the realistic part of the task and memorizing the 8-digit code during the assembly task as the secondary part of the task. Analysis of such aspects of cogntive load has made the study more mentally demanding as can be seen in results and tables. However, the interaction between physical and cogntive demand was not quite strong. As, it was expected that the high cogntive demand would reduce the physical perfromacne. Physical performacne was slightly affected by cogntive demands even with the less number of sample size. Future study need to be carried out to investigate the interaction between physical and cogntive demands in complex tasks with increased number of sample size.

8. CONCLUSION

The findings from present study proved to be highly demanding than the previous study. However, it can be analyzed that the performance in mixed model assembly line may have more errors and quality problems, especially during high pacing conditions, which may affect productivity and quality and hence reduce the quality of performance. Thus, the design of tasks in mixed model assembly line need careful consideration of task complexity, work height and time.

Furthermore, regarding the interaction between physical and cognitive demands, there is no such ergonomics tool that measures the interaction between physical and cognitive demand. However, more studies need to be carried to determine the interaction with the increased number of sample size.

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