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OPERATOR PERFORMANCE AND TASK DIFFICULTY IN PACED WORKING CONDITIONS

by

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INTRODUCTION

Human performance is a clear concept, and the assessment - measurement and evaluation - of human performance is a viable area of research and development. Its relation to productivity and its application to productivity enhancement is difficult but very important, especially in assembly line operations. The term "productivity" implies measurement of both, quantity and quality of worker performance.

However, the study of individual productivity involves measurement of component behaviors and processes that together determine work effectiveness. The logic is that through understanding basic parameters of human performance one may infer the consequences of manipulating particular tasks or situations for productivity. For example, a particular job requires an operator to maintain attention over a considerable period of time. By understanding the processes that govern human attention, it is possible to prescribe changes in job design or work scheduling to maximize human productivity.

Moving a step further, the task of "human assessment" becomes more difficult if an additional constraint of "time" is applied to workers while working. In an assembly line operation it is a common practice to allocate a certain amount of time for workers to finish their task. This is generally termed "pacing".

Late in the Industrial Revolution, the conception of an assembly-line began to play a major role in mass production. It is considered to be indispensible. At present, a large number of workers are employed on tasks which are paced by machines.

Many workers in industry are not free to work at their own pace, but are fed by a conveyor, machine, or other worker, and have a certain maximum period of time within which to complete their specified tasks. In the interest of higher output and profit, the time required to perform an operation tends to decrease and hence this may affect not only quality of work but also induce excessive operator fatigue or ailments. Such considerations should have considerable impact on production planning and on operator training.

The use of repetition and pacing to enhance efficiency and productivity has become a postulate of progress. The resulting stress, however, may cost both the worker and industry. Therefore, it is envisaged, that a comparative study involving both paced and unpaced conditions would be useful in order to determine the correct form / level of pacing which will yield optimum productivity and performance.

Advantages and Disadvantages of Machine Paced Work

In view of the distinct economic advantages in utilizing machine paced work, a substantial portion of manufacturing workers are working in this way. The following are the economic advantages and disadvantages of machine paced work as listed by Salvendy, (1980):

Advantages

(1) Reduces overhead cost through : economic use of high technology , reduction of stock in progress , reduction in

factory floor space , reduction in supervision cost.

(2) Reduces direct cost through : decreased training time , lower hourly wages , high production return per unit of wages.

(3) Contributes to national productivity through : provision of employment for less capable workers , reduction in the production costs of goods and services.

Disadvantages

(1) Does not have provision for the utilization of each worker's maximal work capacity.

(2) Economically viable only for high-volume production.

The psychological disadvantages of machine paced work are that machine-paced work does not provide psychological growth for the workers and cause boredom and job dissatisfaction. Therefore, machine-paced tasks in the environment should be maintained only when appropriate measures to overcome human disadvantages of working in such conditions are also taken.

Classification of Paced Work

Salvendy (1980) has classified-machine paced work by the demand it places on human behaviour and performance or by the research methodologies utilized to study machine paced work. Both classifications are needed in order to effectively integrate and implement the research findings pertaining to machine paced work.

1. Classification by demand on human performance

Human-paced Work

(1) Truly unpaced : No internal or external pacing is imposed. The task is performed at a preferred and chosen pace by the operator.

(2) Socially-paced : Although no pacing is imposed by machinery, there is a peer or group pressure to perform at a set pace. Examples are group performance and lectures.

(3) Self-paced : The work conditions are said to be self paced when the operator paces himself in order to achieve a goal or meet a requirement, which in most cases is the goal set by the management. Thus the operator is not paced by the machine. This condition occurs in most of the industrial tasks which are not strictly paced by machines.

(4) Incentive-paced: An incentive-paced task consists of two additive parts, namely the "self-paced" and the operator's financial motivation to produce above the self-paced work. This is "piecework". The more the operator produces above this "self-paced" level, the higher will be the operator's income. Hence, the intensity and the severity of the pacing is dictated by how much the operator wants to earn.

Machine-paced work

In this case the operator is paced by the machine. The level of pacing depends upon the rate of the machine. The rate of the machine is specified either by the cycle time available for processing or by the number of units passing per unit time. Following are a few terms associated with machine paced work:

(1) Length of work cycle : When the cycle length in machine-paced work is extremely long, it approaches the state of the "self-paced" condition. The shorter the cycle time, the less the operator's performance variability can be tolerated.

(2) Buffer stocks : Buffer stocks is "an arrangement which makes more than one component of feeding position available to an operatorat the same time" (Murrell 1965). Machine-paced work can be operated with or without buffer stocks.

(3) Rate of machine-paced work : When a "fair day's work" is defined as 100 percent, the rate of machine-paced work is frequently performed at rates ranging from 100-125. The impact of machine-paced work on the operator may be different, depending at which rate the task is performed.

(4) Continuous versus discrete pacing : Both pacing modes are widely utilized in industry. For example, in conveyor operations the conveyor can either move continuously, in which case the operator performs the task in a dynamic visual work environment, or the conveyor can be indexed in a discrete mode. In the latter case, the conveyor is in a stationary mode

during a fixed job cycle period when the operator is typically working on the job. At the end of each work cycle, the conveyor indexes to the next workstation. During this indexing period (which usually takes 2-8 seconds), the operator can either be doing preparatory work for the next cycle of operation or be idle. Murrell (1963) described two above stated slightly different types of pacing as Type 1 and 2 pacing.

Different investigators have described other variants of machine pacing. Buxley et al. (1973), for example, identified three types of flow line where pacing may exist : (1) single-model lines (where only one model or type of product is produced); (2) multi-model lines on which two or more similar types of model or products are processed separately in batches ; and (3) mixed-model lines where two or more similar models or products are produced simultaneously. Conway et al. (1977) further described a variation which combines elements of both unpaced and paced work. In this process, cycles were initiated by the operatives. However, once the cycle was started, the worker was paced through a rapid sequence of motions. Finally, Rohmert and Luczak (1973) have extended the concept of pacing to include information-processing tasks. In such "paced-information tasks", the service-time component can be partitioned into an information/decision component, and a motor component.

From the above classification, it should be obvious that numerous varieties of pacing exist and that different paced systems may require vastly different amounts of cognitive and motor activity from the worker. Unfortunately, many of the studies concerned with effects of pacing fail to adequately document the specific characteristics of the system being examined. Thus, one often knows little about the independent variable being considered except that it is something called pacing.

Proposed Taxonomic System

To remedy the above stated deficiency a classificatiory system was proposed by Karasek (1979). In this system, operator control was manifested along two orthogonal dimensions : control over the initialization of the work cycle, and control over the duration of the work cycle. The extent to which the worker, as opposed to the machine, has control over either or both of these functions is reflected in the four-quadrant classification scheme indicated in Figure 1.

In Quadrant I (QI), tasks are initiated by the machine, but work time is under the control of the operator. Such a task could be a telephone switchboard operation in which calls arrive under the control of the machine (external environment), but the operator determines how long it takes to process a call. Recent research on secretarial/clerical workers (Dainoff 1979) suggests the need for the investigation of this type of work.

Quandrant III (QIII) tasks are initiated by the operator, but the machine determines the work time. QIII tasks appear to be similar to those that Murrel (1963) described as Type 1. He

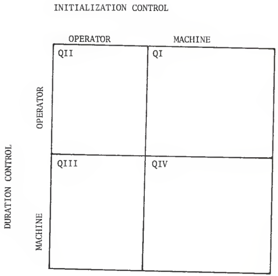


Figure 1. Classification system for paced work

states, "This type of pacing is found when girls feed machines with parts which simply have to be picked up from a bin and placed in an appropriate position..." The operator feeds parts into a waiting machine ; the machine then processes it while the operator is prevented from loading another part.

The majority of work has been done in the quadrants labelled II and IV. Quadrant II (QII) described tasks that are often referred to as "unpaced" (e.g. Conrad 1955, Dudley 1962). The operator both initiates a QII task and controls the length of time to complete it. QIV tasks are machine paced (e.g. Conrad 1955). The machine (or external environment) both initiates a QIV task and controls the length of time to complete it.

2. Classification by research methodologies

(1) Laboratory studies : Typically performed for a very short work period (i.e., less than for one full work day) ; on non-realistic tasks ; on operators who are insufficiently experienced in task performance. Although laboratory studies are typically characterized by highly controlled experiments, the above-listed weakness of machine-paced laboratory studies make the transfer of research findings to real-world work situations suspect.

(2) Epidemiological studies : Frequently in these studies, jobs are confounded with workers since it is extremely difficult to have in epidemiological studies a statistically balanced design. For this reason, epidemiological studies must be interpreted with extreme caution.

(3) Confounded industrial studies : In these studies machine-paced is compared with self-paced work; however , neither the operators nor the job content in the two pacing conditions are the same. Hence, in these studies pacing mode is confounded with job content and operators. This makes it very difficult to make comparitive statements regarding machine-paced and self-paced work.

(4) Controlled industrial studies : In these studies the job content is the same for both machine-paced and self-paced work and operators perform, in a statistically balanced experimental design,in both pacing modes. This mode of studies enables the best transfer of knowledge to real-world work situations. This methodology is by far the most powerful of the four research methodologies.

Basic Terminology

The concept of work in which the worker is required to respond at a rate other than that which would be self-selected is regarded as " paced work ". Franks (1974) considered a task paced if "...there exists external sensory stimuli in the form of temporal signals of any nature which do not depend on a reaction for their presentation". It will be noted that this definition implies a formal seperation of machine action from operator action; while at the same time specifying that the interaction between those temporal factors which determine the former and latter define the nature of the task (Happ 1981, Conway et al. 1977). Thus, in a completely machine-paced task, rate of presentation is under machine control and the action of the operator in no way influences the presentation of succeeding parts (or information). In contrast, in the completely unpaced task, the rate of work depends entirely on the action of the operator.

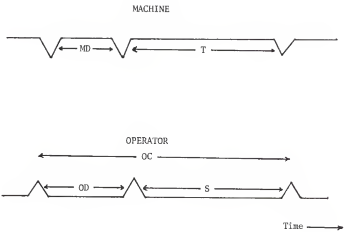
The temporal parameters determining both operator and machine function can, in general, be specified more completely. With respect to description of operator function (Figure 2), operator cycle time is defined as the time elapsed between commencement of work on successive parts or information sources (Sury 1967). This time increment can, in turn, be divided into two further components; service time (S) and operator delay time (OD) (Sury 1967). Service time refers to that portion of the operator cycle time during which the operator is actually working on a part or processing information. Operator delay time, on the other hand, refers to that portion of the cycle during which the operator must wait for a new part or information source.

With respect to machine function, tolerance time (T) refers to the length of time a part or information source is available for processing by the operator (Sury 1967, Franks 1974). Finally, machine delay time (MD) refers to that part of the machine cycle in which the part/information is not available for processing.

Some Additional Terms Used in Pacing:

Hits : Units completely processed and in the right manner by the operator.

Misses : Units on which operator did not work to completion.



OC = Operator cycle time
S = Service time
OD = Operator delay time
T = Tolerance time
MD = Machine delay time

Figure 2. Temporal parameters in paced work

False Alarms: Units not processed in the right manner by the operator.

Literature Survey

Work repetition and pacing have become increasingly common practices in industry for enhancing production efficiency. Performance decrement and potentially harmful stress effects of such job characteristics on the worker were evidenced by physiological, psychological, and performance indices. A review of literature survey clearly indicates such findings.

Physiological Factors

Some Useful Measures

1. Electrodermal
   - Measuring the change in conductivity of the skin.
2. Cardiovascular
   - Measuring the rate and beating of the heart (electrocardiogram)
3. Respiratory
   - Measuring the rate of respiration through strain guages around the chest.
4. Muscle Activity
   - Measures changes in muscle action potentials (electromyogram)
5. Pupillometrics
   - Measures the size of the pupil of the eye.
6. Brain Activity
   - Measures electrical activity of the brain

(electroencephalogram)

7. Gastrointestinal

The usefulness of any one of these various psychophysiological measures in research or in assessing human performance is determined primarily by its validity, but practial difficulties in obtaining good recordings are also of relevance. There are a good number of jobs for which information about how the workers heart rate or other measures affected by the stress of the work would be useful to have, but the awkwardeness of obtaining the measures precludes getting the information.

Psychological Factors

Simultaneous attention to the performance and subjective factors not only influences productivity and health, but, as suggested by Johnson(1970) and by Sontendam(1977), also allows use of economical and direct measures rather than expensive, high-technology ones.

Psychological factors may make their presence known before the physiological or the performance do. High noise job situations, where workers complain even when their productivity is not affected, are an instance. Another is the study by Friedman et al (1977) where volunteers reduced their daily sleep 15 minutes per week, until they were down to 5 hours per night. Throughout the experiment, performance on the battery of tests sensitive to the effects of sleep loss held up very well. Yet, the subjects could not persist because of the subjective feelings of fatigue and exasperation. This implies that some workers may abandon some work, not because they are doing poorly at it, but because they feel tired or dispirited.

In his comments at the Amsterdam ergonomics research planning conference, Singleton(1971) concluded:

> the difficlties of setting adequate standards for physiological stress highlights the problem of equivalent standards for psychological stress and also the lack of knowledge of combined effects of stessors. Even if we did have a reasonable comprehension of effects of stress we would still have problems of determining what are reasonable or acceptable stresses and strains which we can expect workers to accept. It can be argued that the worker will, given the right conditions and freedom, select his own optimum level of work but this is still uncertain. Preference levels are probably different from upper or lower acceptable limits and again we know little about inter-and intra-individual differences(pp. 57-58).

Criterion Relevance in Psycho-Physiological Measurements

The practical usefulness of physiological and psycho-physiological methods in the study of work is that, it brings a very advanced state of measurement. For some areas where psychology must use ratings or subjective estimates, physiology can supply fairly objective numbers.

Most psycho-physiological methods have acceptable reliability and an improving technological simplicity and administrability, but still fall short of what they need in ease of interpretation and validity. No single psycho-physiological measure is useful over a wide range of jobs. Therefore, unless one is fairly sure about what is to be measured, the final selection of appropriate measuring instruments is premature.

The psychophysiological measures might be the best indicators of the state of the organism, but the performance measures are the indicators of what the worker actually produces. The present study takes into account performance measures as well as subjective rating of the perceived task difficulty.

Various studies encompassing one or all the above mentioned factors(indices) are presented in the following pages. Also, an attempt has been made to categorize these studies into various similar headings. Those studies which deal with performance parameters more comprehensibly are dealt with in more detail.

Studies on Psycho-Physiological Effects

Corlett and Mahadeva (1970) studied the relationship between a freely chosen working pace and energy consumption and concluded that

(1) subjects performing repetitive submaximal physical tasks seem, when given the choice, to be able to choose the slowest pace which involves the minimum physiological energy cost per cycle as their working rhythm;

(2) the analysis of results failed to reveal any relationships of the "natural" pace with the subjects physical characteristics as age, height, weight, vital capacity, and body surface area.

Salvendy and Pilitsis (1974) found that the subjects within the 21 to 43 year age range render optimum human body efficiency around the freely chosen or natural rhythm of work region, whereas the subjects within the 45 to 64 year age range did not experience maximum human body efficiency within the freely chosen work region. However, when mean output per work minute during non-pacing was compared, it showed statistical significance, the value being higher for the 45 to 64 year age group.

Racenberg (1977) compared physiological functions during assembly-line work with imposed and free work rate. In this study, heart rate, muscle tone, cardiac output, sensorimotor reaction time and psychogalvanic reflex were investigated in 48 radio parts assembly workers before the shift, before and after the lunch break, and after the shift. Motor and autonomic functions showed better coordination when the work rate was freely chosen than when it was imposed on the worker.

Yet another study involving comparison of physiological indices during paced and unpaced work was done by Manenica (1977). In this study, trained subjects performed a simple assembly task under self-paced and machine-paced working conditions. To produce a level of pacing equal to the subject's mean unpaced performance, a conveyor system and a part-feeding unit were used. During paced work, pieces were queuing up in a chute and were delivered one by one to the conveyor belt by the feeding unit and brought to the subject by the belt. Time interval between successive parts could be varied from 0.1 to 30 seconds, in 0.1 second steps. It was also possible to vary the conveyor belt speed. During unpaced work, however, the parts were queuing up in front of the subject, and were indefinitely available for picking up.

Two hours of training preceded the main experiments. The training was organized in four 30 minute blocks with a 15 minute rest pause between the blocks and was unpaced. In addition to this, each subject was given 10 minutes to adapt and was unpaced. In addition to this, each subject was given 10 minutes to adapt to paced work. This 10 minute training was given before the subject's work under paced condition.

The task was performed continuously for two hours under paced, and for two hours under the unpaced condition. The sequence of the conditions was altered from subject to subject. The training and the two work conditions were employed on different days. The work rate under paced conditions was equal to the subject's mean rate of output under unpaced working conditions (established at the end of training).

Work cycle times, respiratory and cardiac intervals were recorded continuously throughout two hours of unpaced and two hours of paced work of the same rate as the subject's mean unpaced performance. The two kinds of work were shown to be physiologically different, with respect to their general levels and rates of change. The results indicated that the unpaced work imposed a higher load upon the subject than the paced work. It was also indicated that the organism may be prepared in advance for the work under unpaced conditions, while it seemed to be "driven" by the machine under paced conditions, and worked with a kind of momentary "physiological lag".

Studies of machine-paced (paced) and self-paced (unpaced) work by Dudley (1963), Murrell (1962), Sury (1967) and others showed marked differences in output patterns (cycle time distributions) between the two kinds of work.

Bertelson, et al. (1965) found that during a letter sorting task the number of errors was three percent during unpaced work, while when working at the same rate under paced conditions, the operators made nine percent errors.

On the basis of their study of some output patterns during paced and unpaced work, Murrell and Forsaith (1963) suggested that paced work, at the same rate as subjects' unpaced work, was more stressful.

In the study of psychophysiological aspects of paced and unpaced work, Koholova and Matousek (1968) found some differences in heart rate with a signal reading task. The heart rate during the paced conditions increased with the complexity of the task, while it had a decreasing trend during the unpaced work, even if the complexity of the task increased. They did not report, however, on any differences in heart rate between the two conditions at the same work rate.

Amaria (1974) observed the heart rates of subjects who worked under unpaced and paced conditions. Their pacing rates were 10% less than, equal to, and 20% higher than, their individual average unpaced rates. He found higher heart rates during all the three conditions of paced work than when the subjects were working at their own freely chosen pace. The conclusion was that paced work was more stressful than unpaced, even when it was performed at a lower rate.

Effects of personality, perceptual difficulty and physiological stress were found by Salvendy and Humphreys (1979). For this purpose, relative psychological, physiological, and performance advantages and disadvantages of utilizing machine-paced and self-paced work were examined by having 12 subjects perform a marking-stapling task at two levels of perceptual difficulty and under two pacing conditions for 30 minutes each. (a) Three subjects who on the personality tests were identified as introverted, reserved, and trusting preferred to work in the machine-paced condition, (b) the performance errors in machine-paced operation were 372% higher than for self-paced work, and (c) there were no differences between machine-paced and self-paced work on physiological variables, except for sinus arrhythmia for the task with high perceptual load and quantity of production.

Studies on Perceived Difficulty and Trait Anxiety

Dornic and Stone (1974) studied the effect of "time stress" upon the relation between "objective" difficulty (performance) and perceived difficulty. Three serial tasks of increasing complexity were used, all of them involving high information load. The tasks consisted of successively presented complex items which required differentiated response according to a given code. Each of the three tasks was performed under two different conditions, with and without time pressure. In the former condition, the presentation of items was paced, while in the other condition, the presentation was self-paced. The results showed that with increasing complexity, performance deteriorated and perceived difficulty increased considerably more in the paced condition. In cases where performance in the two conditions was the same, paced tasks were experienced as more difficult than self-paced tasks. This was interpreted as due to different "subjective costs" responsible for identical performance.

Mayer (1977) reported findings on effects of self-pacing and trait anxiety. For this purpose, ninety-two subjects solved a series of problems without enough time to finish and worked either at a pace and in an order determined by the experimenter (experimenter-paced) or at their own pace and order under self-administered time deadlines (self-paced). Self-pacing resulted in superior performance on rote and poorer performance on cognitive problems relative to experimenter-paced groups. Self-pacing had no effect on low-anxious subjects, and high-anxious subjects performed better on rote and poorer on cognitive problems relative to low-anxious subjects.

Study of Behavioral Characteristics

Mukai (1981) studied behavioral characteristics of workers in paced tasks. The problem was that workers engaged in paced work had to perform in a monotonous state, and there were two noteworthy factors which might have had adverse mental and/or physical effects on them, viz., (a) heteronomy in work activity, and (b) continuity or quick repetition of a similar motion. The problem of work load should be approached from the viewpont of work type as well as the realities of a worker's adaptation to the task. This study attempted to examine some aspects of behavioral characteristics of workers in paced tasks, and two experiments were conducted. In one experiment two subjects participated. The task was a simple repetitive manual task of easy packing, and it was done in three different restrictive conditions; namely the working time per unit was 15 seconds, 20 seconds, and 30 seconds. Materials (colored cubes) were carried by a belt-conveyor. Subjects picked them up, packed them into a package according to a model presented, and wrapped up the package. Each work cycle time and pause were recorded for analysis. In the other experiment the task was the same as in the first experiment. Six subjects were used. Each subject wore an eye camera. The purpose of the eye movement study was to examine scanning pattern of materials and a model. The major results were as follows: (1) The time-study of the repetitive task revealed that the shorter the time for the unit task, the smaller the variance (standard deviation), but there were considerable variations of each cycle time even under heavy restrictions. (2) There were several scanning patterns throughout the experimental session for the subjects, especially when they were packing cubes into the package. All the patterns could be classified into five categories. Moreover, the scanning pattern varied in each subject under the same restrictive condition. As to the temporal variations, the results of the two experiments were similar. This fact seems to suggest the flexibility of human behavior under heavy temporal restriction to maintain the stability of performance.

Study of Simulated Inspection in Pacing

McFarling and Heimstra, as cited by Eskew and Riche (1982), studied the effects of machine-pacing vs self-pacing on performance and task perception in simulated inspection. The task was to detect flaws in 225 slides of printed circuits as the slides were projected on a screen. Half of the subjects were machine-paced through the task, which took about 52 minutes. The other half were allowed to pace themselves but were asked to try to finish it in 52 minutes. The results showed that not only did the self-paced subjects detect more defects but also rated the task as less unpleasant than did the machine-paced subjects.

Task Performance in Different Working Speeds

Evaluation of pacing on simple repetitive tasks in design of optimum working speed was done by Kumashiro, et al., (1980). Eight working speeds, conveyor-paced and self-paced, were established for a repetitive task whose cycle time was only 30 sec, but which consisted of 100 motions and with considerable difficulty in eye-hand coordination (Table 1). The procedure for calculating pace allowances in this type of repetitive task was experimentally studied from the two angles of physiological and psychological functions of the subjects and quantitative and qualitative variations of the task.

The results obtained were as follows:

1. The physiological functions of the subjects lowered most sharply under the self-paced-max condition.

2. The subjects complained of symptoms of fatigue most

TABLE 1

Experimental Design of Working Speeds in Pacing

Exp. No.	Description	Task Time	Abbreviation
1	The subject performed the task at his free pace.	120 min	self-paced
2	The subject was informed of his output under the self-paced condition and was instructed to perform the same amount of work "at his maximum pace."	-	self-paced-max
3.	The average cycle time obtained under the self-paced condition was used to instruct the speed of the belt conveyor.	120 min	paced
4.	The average cycle time obtained under the self-paced-max condition was used to instruct the speed of the belt conveyor.	120 min	paced-max
5.	The basic cycle time value calculated by the MTM procedure was used to instruct the speed of the belt conveyor.	120 min	paced-MTM1
6.	The basic cycle time value calculated by the WF procedure was used to instruct the speed of the belt conveyor.	120 min	paced WF1
7.	Plates were moved on the belt conveyor at the instructed speed under the paced-MTM1 condition plus 15% allowance, and the task time was set to process the same number of plates as done under the paced-MTM1 condition.	136 min	paced-MTM2
8.	Plates were moved on the belt conveyor at the instructed speed under the paced-WF1 condition, and the task time was set to process the same number of plates as done under the paced-MTM1 condition.	96 min	paced-WF2

frequently under the self-paced-max and paced-WF1 conditions and least frequently under the paced-MTM1 condition.

3. Effective productivity - maximum output and minimum fraction defective - was the highest under the self-paced-max condition and the lowest under the paced-WF1 condition.

4. The individual differences in output was the largest under the paced-max condition and the smallest under the paced condition.

5. The miss rate in conveyor-paced operations was the largest under the paced-WF1 condition and the smallest under the paced condition. The conclusions drawn from the results of the experimental repetitive task with difficulty in eye-hand coordination were as follows:

1. The highest production efficiency was accomplished when:

(1) The self-paced system rather than the conveyor-paced system was employed.

(2) The standard time value was instructed to each operator as the aim of working pace. The standard time (ST) per work cycle was calculated by ST = 0.75x - where x = time value per work cycle, obtained when the operator had performed the task at his free pace.

(3) The maximum length of a continuous working time was set at 90 minutes to prevent operator fatigue.

2. Lowering of the physiological function (cerebral cortex activity level) was affected by the magnitude of output rather than whether the task is conveyor-paced or self-paced.

3. Subjective symptoms of fatigue were affected greatly by the operator's disagreement with conveyor pace as well as the magnitude of output.

4. The output of the operator did not specifically vary with the elapse of time, irrespective of whether the task was conveyor-paced or self-paced, and whether the cycle time was long or short. The fraction defective increased with the elapse of working time and was influenced by the length of the cycle time, irrespective of whether the task was conveyor-paced or self-paced.

5. In the conveyor-paced system, it was desirable to use the basic time value calculated by the MTM procedure to set the standard conveyor speed per work cycle.

An ergonomic study of paced and unpaced conditions for simple repetitive manual tasks was also conducted by Kumashiro and Saito (1979). The purpose of this study was to investigate the relationship between paced (conveyor system) and unpaced work under various conditions. A comparison has been made between the physiological functions and changes in the quantity or in the quality of operator performance. The subjects were eight healthy male students. They were engaged in a simple repetitive manual stamping task. In the unpaced condition, operators worked freely for 30 minutes, 120 minutes, and 150 minutes. They worked for 120 minutes under two pacing conditions; at the mean cycle time of the three unpaced periods and at 150% of the mean cycle time for the unpaced 120 minute period. The results obtained were as follows:

(1) Complaint of subjective symptoms at paced systems tended to increase compared to those experienced during the unpaced condition.

(2) Unsatisfactory results for stamping papers occured where the conveyor speed was kept to 150% of the mean cycle time in the unpaced condition.

(3) For a continuous working period of one hour in an unpaced condition, the operation efficiency decreased exponentially in parallel with time.

Peddada (1983) conducted an experiment to find out the effects of pacing on worker performance in a simple inspection task. One self-paced condition and five machine-paced conditions were tested in the study. The latter five conditions ranged from 90 per cent to 130 per cent (at equal intervals of 10 percentage points) of the subject's mean cycle time in the self paced condition. Hence, the absolute values of the cycle times applied in each condition varied from subject to subject.

Fifteen subjects from a senior level management class participated in the study. The task performed by them was a pennies inspection task. Pennies were 40 per board. Subjects had to mark the defective pennies. The responses recorded were the quantity of good production and the time taken to complete them. The subjects also evaluated the difficulty of the task on a relative perceived exertion scale.

The complete experiment lasted for about two hours including the 20 minute learning period. The total number of pennies in a treatment was a constant (800) and the duration of each treatment was approximately 15 minutes. Therefore, about 20 units (800 pennies) were inspected in 15 minutes with a time of less than one minute per unit. The duration varied depending upon the cycle time of each treatment.

The results indicated that production is high in self-paced conditions and machine-paced speeds lower than 100 percent. But the rate of production was significantly higher at machine-paced speeds of 120 per cent and 130 per cent. Quality of work was not effected due to pacing rate. Perceived task difficulty increased with increase in the rate of pacing but it was less in self-paced as compared to machine-paced based on 100 per cent of mean cycle time in self-paced condition.

Pilot Study

To gain further insight into the complex human behavior in pacing, a preliminary study comparing self-paced and machine-paced conditions was conducted. Unlike six different pacing conditions employed by Peddada (1983), only two conditions were used, namely, self-paced and machine-paced at 100 percent of mean cycle time in self-paced. Also, an assembly-type task was used instead of an inspection type (refer to Method's section). Perceived task difficulty as well as various performance parameters were evaluated.

Ten subjects participated in the experiment. The experiment lasted for about two hours including a 20 minute learning period. The time taken to assemble one unit was in the range of 300-500 seconds. The time for each treatment was about 45 minutes.

The results indicated that no statistically significant differences existed in production, performance and judged task difficulty in self-paced and machine-paced conditions.

Summary

In the light of the above-stated findings and ensuing contradictions by different researchers, it is reasonable to conclude that there is certainly a distinct advantage in comparing self-paced and machine-paced work. Nearly all the previous studies involved cycle times of less than a minute which is not always true as regards assembly-type work.

The pilot study undertaken was unique in that the cycle time was substantially longer (300-500 seconds) and the duration of the treatments was also considerably greater (45 minutes) than usually considered in the various studies - for instance, Peddada (1983) allocated 15 minutes to each treatment.

Unlike most of the previous studies, the emphasis in the pilot study was mainly on two conditions, viz, self-paced and machine-paced at 100 percent of mean cycle time in self-paced. The results of the study indicated subjects did not experience a greater task difficulty and resulting stress in machine-paced (at 100 percent of mean self paced) as compared to self-paced. This was evidenced in Peddada's (1983) study. No statistically significant difference was noted either in production or performance of the operators.

Still the need for longer time periods approaching that of real-world work situations and on realistic tasks prompted a further inquiry into the comparative study of self-paced and machine-paced conditions. An attempt was made by employing a longer "learning" period to make the research findings more applicable to real-world work situations.

PROBLEM

This study dealt with the investigation of pacing and self-pacing on:

1. Production, performance and rate of production of the operator.
2. The effect of prolonged cycle times (300 - 500 secs) on operators performance involved in a repetitios work. (An extention of Peddada's (1983) thesis)
3. Subjective evaluation of the task difficulty perceived by the operator.

The following directional hypotheses were made in the study:

1. The task difficulty as perceived by the subject will be considerably lower in self-paced than in machine paced condition based on 100 percent of the operators mean cycle time in self-paced.

2. Production, rate of production and performance will not differ significantly in the two conditions. Longer cycle times will not result in performance decrement of the subjects.

METHOD

Task

There were two conditions applied to each subject in this experiment. One was self-paced and the other was machine-paced at 100 percent of the subjects mean cycle time in the self-paced condition. The task used in this study was an "electronic circuit assembly task" performed by the subjects at a work station. The units were breadboards (Figure 3) which were used to temporarily wire together the electronic circuit . The breadboard is a digital input-output device used to input digital information into a circuit and detect and display the information that comes out.

Each task was divided into four sub-tasks. A single breadboard in effect contains four independent circuits which were to be wired by the subject (Figure 4). The subject had to complete one sub-task before proceeding to the next one. Therefore, inability of the operator to properly wire one sub-task would be counted as a "false alarm" or a "miss" in the event the subject does not work to completion on the sub-task. Likewise, hits were also considered on the individual sub-tasks. Furthermore, there were two versions of the main task to prevent the subjects from memorizing the circuit and give erroneous results. The circuit diagrams for the two versions of the task are given in Figures 5 and 6. A detailed instruction sheet was provided to the operator for each version of the task for wiring the circuit (Figures 7 and 8).

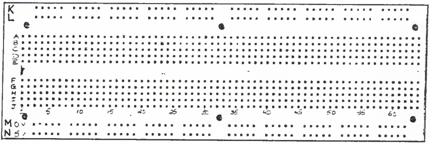


Figure 3. Breadboard

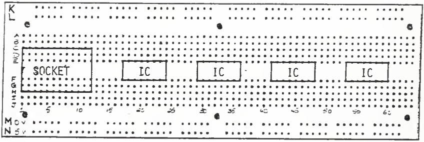


Figure 4. Breadboard - with four sub-tasks

LED STATUS: $\overline{A}_D$, A_1, $\overline{A}_2$, A_3, B_D, B_1, $\overline{B}_2$, B_3, $\overline{C}_0$, C_1, $\overline{C}_2$, C_3, D_D, $\overline{D}_1$, $\overline{D}_2$, D_3

("‾" indicates LED is off)

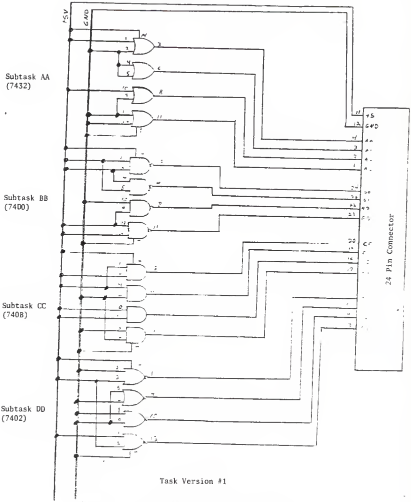


Figure 5. Circuit diagram of the breadboard-task

LED STATUS: A_0, A_1, A_2, $\overline{A}_3$, B_0, B_1, $\overline{B}_2$, $\overline{B}_3$, C_0, $\overline{C}_1$, C_2, $\overline{C}_3$, $\overline{D}_0$, D_1, D_2, $\overline{D}_3$
("—" indicates LED is off)

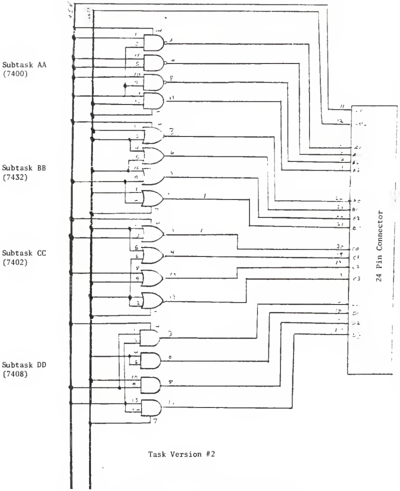
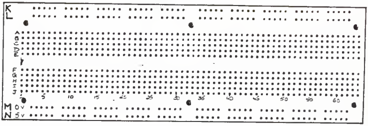


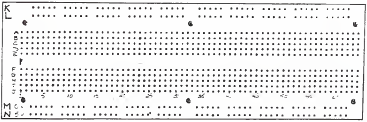
Figure 6. Circuit diagram of the breadboard-task



CONNECTIONS

PART	NO.	FROM	TO
D D	4	J-18	M-18
	6	J-19	N-19
	6	A-18	K-18
	4	A-19	L-19
	4	A-20	L-21
	6	A-22	K-22
A A	4	J-30	M-29
	4	J-31	M-30
	6	A-30	K-29
	6	A-31	K-30
	6	A-32	K-35
	4	A-34	L-35

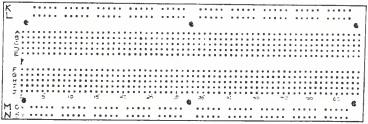
Figure 7. Instructions for wiring breadboard-assembly (Version 1)



CONNECTIONS

PART NO.		FROM	TO
CC	4	J-43	M-43
	4	J-45	M-44
	6	J-46	N-46
	6	A-42	K-42
	4	A-43	L-43
	6	A-46	K-46
	6	A-47	K-47
BB	6	J-55	N-55
	4	J-56	M-56
	6	J-59	N-59
	6	A-54	K-54
	6	A-57	K-56
	4	A-59	L-59
	4	A-60	L-60

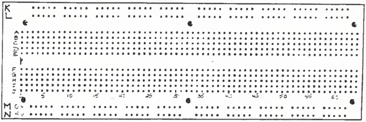
Figure 7. Instructions for wiring breadboard-assembly (continued)



CONNECTIONS

PART NO.		FROM	TO
	4	J-18	M-18
	4	J-21	M-21
A	6	J-24	N-24
A	6	A-18	K-18
	6	A-19	K-19
	4	A-20	L-21
	6	A-22	K-22
	6	J-30	N-29
	6	J-31	N-30
	6	J-36	N-36
D	6	A-30	K-30
D	4	A-31	L-30
	4	A-34	L-35

Figure 8. Instructions for wiring breadboard-assembly (Version 2)



CONNECTIONS

PART NO.		FROM	TO
EE	6	J-43	N-43
	4	J-44	M-44
	6	J-48	N-48
	6	A-42	K-42
	4	A-45	L-44
	4	A-47	L-47
	6	A-48	K-48
CC	6	J-57	N-56
	6	J-60	N-60
	6	A-54	K-54
	6	A-55	K-55
	4	A-58	L-58
	6	A-59	K-59

Figure 8. Instructions for wiring breadboard-assembly (continued)

Each breadboard was attached to a cardboard when it arrived at the workstation. The workstation was situated on a variable speed belt conveyor. The conveyor indexed at the end of the cycle time to bring the next unit into position. However, the subject was not allowed to perform the task while the conveyor indexed. The conveyor would come into a stationary mode when the unit was exactly in position at the work station due to a photo-electric sensing device. Moreover, the plastic bin contained wires which were categorized into different lengths by assigning them different part numbers. This bin was placed in front of the operator and across the conveyor. A pair of "tweezers" was also provided to help in inserting the wires into the breadboard and also to pick wires from the bins.

In the self-paced condition the operator had control over the arrival of the units. He was asked to press the red button near his left hand as soon as he completed assembling the unit at the workplace. This response of his, activated the clock and also indexed the conveyor. In the machine-paced condition, a time delay that was set by the experimenter determined the time that the subject had to wire the units in that condition. The subject was asked to press the button in the machine paced condition also, in order to retain the consistency of the task. In case the subject was done earlier his response gave the exerimenter actual time taken by him to inspect the unit regardless of the set delay. The subject was idle until the conveyor indexed and brought the next unit into position.

The paced condition for each subject was based on his mean cycle time in the self-paced rate. Hence the absolute values of the cycle times applied in each condition varied from subject to subject.

The circuits completed by the subject were examined by the experimenter and the number of hits, misses and false alarms were recorded. This was done by inserting the 24 pin socket into the breadboard, the other end of which was connected to a "test circuit". Its circuit diagram is given in Figure 9. On this test circuit were 16 LED's (light Emitting Diodes). Corresponding to each sub-task - in a given version of the task - a particular set of four LED's would light according to a pre-determined fashion and any deviation from this was regarded as a false alarm. The complete experiment per subject lasted for about five hours.

Order of Application of Treatments

As mentioned above, the total duration of the experiment was five hours. The first hour involved learning and the data obtained during this time was used only for calculating the learning rate. The remaining time was divided into one hour sessions with five minutes break after the first and third hour and a 20-minute break after the second hour. The self-paced and machine-paced treatment were applied to subjects on an hourly basis according to a sequence given in Table 2.

Learning and Calibration

The subjects were allowed a one-hour learning period to gain skill and experience in performing the task. This learning

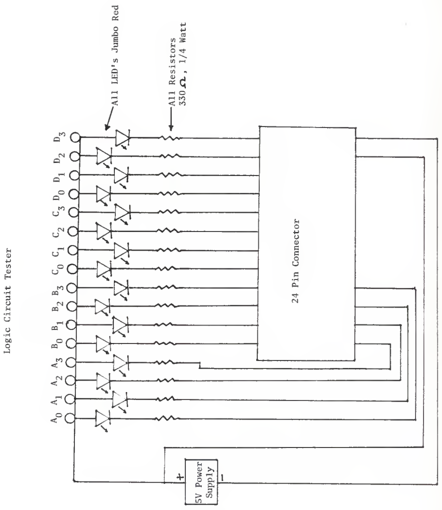


Figure 9. Circuit diagram for the fault-detecting tester

TABLE 2

Treatment Pattern of Main Task

SUBJECT	TREATMENT PATTERN			
#	1ST Hour	2ND Hour	3RD Hour	4TH Hour
1	SP	MP	SP	MP
2	SP	MP	MP	SP
3	MP	SP	SP	MP
4	MP	SP	MP	SP
5	SP	MP	SP	MP
6	SP	MP	MP	SP
7	MP	SP	SP	MP
8	MP	SP	MP	SP
9	SP	MP	SP	MP
10	SP	MP	MP	SP

SP = Self-paced

MP = Machine-paced

period comprised of self-paced and machine-paced treatments. Keeping in mind ivdividual variations in learning time, it was limited to six observations within the allocated one hour. The order of application helped the subjects in gaining more skill in performing tasks as well as computing the required learning rate.

The learning rate is given as

LNRATE = (2X)(TIME)/(X)(TIME)

where:

LNRATE = Learning rate

(2X)(TIME) = Time/unit at quantity (2X)

(X)(TIME) = Time/unit at quantity (X)

This means when the quantity doubles, the time at the doubled unit is "p" percent of the time at the original unit.

In order to take into account the continuous learning on the part of the subjects an attempt was made to incorporate this into the analysis. This was done by applying a correction (as described in Results Section) to the readings (cycle times) of the operators when they were performing in the self-paced mode during the learning period.

Instructions and Informed Consent

The detailed instuctions given to the subject prior to the start of the experiment appear in Figure 10. The format of the informed consent signed by the subjects is shown in Figure 11

INSTRUCTIONS

You are about to participate in an experiment that tests the effects of pacing on operator's performance. You will have to perform an electronic circuit assembly task under two pacing conditions. You are to perform the task as fast as you can without sacrificing accuracy. You will have 55 minutes to familiarize yourself with the task and also gain enough practice in performing the task.

TASK

The breadboard will arrive at the specified work station on the conveyor. You are to wait until the conveyor comes to a stop before you start performing the task. This instant is represented by the red light in front of you not glowing. You are to read the connections from the sheet in front of you and start completing the circuit. The wires that you will use in making the circuit are precut and stripped. You are to pick up the right kind of wire and insert it in the proper hole in the breadboard. Each breadboard will have four small I.C. chips and one large I.C. chip. Each small chip designates a circuit which will be completed by you. So you will complete four circuits on one breadboard. There are two different types of conditions that can signify the completion of the task. The two conditions are (1) Self-paced condition. In this condition you have to press the red button provided to you, as soon as you complete the task. This response activates the conveyor and brings the next unit into position. (2) Paced condition. In this condition the breadboard

Figure 10. Instruction form

will arrive at a rate set by me. You will be allowed only a certain amount of time for the completion of the task and at the end of the allowed time, the next unit will come into position. It is possible that in some cases you will complete the task before the allowed time, while in other cases the allowed period of time might not be sufficient. In case you finish the task earlier you have to press the red button signifying your completion of the task and wait for the arrival of the next unit. In the other case if you cannot complete the task in specified time the conveyor will be timed to start automatically at the end of this time thus bringing in the next unit in its position.

At no time you can perform the task while the conveyor is moving. After the familiarization period, you will have two conditions - self-paced and machine-paced. At the end of each condition you are to rate the difficulty of the task on the Borg's Perceived Exertion Scale supplied to you. Later you are to identify the conditions that you most prefer and also state the reason in a sentence or two for your preference.

You can clear your doubts with me any time during the experiment. There is no danger or risk involved in the experiment and the data recorded by me is strictly confidential. You are free to leave the experiment at any time but I would very much appreciate it if you complete it to the end.

Your participation in the experiment is very much appreciated.

Figure 10. Instruction form (continued)

INFORMED CONSENT

I have read the instructions of the experiment carefully and I do hereby fully agree to participate in the experiment.

________________ Date

______________________ Signature of subject

NAME ________________________

AGE ________ SEX __________

Figure 11. Informed consent form

Experimental Design

The "same subjects design" was chosen in which the comparison of two treatments was done on the basis of a "paired t-test". The paired t-test will tell whether there is a statistically significant difference between the two treatments (paced and unpaced) for each of the variables.

Independent Variables

There were two levels of the independent variable in the study. One was self-paced and other was machined paced rate.

Dependent Variables

The various responses of the subject recorded were:

1. Time taken to wire each breadboard unit.
2. The number of hits on each unit.
3. The number of misses on each unit.
4. The number of false alarms on each unit.
5. The subjective evaluation of the conditions and the preference of the subject to either self-paced or machine paced.

The subjective ratings on the relative perceived exertion scale of Borg indicated the task difficulty from very very easy (6) to very very hard (21) (Figure 12).

The above responses of the subject were transformed into production, production rate, and performance according to the following formulas:

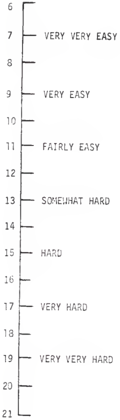


Figure 12. Borg's Perceived Exertion Scale

$$\text{Production} = \frac{\text{Number of circuits correctly wired (hits)}}{\text{Total no. of ccts. to be wired (const.60)}}$$

$$\text{Production Rate} = \frac{\text{Number of circuits correctly wired (hits)}}{\text{Number of circuits actually wired}}$$

$$\text{Performance} = \frac{\text{Number of circuits correctly wired (hits)}}{\text{Time taken to wire the circuits}}$$

The production and production rate has been normalized to a maximum of one.

Subjects and Recruitment Procedure

An incidental sample of ten subjects was recruited for the experiment and were paid at the rate of $5.00/hour.

Apparatus and Materials

The apparatus for the experiment mainly consisted of a belt conveyor, breadboards, and an electronic circuit specially built for the experiment. The circuit was provided with the capabilities to:

1. set the type of pacing (self-paced or machine-paced);
2. set the delay in machine-paced conditions; and
3. an LED display of the time taken by the subject to assemble the unit, accurate to one-tenth of a second.

The circuit used a photoelectric sensing device to activate the clock. The earlier of the two responses, either of the subject (press of a button) or end of the set delay clocked the time.

TABLE 3

Production of All subjects*

SUB	SP	MP	DIFF
1	0.95	0.97	0.02
2	0.98	0.92	-0.06
3	0.98	0.97	-0.01
4	0.98	0.92	-0.06
5	0.93	0.87	-0.06
6	0.97	0.98	0.01
7	0.93	0.95	0.02
8	1.00	0.97	-0.03
9	0.93	0.90	-0.03
10	0.88	0.97	0.09
Mean	0.95	0.94	-0.01

SP = Self-paced

MP = Machine-paced

* Subjects responses like hits, misses and false alarms transformed into production by dividing total hits by total number of circuits (60).

RESULTS

The responses of the subjects were hits, misses, false alarms, and subjective rating in the Borg's scale (Appendix I). These responses were then transformed into production, rate of production, and quality of work (performance) as given in Tables 3, 4, and 5 respectively. Production and performance values were normalized to a maximum of one. These tables clearly show the closeness of the self-paced and machine-paced values since the differences are very small.

The subjective evaluation of task difficulty, as perceived by the subjects, is also shown in Appendix I and their means in Tables 6 and 7. Table 6 gives means of RPE values recorded after each observation whereas Table 7 has RPE values recorded every hour of the treatment for self-paced and machine-paced conditions. The differences in RPE values in self-paced and machine-paced conditions as shown in Table 6 and 7 are negligible.

The mean values of all performance variables in self and machine-paced conditions for the ten subjects are given in Table 8. There is no significant difference in the values for judged task difficulty, production, and performance but the rate of production is about ten percent higher in machine-paced condition as compared to self-paced. It should be noted that the higher production rate is not accompanied by an additional stress or increased task difficulty,since the subjective rating on Borg's scale for both conditions are almost identical.

TABLE 4

Rate of Production of All Subjects*

SUB	SP	MP	DIFF
1	0.1729	0.2076	0.0347
2	0.1638	0.1773	0.0135
3	0.2233	0.2361	0.0128
4	0.1620	0.1690	0.0070
5	0.2166	0.2122	-0.0044
6	0.2343	0.2492	0.0149
7	0.1803	0.2109	0.0301
8	0.1865	0.1984	0.0119
9	0.1127	0.1425	0.0298
10	0.1417	0.1771	0.0354
Mean	0.1795	0.1980	0.0185

SP = Self-paced

MP = Machine-paced

* Subjects responses like hits, misses, and false alarms transformed into rate of production by dividing total hits by time.

TABLE 5

Performance of All Subjects*

SUB	SP	MP	DIFF
1	0.95	0.97	0.02
2	0.98	0.95	0.03
3	0.98	1.00	0.02
4	0.98	1.00	0.02
5	0.93	0.88	-0.05
6	0.97	1.00	0.03
7	0.97	1.00	0.03
8	1.00	1.00	0.00
9	0.93	0.90	-0.03
10	0.88	0.97	0.09
Mean	0.96	0.97	0.01

SP = Self-paced

MP = Machine-paced

* Subjects responses like hits, misses and false alarms transformed into performance by dividing total hits by number of circuits actually wired (total - misses)

TABLE 6

Mean RPE Values of Subjects

SUB	SP	MP	DIFF
1	10.00	9.73	-0.27
2	11.20	11.47	0.27
3	9.40	9.53	0.13
4	13.67	12.93	-0.74
5	7.73	8.00	0.27
6	9.20	8.10	-1.10
7	8.93	10.20	1.27
8	11.53	14.27	2.74
9	10.47	10.20	-0.27
10	12.40	11.93	-0.47
Mean	10.45	10.64	0.19

RPE = Relative Perceived Exertion Scale

TABLE 7

Mean RPE(Hourly) Values of Subjects

SUB	SP	MP	DIFF
1	10.5	9.5	-1.0
2	11.0	12.0	1.0
3	9.5	9.0	-0.5
4	14.5	13.5	-1.0
5	9.5	8.0	-1.5
6	9.5	9.5	-1.5
7	9.5	10.0	0.5
8	11.0	15.0	4.0
9	10.0	10.0	0.0
10	12.5	12.0	-0.5
Mean	10.75	10.70	-0.05

RPE = Relative Perceived Exertion

The various responses recorded on the subject data sheet (Appendix I) were used to carry out the paired comparision t-tests. The hypotheses were tested at the five percent significance level. The results of the paired t-tests for RPE, RPE(hourly), production, rate of production, and performance are depicted in Table 9. This substantiates the earlier stated results because statistically significant differences in self-paced and machine-paced conditions were observed only in the case of rate of production.

The results from means table (Table 8) and paired comparision t-tests (Table 9) can be summarized as follows:

1. There was no statistically significant difference in RPE (task difficulty) between self-paced and machine-paced conditions.

2. Production and production rate were also found statistically non-significant.

3. The rate of production was significantly different between machine-paced and self-paced at five percent alpha level. Production rate was approximately ten percent higher in machine-paced conditions.

Appendix II shows the subject data sheet (learning) which gives the time recorded for six observations in the allocated one hour of learning. The subjects gained practice and skill in working in both the self and paced conditions. It is worth noting that the downward trend in cycle times as the experiment progressed, is common in all the ten subjects. It is also seen from subjects data sheets in learning that the difference in time

TABLE 8

Means of Self and Machine Paced Conditions

VARIABLE	MEAN (SP)	MEAN (MP)
RPE	10.4500	10.6400
RPE(HRLY)	10.7500	10.7000
PRODUCTION	0.9530	0.9420
PERFORMANCE	0.9570	0.9670
PRODUCTION RATE	0.1795	0.1980

RPE = Relative Perceived Exertion
SP = Self-paced
MP = Machine-Paced

TABLE 9

Paired Comparisons t-Test (α =0.05)

VARIABLE (MP-SP)	MEAN	STANDARD ERROR OF MEAN	T	PR > T
RPE	0.18300	0.35075	0.52000	0.61450
RPE(HRLY)	-0.05000	0.51881	-0.10000	0.92530
PRODUCTION	-0.01100	0.01508	-0.73000	0.48450
PERFORMANCE	0.01000	0.01265	0.79000	0.44950
PRODUCTION RATE	0.01857	0.00419	4.43000	0.00160

RPE = Relative Perceived Exertion
SP = Self-Paced
MP = Machine-Paced

between the first and sixth observations is subtantially higher indicating a rapid improvement in performance of the task.

The learning period assigned to subjects was used not only to familiarize the subjects with the task but also to set the machine-paced rate. This machine paced rate was to be set at 100 percent of subject's mean cycle time in self-paced, but it should be kept in mind subjects were continuously learning, even after the first hour. Therefore, a correction or adjustment was made to the readings (cycle times) of the subjects when they were performing in the self-paced mode.

To apply the above stated correction, a learning curve was first drawn. Figure 13 shows a sample plot of operator learning curve for the second operator. The number of units assembled is on the horizontal axis and the cycle time on the vertical axis. The first two data points on the curve correspond to the self-paced readings obtained during the learning period. These two points were used to determine the learning rate. The cycle time of the second self-paced reading was multiplied successively to obtain the time corresponding to the eigth and sixteenth unit. As, seen from the graph the curve has a "decelarating" slope and levels off between the eigth and sixteenth unit, hence the time corresponding to the eigth assembly was used to set the machine paced rate. This time was chosen arbitrarily - based on judgement - keeping in mind that during the ensuing four hours after the learning period, operators will be more proficient in working at the selected task. Although, the operator can continue to improve for years but the reduction in cycle times would be very small as the time

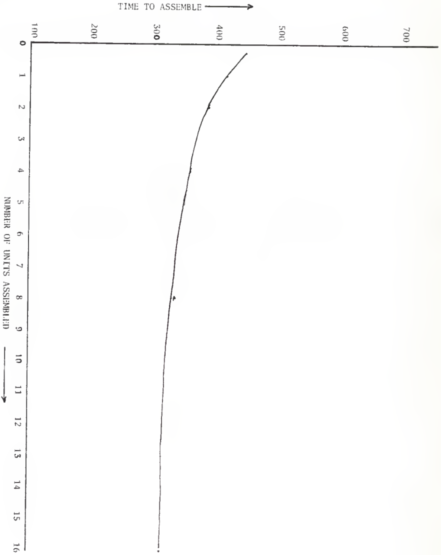


Figure 15. Sample plot of learning curve (for second operator)

progresses. Hence the time (corresponding to the eigth observation) used was a trade-off between the two - high and low - setting of machine paced rate. The above stated procedure is summarized in Figure 14 which shows a sample calculation of how the learning rate was computed and adjusted to set the machine-paced rate.

Sample Calculation

Time to assemble first unit = 415 seconds

Time to assemble second unit = 386 seconds

$$\text{Learning Rate} = \frac{\text{Time to assemble second unit}}{\text{Time to assemble first unit}}$$

$$= \frac{386}{415} = 0.93$$

Taking into account the learning rate:

Estimated time to assemble fourth unit = 386 x 0.93

= 359 seconds

Estimated time to assemble eighth unit = 359 x 0.93

= 334 seconds*

* Time selected to set the machine-paced rate.

Figure 14. Sample calculation to adjust the maching-paced rate

DISCUSSION

It was hypothesized that the task difficulty as perceived by the subjects would be considerably higher in machine-paced conditions (based on 100 percent of the subjects mean cycle time in self-paced) as compared to self-paced. Specifically, this meant that if the subjects were to work under a time constraint, it will induce a higher psychological load on them with resulting stress and hence a higher rating on the Borg perceived exertion scale. The other hypothesis was that the overall performance of the subjects would not deteriorate by virtue of working under a paced condition.

Effect of Pacing Condition on Performance

The subjects did not perform significantly better in the self-paced condition as compared to the paced condition. This is not consistent with the findings of McFarling and Heimstra (1975) who reported a greater percentage of hits in self-paced as compared to machine-paced nor the findings of Bertelson, et al. (1965) who found that false alarms (errors) were half as much during unpaced work, when compared to working at the same rate under paced conditions. The results of present study on performance is, however, consistent with that of Peddada (1983). The only deviation occurred in the rate of production. The analysis of results showed that working in the paced condition yielded a ten percent higher rate output. This is a significant finding. It's importance can readily be seen from the fact that this higher output did not adversely affect the quality of work or the task difficulty perceived by the subject. Thus, all factors remaining the same, higher production per unit of time is obtained in the machine-paced environment without incurring any human disadvantages of working in such conditions.

Effect of Pacing Condition on Task-Difficulty

The results clearly show that, contrary to the first hypothesis, the subjects in this study perceived no additional amount of stress or difficulty in performing a task under a time constraint. Peddada (1983) found that the mean of subjective evaluation of the subjects on the Borg relative perceived exertion scale was lower in self-paced relative to the machine-paced. The machine-paced condition was based on 100 percent of subjects mean cycle time in self-paced.

Figure 15 as plotted by Peddada shows the relationship between RPE rating and the rate of work. This result is rather interesting and consistent with the findings of Dornic and Stone (1974). However, the present study did not yield such results. The aforementioned researchers attributed psychological satisfaction (due to having the control) and different "subjective costs" responsible for such findings.

Effect of Learning

Learning is the more or less stable improvement shown by the operator on a task which has been previously performed. Improvement is realized from faster movement, tool and workpiece

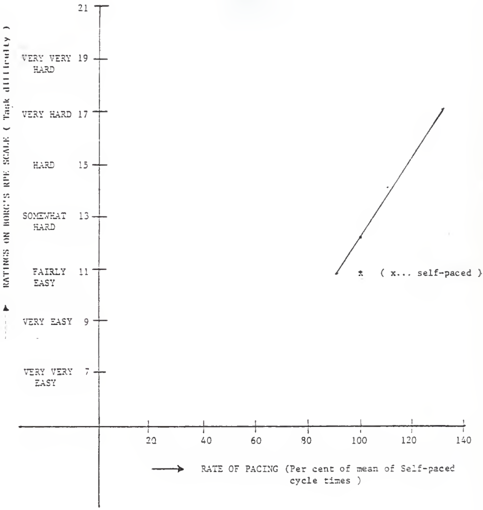


Figure 15. Plot of task difficulty vs. rate of pacing as plotted by Peddada (1983)

familiarity, elimination of fumbles, reduced information gathering and decision time, and the reduced need for diligent attention.

Dudley (1963) showed the difference in performance of an inexperienced operator as opposed to an experienced one. Consider his figure (16). It shows the frequency distribution of cycle times of the inexperienced and the experienced operators. In the former case, the curve is normal, whereas, in the latter case the curve shows a marked positive skewness. It can be seen that in both the cases, the range of the cycle times is the same but the mean cycle time of the experienced operator is shifted to a lesser value. Further, the deviation about the mean is less in the cases of experienced worker as compared to those of the inexperienced workers.

The example highlights the importance of employing experienced worker for any production study to yield effective results. This fact was not emphasized by previous researchers, and it leads one to question the validity of their findings. It is not that this study did not suffer from the shortcoming of relatively inexperienced operators. However, the fact that this was recognized and accounted for by adjusting the self-paced rate, to a large extent, precludes the possibility of obtaining erroneous results during the experiment.

Effect of Fatigue

Decades ago, when work was mainly physical, the idea that a rest allowance should be given was quite proper. But, under

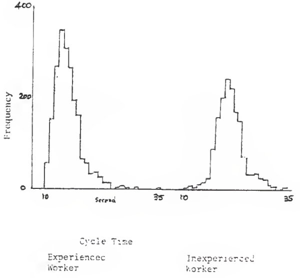


Figure 16. Frequency distributions of experienced and inexperienced operatives as plotted by Dudley (1964)

the modern condition, this is usually no longer true; many tasks have only a small physical content and the energy expended, even in small muscle groups, is usually well below the level at which the effects of muscular fatigue would be observed. The task used in this study was tiring from the constant use of fingers to insert the wires in the breadboard. The wires, being quite small in 'length, rendered the use of tweezers awkward for some subjects. The task became fatiguing, particularly since the average cycle times were longer and operators were new to the task and not conditioned for it.

The use of a tiltable conveyor system and a convenient sized chair allowed subjects to adopt comfortable postures. Light background music also helped ease the monotony of doing repetitious work. Nevertheless, fatigue was complicated by the boredom of building a circuit-assembly for the sole purpose of taking it apart and starting over again.

Practical Considerations

This study did not bring out significant performance differences between the self-paced and paced conditions. This might be due to the prolonged nature of the cycle time for completing one unit (300-500) seconds. Although the learning period was adjusted for longer times, it might have proved to be on the higher side thereby enabling the subjects to complete the task within the time limitations. Therefore, one hour learning period might have proved to be inadequate in view of the longer cycle time taken to complete the task. Another reason can be that as the experimental design for this study was for an alpha level of 0.05 and power of 30 , another experiment with an increased power might show the self-paced condition to be significantly different from the machine-paced.

Furthermore, earlier experimenters assigned various levels of pacing to the subjects in a randomized sequence, that might have yielded a different effect on the subjects perception of task difficulty, whereas this study involves only one machine-paced condition.

One important factor to be considered is that of rate of output. The variable, production rate, incorporates the effect of time taken for completing the task also. The higher machine rates would take time but results in greater number of misses. Hence the basic tradeoff is between the cost of misses and the cost of time primarily labor cost and also the cost of overheads, utilities, etc.). The results indicates a ten percent greater rate of output in machine-paced as compared to self-paced with no apparent loss of overall production or quality of work. Had the experiment be performed for much longer period of time, it is likely, that the overall production might also have improved. The results of laboratory experiments fail to apply in industry in some cases as the considerations vary widely and the motivation of the workers also differ in the two situations.

Future Research

Factors such as the nature of the assembly task, (such as, complexity of the task), task time and the way learning was performed remain to be researched. Hence, the results of this study are valid only to tasks of similar nature and that have about the same levels of complexity and worker motivation.

This study points out that production rate is higher in machine-paced as compared to the self-paced condition. In an industry, the management may be more concerned about production per unit time rather than total production as such. If such is the case, management should consider using machine-pacing as a possible alternative to self-pacing in assembly, especially when it is not accompanied by any excessive stress which can have a detrimental effect on the health of the operators.

CONCLUSIONS

1. The overall production and quality of work were not found significantly different in self-paced as compared to machine - paced condition based on 100 percent of mean cycle time in self-paced.

2. The rate of production was found to be about ten percent higher in machine-pace as compared to self-paced condition.

3. Task difficulty as judged by subjects based on Borg's Relative Perceived Exertion Scale did not differ significantly for self-paced and machine-paced condition.

4. Subjects performance was not adversly affected by the prolonged nature of cycle times (300 - 500 secs.) in this study.

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Appendix I

Subject Data Sheets

TABLE

Subject Data Sheet

Obs	Sex	Trt	Time	RPE	RPE-hr	FA	Miss	Hits
1	M	SP	431	11		0	0	4
2		SP	344	11		0	0	4
3		SP	424	11		0	0	4
4		SP	386	10	11	0	0	4
5		SP	378	10		1	0	3
6		SP	369	10		1	0	3
7		SP	341	10		0	0	4
8		MP	300	9		0	0	4
9		MP	313	9		0	0	4
10		MP	297	9		0	0	4
11		MP	282	8	9	0	0	4
12		MP	310	9		0	0	4
13		MP	259	9		0	0	4
14		MP	312	10		0	0	4
15		SP	304	10		1	0	3
16		SP	264	9		0	0	4
17		SP	289	9		0	0	4
18		SP	322	10	10	0	0	4
19		SP	276	10		0	0	4
20		SP	286	10		0	0	4

TABLE (Contd.)

Subject Data Sheet

Obs	Sex	Trt	Time	RPE	RPE-hr	FA	Miss	Hits
21	M	SP	277	10		0	0	4
22		SP	255	9		0	0	4
23		MP	290	10		0	0	4
24		MP	232	10		0	0	4
25		MP	231	9		0	0	4
26		MP	261	9	10	0	0	4
27		MP	221	9		0	0	4
28		MP	311	12		1	0	3
29		MP	237	12		1	0	3
30		MP	312	12		0	0	4

SP = Self Paced
MP = Machine Paced
RPE = Relative Perceived Exertion (Borg Scale)
FA = False Alarm

TABLE

Subject Data Sheet

Obs	Sex	Trt	Time	R-E	R-E-mn	FA	Miss	Hits
1	M	SP	434	11		0	0	4
2		SP	345	11		0	0	4
3		SP	413	10		0	0	4
4		SP	425	11	11	0	0	4
5		SP	480	12		0	0	4
6		SP	361	10		0	0	4
7		SP	404	12		0	0	4
8		MP	334	12		0	1	3
9		MP	298	12		0	0	4
10		MP	314	12		1	0	3
11		MP	278	12	12	0	0	4
12		MP	303	11		0	0	4
13		MP	308	11		1	0	3
14		MP	317	11		0	0	4
15		MP	331	11		0	0	4
16		MP	317	11		0	0	4
17		MP	334	12		1	1	2
18		MP	296	11		0	0	4
19		MP	334	13	12	0	1	3
20		MP	256	11		0	0	4

TABLE (Contd.)

Subject Data Sheet

Obs	Sex	Trt	Time	RPE	R-E-hr	FA	Miss	Hits.
21	M	MP	288	11		0	0	4
22		MP	308	11		0	0	4
23		SP	344	10		1	0	3
24		SP	322	11		0	0	4
25		SP	276	11		0	0	4
26		SP	280	11	11	0	0	4
27		SP	323	12		0	0	4
28		SP	318	12		0	0	4
29		SP	347	12		0	0	4
30		SP	330	12		0	0	4

SP = Self Paced
MP = Machine Paced
RPE = Relative Perceived Exertion (Borg Scale)
FA = False Alarm

TABLE

Subject Data Sheet

Obs	Sex	Trt	Time	RPE	RPE-hr	FA	Miss	Hits
1	M	MP	267	11		0	1	3
2		MP	267	11		0	1	3
3		MP	259	10		0	0	4
4		MP	266	10	10	0	0	4
5		MP	251	10		0	0	4
6		MP	254	10		0	0	4
7		MP	251	10		0	0	4
8		SP	268	11		0	0	4
9		SP	279	11		0	0	4
10		SP	265	10		0	0	4
11		SP	261	10	10	1	0	3
12		SP	279	10		0	0	4
13		SP	311	10		0	0	4
14		SP	268	10		0	0	4
15		SP	227	10		0	0	4
16		SP	257	9		0	0	4
17		SP	257	9		0	0	4
18		SP	239	9		0	0	4
19		SP	266	8	9	0	0	4
20		SP	277	8		0	0	4

TABLE (Contd.)

Subject Data Sheet

Obs	Sex	Trt	Time	RPE	RPE-Hr	FA	Miss	Hits
21	M	SP	257	8		0	0	4
22		SP	252	8		0	0	4
23		MP	248	8		0	0	4
24		MP	217	8		0	0	4
25		MP	233	8		0	0	4
26		MP	251	10	8	0	0	4
27		MP	254	9		0	0	4
28		MP	199	8		0	0	4
29		MP	268	11		0	0	4
30		MP	200	9		0	0	4

SP = Self Paced
MP = Machine Paced
RPE = Relative Perceived Exertion (Borg Scale)
FA = False Alarm

TABLE

Subject Data Sheet

Obs	Sex	Trt	Time	RPE	RPE-Hr	FA	Miss	Hits
1	M	MP	363	10		0	1	3
2		MP	331	10		0	0	4
3		MP	330	10		0	0	4
4		MP	320	11	12	0	0	4
5		MP	363	12		0	2	2
6		MP	351	12		0	0	4
7		MP	290	12		0	0	4
8		SP	353	10		0	0	4
9		SP	378	10		0	0	4
10		SP	400	13		0	0	4
11		SP	352	14	15	0	0	4
12		SP	340	15		0	0	4
13		SP	348	15		0	0	4
14		SP	366	16		0	0	4
15		SP	352	16		0	0	4
16		MP	317	12		0	0	4
17		MP	363	14	15	0	1	3
18		MP	302	15		0	0	4
19		MP	297	16		0	0	4
20		MP	316	16		0	0	4

TABLE (contd.)

Subject Data Sheet

Obs	Sex	Trt	Time	RPE	RPE-r	FA	Miss	Hits
21	M	MP	315	16		Ø	1	3
22		MP	258	16		Ø	Ø	4
23		MP	330	12		Ø	Ø	4
24		SP	297	12		Ø	Ø	4
25		SP	395	13		Ø	Ø	4
26		SP	416	13		Ø	Ø	4
27		SP	375	14	14	Ø	Ø	4
28		SP	321	14		Ø	Ø	4
29		SP	375	15		1	Ø	3
30		SP	395	15		Ø	Ø	4

SP = Self Paced
MP = Machine Paced
RPE = Relative Perceived Exertion (Borg Scale)
FA = False Alarm

TABLE

Subject Data Sheet

Obs	Sex	Trt	Time	RPE	RPE-rr	FA	Miss	Hits
1	M	SP	301	8		1	0	3
2		SP	259	8		0	0	4
3		SP	246	7		0	0	4
4		SP	288	9	10	0	0	4
5		SP	228	7		0	0	4
6		SP	268	8		0	0	4
7		SP	261	8		1	0	3
8		MP	254	8		0	0	4
9		MP	250	7		1	0	3
10		MP	253	8		1	0	3
11		MP	225	9	8	1	0	3
12		MP	244	8		1	0	3
13		MP	242	9		0	0	4
14		MP	248	9		0	0	4
15		MP	210	8		1	0	3
16		SP	308	9		0	0	4
17		SP	265	7		0	0	4
18		SP	255	8		0	0	4
19		SP	233	7	9	0	0	4
20		SP	234	7		0	0	4

TABLE (Contd.)

Subject Data Sheet

Obs	Sex	Trt	Time	RPE	RPE-hr	FA	Miss	Hits
21	M	SP	217	7		0	0	4
22		SP	264	7		1	0	3
23		SP	251	9		1	0	3
24		MP	270	8		0	0	4
25		MP	282	9		0	1	3
26		MP	261	8		1	0	3
27		MP	207	7	8	0	0	4
28		MP	230	7		0	0	4
29		MP	248	7		0	0	4
30		MP	252	8		1	0	3

SP = Self Paced
MP = Machine Paced
RPE = Relative Perceived Exertion (Borg Scale)
FA = False Alarm

TABLE

Subject Data Sheet

Obs	Sex	Trt	Time	RPE	RPE-avg	[illegible]	[illegible]	[illegible]
1	M	SP	285	11		2	2	4
2		SP	317	11		0	2	4
3		SP	303	11		1	2	3
4		SP	307	11	11	2	2	4
5		SP	254	12		2	2	4
6		SP	270	12		1	2	2
7		SP	245	9		2	2	4
8		SP	242	8		2	2	4
9		MP	259	8		0	2	4
10		MP	235	8		0	2	4
11		MP	237	8		2	2	4
12		MP	264	8	8	2	1	3
13		MP	243	8		2	2	4
14		MP	245	8		2	2	4
15		MP	246	8		0	2	4
16		MP	212	2		2	2	4
17		MP	244	6		2	2	4
18		MP	257	8		2	2	4
19		MP	215	8	8	2	2	4
20		MP	241	8		0	2	4

TABLE (Contd.)

Subject Data Sheet

Obs	Sex	Trt	Time	RPE	RPE-hr	FA	Miss	Hits
21	M	MP	224	8		0	0	4
22		MP	234	8		0	0	4
23		MP	206	8		0	0	4
24		SP	197	8		0	0	4
25		SP	203	8		0	0	4
26		SP	214	8		0	0	4
27		SP	228	8	8	0	0	4
28		SP	233	8		0	0	4
29		SP	206	8		0	0	4
30		SP	209	8		0	0	4

SP = Self Paced
MP = Machine Paced
RPE = Relative Perceived Exertion (Borg Scale)
FA = False Alarm

TABLE

Subject Data Sheet

Obs	Sex	Trt	Time	RPE	RPE-hr	FA	Miss	Hits
1	M	MP	290	12		0	1	3
2		MP	289	11		0	0	4
3		MP	290	12		0	1	3
4		MP	258	10	11	0	0	4
5		MP	280	11		0	0	4
6		MP	264	10		0	0	4
7		MP	280	12		0	0	4
8		SP	335	11		0	0	4
9		SP	327	11		0	0	4
10		SP	283	10		1	0	3
11		SP	348	9	10	0	0	4
12		SP	334	9		0	0	4
13		SP	354	10		0	0	4
14		SP	301	9		0	0	4
15		SP	334	9		0	0	4
16		SP	260	9		1	0	3
17		SP	315	9		0	0	4
18		SP	310	9		0	0	4
19		SP	312	8	9	0	0	4
20		SP	274	7		0	0	4

TABLE (Contd.)

Subject Data Sheet

Dos	Sex	Trt	Time	RPE	RPE-HR	FA	Miss	Hits
21	M	SP	252	7		0	0	4
22		SP	307	7		0	0	4
23		MP	275	9		0	0	4
24		MP	247	9		0	0	4
25		MP	260	9		0	0	4
26		MP	265	9	[illegible]	0	0	4
27		MP	290	13		0	1	3
28		MP	250	9		0	0	4
29		MP	264	9		0	0	4
30		MP	232	9		0	0	4

SP = Self Paced
MP = Machine Paced
RPE = Relative Perceived Exertion (Borg Scale)
FA = False Alarm

TABLE

Subject Data Sheet

Obs	Sex	Trt	Time	RPE	RPE-hr	FF	Miss	Hits
1	M	MP	313	16		0	1	3
2		MP	264	14		0	0	4
3		MP	266	14		0	0	4
4		MP	313	15	14	0	1	3
5		MP	327	13		0	0	4
6		MP	309	15		0	0	4
7		MP	281	10		0	0	4
8		MP	275	12		0	0	4
9		SP	336	10		0	0	4
10		SP	347	11		0	0	4
11		SP	383	12		0	0	4
12		SP	353	11	11	0	0	4
13		SP	298	11		0	0	4
14		SP	250	13		0	0	4
15		SP	302	12		0	0	4
16		MP	287	14		0	0	4
17		MP	238	14		0	0	4
18		MP	313	16		0	0	4
19		MP	309	16	16	0	0	4
20		MP	310	16		0	0	4

TABLE (Contd.)

Subject Data Sheet

Obs	Sex	Trt	Time	RPE	RPE-r	FA	Miss	Hits
21	M	MP	286	15		0	0	4
22		MP	313	16		0	0	4
23		SP	260	12		0	0	4
24		SP	312	12		0	0	4
25		SP	264	11		0	0	4
26		SP	245	12	11	0	0	4
27		SP	303	13		0	0	4
28		SP	325	11		0	0	4
29		SP	38[illegible]	12		0	0	4
30		SP	342	11		0	0	4

SP = Self Paced
MP = Machine Paced
RPE = Relative Perceived Exertion (Borg Scale)
FA = False Alarm

TABLE

Subject Data Sheet

Obs	Sex	Trt	Time	RPE	RPE--r	FP	Miss.	Hits
1	F	SP	512	11		1	0	3
2		SP	633	11		0	0	4
3		SP	624	11		0	0	4
4		SP	662	11	11	0	0	4
5		SP	584	11		0	0	4
6		SP	614	11		1	0	3
7		SP	613	11		0	0	4
8		SP	505	11		0	0	4
9		MP	386	9		0	0	4
10		MP	439	11		0	0	4
11		MP	387	9		2	0	3
12		MP	396	11	9	0	0	4
13		MP	378	9		0	0	4
14		MP	402	11		1	0	3
15		MP	362	11		0	0	4
16		SP	364	9		0	0	4
17		SP	502	11		0	0	4
18		SP	344	9		0	0	4
19		SP	327	9	9	1	0	3
20		SP	332	9		0	0	4

TABLE (Cont.)

Subject Data Sheet

Obs	Sex	Trt	Time	RPE	RPE-Err	FA	Miss	Hits
21	F	SR	364	11		0	2	4
22		SR	408	11		1	2	3
23		MR	352	11		1	2	3
24		MR	422	11		1	2	3
25		MR	317	8		2	2	4
26		MR	327	11	11	2	2	4
27		MR	387	9		2	[illegible]	[illegible]
28		MR	324	11		1	2	3
29		MR	309	9		0	2	4
30		MR	352	11		0	2	4

SR = Self Rated
MR = Machine Rated
RPE = Relative Perceived Exertion Rating Scale
FA = False Alarm

TABLE

Subject Data Sheet

Obs	Sex	Trt	Time	RPE	RPE-[illegible]	[illegible]	[illegible]	[illegible]
1	M	SP	4[illegible]4	[illegible]		[illegible]	[illegible]	[illegible]
2		SP	397	[illegible]		[illegible]	[illegible]	[illegible]
3		S[illegible]	407	[illegible]		[illegible]	[illegible]	[illegible]
4		SP	4[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5		SP	4[illegible]	[illegible]4		[illegible]	[illegible]	[illegible]
6		SP	3[illegible]4	[illegible]		[illegible]	[illegible]	[illegible]
7		SP	3[illegible]7	[illegible]		[illegible]	[illegible]	[illegible]
8		SP	384	[illegible]		[illegible]	[illegible]	[illegible]
9		MD	36[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
10		MD	360	[illegible]		[illegible]	[illegible]	4
11		MD	339	[illegible]		[illegible]	[illegible]	4
12		MD	330	[illegible]	[illegible]	[illegible]	[illegible]	4
13		MD	[illegible]	[illegible]		[illegible]	[illegible]	4
14		MD	35[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
15		MD	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
16		MD	350	[illegible]		[illegible]	[illegible]	[illegible]
17		MD	[illegible]	[illegible]		[illegible]	[illegible]	4
18		MD	33[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
19		MD	3[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20		MD	334	[illegible]		[illegible]	[illegible]	[illegible]

TABLE (Contd.)

Subject Data Sheet

Obs	Sex	Trt	Time	RPE	RPE-Avg	FA	Miss	Hits
21	M	MP	31[illegible]	13		0	2	4
22		MP	31[illegible]	14		0	2	4
23		MP	321	14		[illegible]	2	4
24		SP	33[illegible]	1[illegible]		1	[illegible]	[illegible]
25		SP	3[illegible]	13		[illegible]	0	[illegible]
26		SP	30[illegible]	13		[illegible]	[illegible]	4
27		SP	[illegible]	13	13	[illegible]	[illegible]	[illegible]
28		SP	427	13		[illegible]	2	4
29		SP	32[illegible]	1[illegible]		[illegible]	0	4
30		SP	30[illegible]	13		2	2	4

SP = Self Paced
MP = Machine Paced
RPE = Relative Perceived Exertion ([illegible] Scale
FA = False Alarm

Appendix II

Subject Data Sheets (Learning)

TABLE

Subject Data Sheet (Learning)

Sub	Obs	Sex	Trt	Time(s)
1	1	M	SP	745
	2		SP	540
	3		MP	525
	4		MP	349
	5		SP	477
	6		SP	414

SP = Self-Paced
MP = Machine-Paced

TABLE

Subject Data Sheet (Learning)

Sub	Obs	Sex	Trt	Time(s)
2	1	M	SP	515
	2		SP	570
	3		MP	550
	4		MP	421
	5		SP	415
	6		SP	386

SP = Self-Paced
MP = Machine-Paced

TABLE .

Subject Data Sheet (Learning)

Sub	Obs	Sex	Trt	Time(s)
4	1	M	SP	625
	2		SP	500
	3		MP	416
	4		MP	562
	5		SP	401
	6		SP	385

SP = Self-Paced
MP = Machine-Paced

TABLE

Subject Data Sheet (Learning)

Sub	Obs	Sex	Trt	Time(s)
3	1	M	SP	430
	2		SP	372
	3		MP	337
	4		MP	211
	5		SP	437
	6		SP	355

SP = Self-Paced
MP = Machine-Paced

TABLE

Subject Data Sheet (Learning)

Sub	Obs	Sex	Trt	Time(s)
5	1	M	SP	400
	2		SP	425
	3		MP	295
	4		MP	283
	5		SP	412
	6		SP	353

SP = Self-Paced
MP = Machine-Paced

TABLE

Subject Data Sheet (Learning)

Sub	Obs	Sex	Trt	Time(s)
6	1	M	SP	445
	2		SP	240
	3		MP	324
	4		MP	281
	5		SP	343
	6		SP	309

SP = Self-Paced
MP = Machine-Paced

TABLE

Subject Data Sheet (Learning)

Sub	Obs	Sex	Trt	Time(s)
7	1	M	SP	481
	2		SP	505
	3		MP	480
	4		MP	353
	5		SP	385
	6		SP	345

SP = Self-Paced
MP = Machine-Paced

TABLE

Subject Data Sheet (Learning)

Sub	Obs	Sex	Trt	Time(s)
8	1	M	SP	540
	2		SP	450
	3		MP	441
	4		MP	390
	5		SP	425
	6		SP	383

SP = Self-Paced

MP = Machine-Paced

TABLE

Subject Data Sheet (Learning)

Sub	Obs	Sex	Trt	Time(s)
9	1	F	SP	889
	2		SP	737
	3		MP	770
	4		MP	752
	5		SP	750
	6		SP	690

SP = Self-Paced
MP = Machine-Paced

TABLE

Subject Data Sheet (Learning)

Sub	Obs	Sex	Trt	Time(s)
10	1	M	SP	524
	2		SP	520
	3		MP	463
	4		MP	454
	5		SP	438
	6		SP	407

SP = Self-Paced
MP = Machine-Paced

OPERATOR PERFORMANCE AND TASK DIFFICULTY

IN PACED WORKING CONDITIONS

by

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B.E. (Mechanical), N.E.D. University of Engineering
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AN ABSTRACT OF A MASTER'S THESIS

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ABSTRACT

This study investigated the effects of self-paced and machine-paced conditions in an assembly type task. The machine-paced condition was at 100 percent of subjects mean cycle time in self-paced. These two conditions were applied to each subject in the experiment. Ten subjects participated in the experiment for about five hours each including one hour learning period. In this study, production, rate of production, and quality of work were determined by first noting down the responses of each subject in the form of hits, misses, and false alarms. Subjective evaluation of task difficulty as perceived by the subjects was also determined.

The paired comparisons t-test showed that no statistically significant differences existed in the production and quality of work (performance) of the subjects in the self-paced as compared to machine-paced condition. The rate of production was, however, found to be ten percent higher in the machine-paced condition. Further, no significant difference in judged task difficulty existed in these two conditions. Since the subjects did not perceive greater task difficulty in machine-paced as compared to self-paced, further research should be done to examine the long-term performance of the subjects with higher machine-paced rates.