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The effects of energy expenditure rate on work productivity performance at different levels of production standard time

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Abstract. [Purpose] The purpose of this study was to investigate the effects of energy expenditure rate on work productivity performance at different levels of production standard time. [Subjects and Methods] Twenty industrial workers performed repetitive tasks at three different levels of production standard time, normal, hard, and very hard. Work productivity and energy expenditure rate were recorded during the experimental tasks. [Results] The work productivity target was not attainable for the hard and very hard production standard times. This was attributed to the energy expenditure rate, which increased as the level of production standard time became harder. The percentage change in energy expenditure rate for the very hard level (32.5%) relative to the normal level was twice that of the hard level (15.5%), indicating a higher risk of work-related musculoskeletal disorders for the harder production standard time. The energy expenditure rate for the very hard production standard time (1.36 kcal/min) was found to exceed the maximum energy expenditure rate recommended for light repetitive tasks involving both arms (1.2 kcal/min). [Conclusion] The present study shows that working with an energy expenditure rate that is either equal to or above the maximum energy expenditure rate of the tasks results in decreased work productivity performance due to the onset of physical fatigue and a higher risks of work-related musculoskeletal disorders.
Key words: Energy expenditure rate, Work productivity, Work-related musculoskeletal disorders

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INTRODUCTION

The current trend in industrial tasks is moving towards more time-intensive production with standardized, short cycle times[1)] and limited completion times[2)] since an aim of the manufacturing industry is to attain high work productivity. Process standard times, such as the work pace or duty cycle time for a particular task, are determined by a process engineer based on task time analysis. However, because workers must work in their designated work locations and must adhere to predetermined task times[3)], their capacities and productivity state are often overestimated.

High work productivity is typically associated with hard production standard times. Hard production standards generally produce high work productivity compared with low or no production standards[4)]. In general, tasks become more repetitive in the case of harder production standard times and may expose workers to a higher risk of work-related musculoskeletal disorders (WMSDs). WMSDs complaints are frequently observed among workers involved in repetitive tasks[5, 6)]. The capability of workers performing repetitive tasks and the risk of WMSDs can be assessed by energy expenditure measurement[7)]. Energy expenditure is a physiological measurement used to assess the influence of physical fatigue on work performance among industrial workers[7, 8)].

Energy expenditure is increased when tasks are carried out beyond a worker's limitations[9)]. Hence, estimation of energy expenditure is important indeed, as it serves as a reference in design of tasks that will not induce fatigue and WMSDs among workers. The ability to accurately track energy expenditure (EE) would be beneficial in the prevention of WMSDs[7, 10)]. Energy expenditure rate may vary according to the levels of production standard time assigned to workers. Therefore, the objective of this study was to investigate the effects of energy expenditure rate on work productivity performance at different levels of production standard time in order to identify the maximum capability of the workers. This data could be used to help ensure that tasks assigned to workers will not induce fatigue and to minimize the risk of WMSDs.

SUBJECTS AND METHODS

A total of 20 subjects, 10 male and 10 female industrial workers, were recruited for a series of experimental tasks.

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Table 1. Work productivity at different levels of production standard time

Production Standard (PS)	Work Productivity Target	Work Productivity (Quantity/Hour)	Percentage of Normal Standard (%)
PSN	100%	851	118.0
PSH	126%	890	123.0
PSVH	140%	928	129.0

Table 2. Mean and standard deviation for energy expenditure (kcal/min) and heart rate (BPM) at different levels of production standard time

Production standard time	Energy expenditure		Heart rate	
	Mean	Standard deviation	Mean	Standard deviation
PSN	1.03	0.05	89.8	3.05
PSH	1.19	0.14	96.7	4.69
PSVH	1.36	0.59	102.4	5.75

The subjects were between the ages of 22 and 45 years old (30.9±7.711). They were first briefed on the experimental task process flow and equipment to be used prior to performing the series of experimental tasks. Each subject was given an information sheet outlining their involvement in the study and its potential risks. The study was approved by the local ethics committee. Written informed consent was obtained from each subject to ensure that they fully agreed to participate in the study. An Actiheart monitoring device was placed on the chest of the subjects. The subjects were then instructed to adopt a comfortable sitting posture with the sitting height adjusted individually to obtain a knee angle of 90°. The working height was standardized by placing the work table's surface 5 cm below the position of the wrist when the elbow was flexed at 90°[11]. The subjects were required to perform the experimental tasks after familiarizing themselves with them for 30 minutes. The tasks involved repetitive assembly actions similar to an actual industrial assembly task. The subjects were given two types of component, plastic clips and plastic foam rings. These components were placed into a polybox and plastic container, respectively. The subjects were instructed to connect the foam rings to the plastic clips using a jig, which pushed the foam rings onto the clips. The subjects performed the tasks according to the production standard times assigned to them. The production standard times used in the experimental tasks were 100% normal standard time (PSN-normal), 126% normal standard time (PSH-hard), and 140% normal standard time (PSVH-very hard). The normal standard time was determined from a Methods-Time Measurement (MTM) analysis. Heart rate and energy expenditure rate were recorded using the Actiheart monitoring device, and work productivity of the subjects was recorded for every 30 minutes.

RESULTS

Work productivity data were recorded in terms of quantity per hour and the percentage of normal standard time achieved. The results for work productivity at different levels of production standard time are summarized in Table 1.

The very hard production standard time resulted in the highest output, followed by the hard production standard time and the normal production standard time. Work productivity data were then analyzed to investigate the effect of production standard times on work productivity. Repeated measures ANOVA was carried out for this purpose, and the results revealed that production standard time had a significant effect on work productivity (Wilk's Lambda = 0.257, $F(2, 18) = 2.8$, $p < 0.001$, multivariate partial eta squared = 0.743). It is evident that the average work productivity differed significantly among the three production standard times (work productivity targets).

The means and standard deviations of energy expenditure and heart rate are summarized in Table 2.

It can be observed that the workers' energy expenditure and heart rate were higher for harder production standard times. Repeated measures ANOVA analysis revealed that the energy expenditure increased significantly as the production standard time became harder (Wilk's Lambda = 0.06, $F(3, 17) = 89.036$, $p < 0.005$, multivariate partial eta squared = 0.940). The energy expenditure rate for the hard production standard time was higher than that for the normal production standard time, with the percentage difference being 15.5%. The assignment of a very hard production standard time resulted in an increase in energy expenditure relative to the normal and hard production standard times, with the percentage increases being 32.5% and 14.6%, respectively.

DISCUSSION

The results showed that work productivity increases significantly as the production standard time becomes harder. This indicates that the workers were able to achieve higher work productivity in the case of harder production standard times compared with the normal production standard time. This observation agrees well with the findings of Shikdar and Das[12], who showed that work productivity increases in the case of harder production standard times. The work productivity target is attainable with the normal production standard time, but this is not the case for the hard and very hard production standard times. The work productivity target for the hard production standard time was 126% of the normal standard time. The results showed that the workers were only able to achieve 123% of the normal standard time. Similarly, the work productivity target for the very hard production standard time was 140% of the normal standard time, and it was found that the workers were only able to achieve 129% of the normal standard time. There is an increase in job requirement in the case of harder production standard times. In general, workers perform more repetitions of tasks in the case of harder production standard times and are exposed to a higher risk of WMSDs. The results agreed well with the results of previous studies, which also reported an association between the risk of contracting WMSDs with higher repetition of tasks[13, 14] and increases in job requirement[15]. The results indicated that workers tend to slow down in the case of harder production standard times due to WMSD risks. The results are consistent with the findings of previous studies, which showed that workers tend to slow down when they are fatigued due to WMSDs[16]. The findings concerning work productivity can be attributed to the variations in energy expenditure rate at different levels of production standard time. The energy expenditure rate for an activity was found to increase significantly as the production standard time becomes harder. This agrees with the findings of Li et al.[7], who revealed that energy expenditure increases when the frequency of tasks increases. The percentage change in energy expenditure rate for the very hard level (32.5%) relative to the normal level was twice that of the hard level (15.5%). The results also revealed that the average energy expenditure rates for an activity in the case of the normal (1.03 kcal/min) and hard production standard times (1.19 kcal/min) were less than the maximum value, 1.2 kcal/min, for light repetitive tasks involving both arms in a previous study[17]. The energy expenditure value reported by Garg et al.[17] is used as a reference because it serves as a reliable benchmark in estimating energy expenditure[7, 18]. In contrast, the average activity energy expenditure rate obtained in the case of the very hard production standard time (1.36 kcal/min) exceeded the reference value, which suggested that the workers were exposed to a higher risk of WMSDs.

The heart rate of the workers was also found to be higher in the case of a harder production standard time, and the energy expenditure rate increased with the increment in heart rate. These results agreed well with the findings of a previous study that discovered a linear relationship between energy expenditure, heart rate, and oxygen uptake[19]. The dynamic muscle exertions during repetitive tasks require oxygen, and the metabolic demands of the muscles increase as activity increases. Therefore, consumption of oxygen will increase in conjunction with an increase in heart rate in order to circulate more blood, which will carry oxygen to the working muscles. The results of this study indicated that workers are exposed to a higher risk of WMSDs when carrying out tasks with a very hard production standard time. This is because the energy expenditure rate exceeds the maximum capability of workers when working with a very hard production standard time. The results are supported by the findings of previous studies that emphasized the need to accurately track the energy expenditure rate of workers in order to prevent WMSDs[7, 10]. In conclusion, working with an energy expenditure rate that is either equal to or above the maximum energy expenditure rate of the tasks will decrease work productivity performance due to the onset of physical fatigue and increase the risk of WMSDs. Therefore, it is important to identify the maximum energy expenditure rate to ensure that the tasks assigned will not result in excessive fatigue in workers, which would lead to a risk of WMSDs and a reduction in work productivity performance.

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