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Workload measurement with Bourdon Wiersma and Cardiovascular Load (CVL) methods

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ABSTRACT

A company operating in the sector of workshop production of nuts and bolts requires workers to maintain high levels of speed, precision, and consistency, as well as significant responsibility to deliver the best results for customers. However, while carrying out their tasks, workers may make mistakes due to work fatigue. Therefore, researchers conducted a study to determine the extent of mental and physical workload using the Bourdon Wiersma and Cardiovascular Load (CVL) methods. Bourdon Wiersma is an objective method of measuring workload to determine the level of mental burden in tasks requiring precision, speed, and high consistency, including monotonous tasks. Cardiovascular Load (CVL) involves comparing the increase in heart rate with the maximum heart rate and classifying workload based on the increase in working heart rate compared to the maximum heart rate, expressed as cardiovascular load (% CVL). The research results show that the Bourdon Wiersma percentage for the three job tasks was generally quite good before work and fell within the category of moderate or mild tiredness after work. Additionally, the largest average %CVL occurred in operators at 63%.

1. Introduction

Fatigue is a common complaint among the general population and workers. Among workers, approximately 20% experience symptoms of work fatigue [1]. Work fatigue can be characterized by decreased work performance or any condition that affects all organism processes, including several factors such as a subjective feeling of fatigue, decreased motivation, and decreased mental and physical activity. Work fatigue is directly influenced by job conflict, job stress, physical environment, and work capacity [2].

PT Sentral Teknik Sentosa is a company operating in the field of workshop production of nuts and bolts, as well as machine repair and maintenance, located in Kramatwatu, Serang, Banten. The company was established in 2016 and has 1 leader, 2 admins, and 8 employees who also serve as operators and helpers. The company utilizes a make-to-order production model, and any leftover goods are put into stock.

The production process in this company still relies on human-machine or manual labor. In this manual production process, some of the tasks include raw material handling, raw material cutting, material forming, and quality control checks. Because these four processes are carried out manually, they result in employee fatigue and loss of concentration, leading to various production problems such as size errors, errors in part manufacturing, and inventory discrepancies. Several errors occurring will affect both the mental and physical workload. Measuring physical and mental workload is one of the factors needed by the company to understand the workload of the workers. One way to assess the magnitude of the mental and physical workload of the workers is by using the Bourdon Wiersma method and CVL. The Bourdon Wiersma Test is a cognitive assessment or objective test to measure fatigue. It is an objective workload measurement tool to determine the level of mental fatigue in tasks requiring precision, speed, and high consistency, as well as tasks that are monotonous [3].

Several types of Cardiovascular Load (CVL) can be evaluated using the method of measuring heart rate. An oximeter is one of the devices used to measure heart rate. There are several types of heart rates, including resting heart rate (before performing tasks), working heart rate (during tasks), and workload (the difference between resting heart rate and working heart rate) [4].

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Previous research on Bourdon Wiersma and CVL has been conducted by [5] in a manufacturing company, [6] in a hospital using the Bourdon Wiersma and subjective self-rating test, and [7] in mechanical construction using CVL and NASA-TLX, and others.

Previous research has often separated physical and mental workloads, and there is still a lack of studies combining the measurement of mental and physical workloads using the Bourdon-Wiersma method. Some studies have measured mental workload using NASA-TLX. Physical and mental workloads were measured using CVL and NASA [8], heart rate and NASA [9], and CVL, NASA, and WLA (Workload Analysis) [10]. This study measures all stations or processes from raw material handling to quality control. Although the number of operators is small, examining all workstations can provide an accurate depiction of the conditions of workers at each station. Based on the issue above, this research aims to measure mental and physical workloads using Bourdon Wiersma and CVL.

2. Material and method

2.1. Bourdon Wiersma

The Bourdon Wiersma test is a method of objectively measuring workload to determine the level of mental burden in tasks that require high precision, speed, and consistency, as well as tasks of a monotonous nature [11]. The mental workload is the disparity between the mental demands of the job and the mental capacity possessed by the worker in question [12]. This test is used to evaluate concentration, attention, working speed for routine and monotonous tasks, work precision, and endurance in long-term work.

2.2. Cardiovascular Load (CVL)

Cardiovascular Load (CVL) is used to determine physical workload through heart rate measurements. A person's heart rate is influenced by various factors, including both normal and abnormal conditions and physical activities, which can be observed after examining the heart rate. The heart rate is quite sensitive to changes in the body's workload. It will immediately change in response to changes in workload. Calculations are based on the increase in working heart rate compared to the maximum heart rate [11].

The study includes 11 male respondents aged between 18 and 55 years old. The methods used in this research are Bourdon Wiersma and Cardiovascular Load (CVL) to assess speed, precision, consistency, and oxygen consumption. The research and data collection took place at PT. Sentral Teknik Sentosa located in Serang City, Banten Province.

3. Results and discussions

The results of the Bourdon Wiersma were shown in Table 1, 2, and 3 whereas those of that CVL were shown in Table 4, 5, and 6. Based on Table 1, the difference is not significant, both in terms of speed fatigue before and after work, where the condition before and after work mostly indicates good or normal fatigue levels. Based on Table 2, it can be observed that the differences are quite significant, especially in terms of precision fatigue before and after work. Before working, individuals generally feel quite good or only slightly tired. However, after work, everyone experiences moderate or mild fatigue.

Table 1.
Speed calculation results

No	Fatigue Level	Before		After	
		Quantity (People)	Percentage	Quantity (People)	Percentage
1	Good	6	55%	10	91%
2	Fair enough	2	18%	0	0%
3	Enough	3	27%	1	9%
4	Doubtful	0	0%	0	0%
5	Less	0	0%	0	0%
	Total	11	100%	11	100%

Table 2.
Precision calculation results

No	Fatigue Level	Before		After	
		Quantity (People)	Percentage	Quantity (People)	Percentage
1	Good	0	0%	0	0%
2	Fair enough	7	64%	0	0%
3	Enough	4	36%	11	100%
4	Doubtful	0	0%	0	0%
5	Less	0	0%	0	0%
	Total	11	100%	11	100%

Table 3.
Consistency calculation results

No	Fatigue Level	Before		After	
		Quantity (People)	Percentage	Quantity (People)	Percentage
1	Good	2	18%	0	0%
2	Fair enough	5	45%	0	0%
3	Enough	4	36%	11	100%
4	Doubtful	0	0%	0	0%
5	Less	0	0%	0	0%
	Total	11	100%	11	100%

Table 4.
The average working heart rate of operators, admins, and owners

Operator	Average heart rate					
	Monday	Tuesday	Wednesday	Thursday	Friday	Average
1	139	142,3	143	148	146	143,7
2	141,7	140,2	145,6	144	147	143,7
3	142	145,4	143,9	143,5	144,3	143,9
4	145,4	146	144,9	145,3	145,5	145,5
5	144	142,7	142,7	145,3	144	143,8
6	142,3	140,8	143,8	143,4	144,7	143
7	143,4	141,7	138,3	138,8	138,3	140,1
8	138,5	142,8	141,2	138	143,5	140,8
9	141,7	136,5	141,3	137	139,3	139,2
10	141,2	135,5	141	134,4	141,5	138,8
11	133,2	133,8	133,4	134,5	133,3	133,7

Table 5.
Average resting heart rate for operators, admins, and owners

Operator	Average heart rate					
	Monday	Tuesday	Wednesday	Thursday	Friday	Average
1	85,8	84	85,6	84,2	83,4	84,6
2	85,6	85	86,2	85,4	84,2	85,3
3	86	86,2	86	84,4	83,6	85,3
4	83,8	86	86,2	88	84,4	85,7
5	82,2	84,8	83,4	84,6	84,8	84
6	85,6	85,8	86,2	86,4	83,8	85,6
7	82,8	85,2	85,4	86	84,6	84,8
8	85,6	84,8	85,2	86,8	84	85,3
9	84,6	84,4	84,6	85,4	82,8	85,5
10	84,6	84,4	87,4	85	85,8	85,5
11	86,8	84,4	84,6	85,6	84,4	85,2

Table 6.
Calculation of %CVL for operators, admins, and owners

No	Operator	Average heart rate	Resting heart rate	N Max	CVL
1	1	143,7	84,6	166	73%
2	2	143,7	85,3	178	63%
3	3	143,9	85,3	179	63%
4	4	145,5	85,7	162	78%
5	5	143,8	84	182	61%
6	6	143	85,6	173	66%
7	7	140,1	84,8	188	54%
8	8	140,8	85,3	202	48%
9	9	139,2	84,5	200	47%
10	10	138,8	85,5	193	50%
11	11	140,6	85,2	185	56%

Based on Table 3, there is a significant difference, especially in consistency fatigue before and after work. Before working, individuals generally feel quite good or only slightly tired, but after working, everyone experiences moderate or mild fatigue. Out of the 11 measured workers, 9 are above the age of 32. Research by [13] indicates that there is no significant relationship between age and work fatigue. Research by [14]

suggests that factors influencing the accuracy, speed, and consistency of employee work—such as age, gender, Body Mass Index, and length of employment—are not particularly dominant, as the number of employees is still relatively small.

Physical workload requires the muscles, heart, and lungs to work harder. Therefore, if the physical workload is high, the muscles, heart, and lungs will have to work more intensively, and vice versa [15]. The resting pulse is measured once per minute, repeated five times. The maximum pulse rate is calculated based on the age of the workers. Work pulse and rest pulse measurements are carried out from Monday to Friday. Pulse measurements at specific times during work are done using an oximeter placed on each worker's index finger [16].

Table 5 presents the calculation of the operators' maximum heart rates, derived by subtracting their age from 220. Additionally, it includes the %CVL calculation, obtained by comparing the difference between the working and resting heart rates with the difference between the maximum and resting heart rates. After determining the %CVL for each operator, an average %CVL is computed to assess the physical workload conditions experienced by workers and identify necessary actions. The final %CVL result, at 63%, indicates a need for improvement.

4. Managerial implications

The workload perceived by operators is quite substantial, indicating a need for improvement to reduce it. Before implementing any improvements, an analysis of the causes of the operators' workload is conducted using a Fishbone Diagram. The following are the results of this analysis.

Fig. 1 illustrates the results of an analysis of the causes of high operator workload from several factors: human, environment, machinery, and method. Human factors are associated with the presence of elderly workers, resulting in decreased concentration, long working hours leading to fatigue, and lack of training resulting in skill shortages. Research [17] also states that the root cause of human factors is a lack of training. Method factors relate to the absence of standard operating procedures (SOPs) regulating work positions, high average heart rate causing high energy consumption, and insufficient machinery leading to increased working hours. Environmental factors are related to the old age of machinery causing noise, and the limited workspace due to a small workshop.

High mental workload caused by the environment includes factors such as workplace temperature, noise, and dusty working conditions [18]. A good and clean working environment with sufficient lighting, free from noise and disturbances, will inherently motivate employees to perform well. However, a poor working environment—dirty, dark, stuffy, humid, and so forth—will lead to fatigue and decreased creativity [19]. Machinery factors are associated with the absence of supporting pallets causing the machine position to be too low. From all these causes, the calculation result of %CVL for operators at 63% indicates the need for additional rest time.

The required duration of rest for operators can be determined by measuring the energy levels used by each of them, in line with research [20], which provides additional rest time. Determining the operator's energy consumption level can be done by observing their heart rate during rest and during working hours.

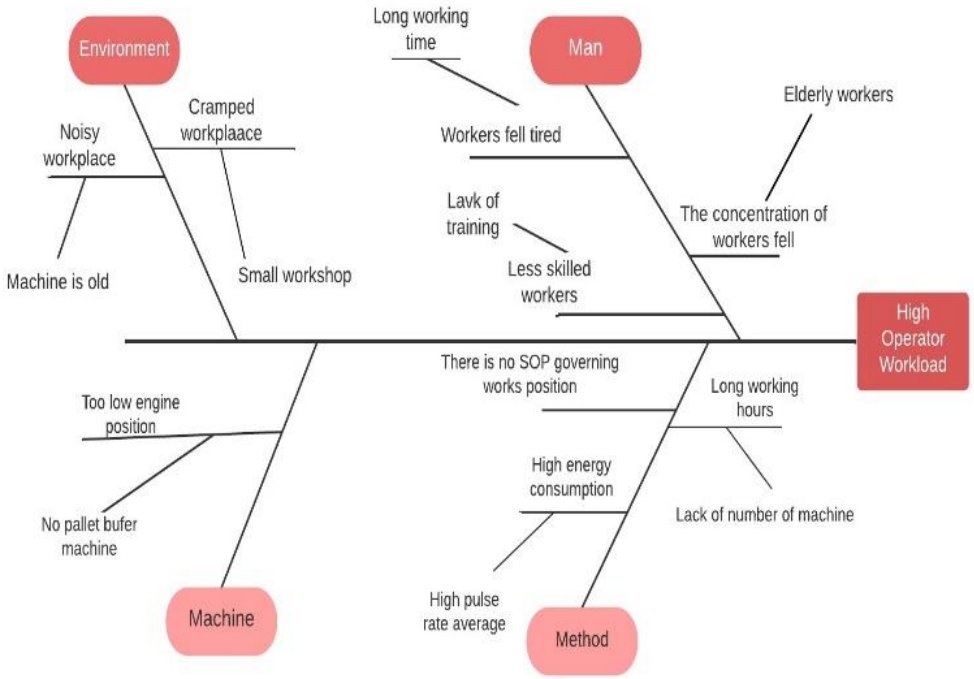

Figure `1. Fishbone diagram for improvements

The research conducted by [21] aims to reduce physical strain, enhance working positions according to ergonomic aspects, and utilize assisting tools for lifting and moving objects. It is also possible to improve workplace conditions [22]. Mental burden can be reduced by forming social groups or labor unions to interact with fellow workers, enhancing mutual assistance among colleagues when someone complains of fatigue during work. Socializing the importance of taking breaks every 2 hours of work, food intake during work, and physical activity through the utilization of available support facilities is also crucial. Supporting facilities for workers include efforts to improve rest huts [23].

5. Conclusions

Based on the research conducted at PT Sentral Teknik Sentosa, the results of data collection and processing indicate that the Bourdon Wiersma categories for speed before and after work are mostly good or normal. However, at the precision level before work, most workers feel good or slightly tired, but after work, everyone experiences sufficient fatigue or slight tiredness. Similarly, at the consistency level before work, most workers feel good or slightly tired, but after work, everyone experiences sufficient fatigue or slight tiredness. The CVL measurement results show the highest value for operators at 63%, indicating the need for immediate work hour reduction. Therefore, the proposed improvement for physical workload is to add a rest time of 116 minutes or 1 hour and 44 minutes, with breaks distributed every working hour for about 5 minutes and a one-hour break from 12:00 to 13:00.

Declaration statement

Ade Sri Mariawati: **Conceptualization, Methodology, Supervision, Project administration,** Shanti Kirana Anggraeni: **Conceptualization, Methodology**. Maura Citra Nisfulail: **Resources, Validation, Formal analysis**. Nustin Merdiana Dewantari: **Resources, Visualization, Investigation**. Lely Herlina: **Data curation, Validation**. Ani Umyati: **Writing - Original Draft**.

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The authors report there are no competing interests to declare.

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Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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