Correlational Analysis of Physical and Cognitive Workload Factors to Musculoskeletal Discomfort Experienced by Machine Operators in Semi-automated Hollowblock Manufacturing Sites

Roland Emerson Mabuting, Dominic F. Dastas, Sean Joseph Z. Rabe,
Dr. James Louie R. Meneses, Engr. Luzviminda D. Sinapilo
College of Engineering
Manuel S. Enverga University Foundation
Lucena City, Quezon, Philippines
ermabuting@gmail.com; jameslouie.meneses@mseuf.edu.ph

Abstract

With the goal to increase production due to the growing demands in the construction industry, small businesses that manufacture hollowblocks utilize semi-automatic machines (to support the molding and compacting process) which is more financially feasible than adapting large-scale and fully automatic equipment. However, the process still requires intensive manual labor and operators exposed to such tasks experience discomfort often manifesting as muscle pain, fatigue, and stress. Understanding the discomfort experienced by these workers in relation to physical and cognitive workload factors helps in designing work that maximizes productivity while also promoting occupational safety and health. In this study, the researchers used the Cornell Musculoskeletal Discomfort Questionnaire to assess worker discomfort, the Fatigue Assessment Scale and cycle time measurement to describe physical workload, and the NASA-TLX and physiological measurements associated with stress level (pulse rate and blood oxygen level) to describe cognitive workload. Results of the Spearman Rank-Order correlation analysis show that CMDQ scores are higher in those workers with higher physical workload measurements [FAS score with rs=0.465 (p=0.06) and cycle time with rs=0.486 (p=0.048)]. Meanwhile, when correlated against cognitive workload factors, CMDQ scores are found to have a positive relationship with raw NASA-TLX score (rs=0.959; p=0.000) and pulse rate (rs=0.435; p=0.081), and a negative relationship with blood oxygen level (rs=-0.65; p=0.005). To mitigate workplace hazards and ergonomic risks that were found in the semi-automated hollowblock manufacturing sites, the researchers then developed an action plan implementing engineering and administrative controls focusing on modifications on the equipment, workplace layout, and operating procedures.

Keywords
Musculoskeletal discomfort, physical workload, cognitive workload, and hollowblock manufacturing

1. Introduction
Production of concrete blocks remains relevant in the construction industry – providing a versatile building material which basically consists of a mixture of cement, sand, other fine aggregates (optional), and water (Maunahan and Adeba, 2021). Compared to conventional bricks, they are relatively cheaper and allow faster construction. With the increasing construction activity, the demand for hollowblocks grows, being preferable than solid concrete blocks, for its greater tensile strength, cost, and applicability (the hollowness of the block tends to make walls act as thermal insulators) (Chaure et al., 2018). Hollowblock production consists of the following fundamental processes: batching and mixing, feeding and de-molding, curing, and stacking – all of which can be done manually with specified tools and equipment as can be observed in small production sites. However, increasing hollowblock production through manual labor on a daily basis can be very challenging, considering the potential health risks that could affect the workers who are continuously exposed to such heavy tasks. Integrating semi-automation in the work environment is a potential solution to mitigate the risks while also enhancing productivity and worker performance reliability.

In workplace ergonomics, safety is an important consideration in creating an environment that can streamline critical processes and support the welfare of workers simultaneously. When ergonomic hazards are overlooked and neglected, they can cause severe health issues (such as the development of work-related musculoskeletal disorders or WMSD, injuries, and fatigue) which can affect worker performance and eventually lead to the decline in productivity and accumulation of additional costs incurred by the company to compensate with their losses and damage. For such reason, ergonomists are frequently called upon to assess work environmental conditions – judging based on established criteria whether they are fit and ideal for specific tasks – so companies could leverage good workplace and process design to significantly impact productivity, employee turnover, health and safety, and worker satisfaction (Lehto and Buck, 2008).

While physical ergonomics mainly focus on reducing work-related MSDs by fitting the working conditions on the job requirements and worker capabilities (Middlesworth, 2022), the scope of research on mental workload falls under the cognitive domain – assessing task demands and their impact on workers through subjective and physiological measures. Higher mental workload is often associated with higher risks and higher occurrence of human errors. In their published article, Young and his colleagues (Young et al., 2015) provided an overview of the current trends in the application of mental workload measurements in the design of systems showing how both physical and cognitive workload interact – implying the importance of achieving holistic ergonomic improvements to address safety and health concerns in the workplace and to maximize productivity as well.

The researchers visited semi-automated hollowblock manufacturing sites located at Brgy. Silangang Mayao, Lucena City – to observe and identify potential hazards in their workplace and assess the working conditions during their operations. There are two types of machines installed in the site to automate the mixing and molding process: the concrete mixer machine and the semi-automated hollowblock making machine. Each hollowblock making machine is capable of batch-producing four hollowblock units and is primarily used to compress and vibrate the concrete mix in the mold. After the demolding process, the fresh and fragile blocks are then manually handled, transported, and stacked in dry and covered areas.

Upon preliminary field observation, potential health risks and workplace hazards were identified associated with awkward posture, high hand force, highly repetitive motion, repeated impact, electrical hazard, slipping and tripping, and other hazards such as excessive noise, poor ventilation, and temperature. The study aims to assess the musculoskeletal discomfort experienced by workers in the hollowblock manufacturing sites and conduct a correlational analysis to determine if discomfort has a significant relationship with the components of physical and cognitive workload. By understanding the relationship of these factors and considering the results of workplace hazard and ergonomic risk assessments, the researchers will propose an action plan to mitigate hazards and promote workplace safety and health in the hollowblock manufacturing sites.

1.1 Objectives

The study aims to promote workplace safety and health by studying the relationship of physical and cognitive workload factors to musculoskeletal discomfort that workers commonly experience during and after the process of hollowblock production. This should provide a deeper understanding on how physical, cognitive, and workplace ergonomics are related – thus, highlighting the relevance of integrating these areas in designing safe working conditions and better workplace to help improve worker performance well-being. Results of the workplace hazard and ergonomic risk assessments and correlation analysis were considered in creating an action plan to mitigate the hazards found in the hollowblock manufacturing sites.

2. Literature Review

Concrete hollow blocks (CHB) are used in construction to build floors, walls, footers, and foundations that support the structural surface of a building. Unlike solid concrete blocks, CHB units have a core-zero area greater than 25% of the total area – the hollow space allows the masonry to have effective sound, heat, and moisture insulation (Patil, 2020). In addition, its great tensile strength and resistance against adverse atmospheric conditions makes it an ideal construction material. For such reasons, the market growth is forecasted to rise exponentially especially in the Asia-Pacific region where the consumption of concrete hollow blocks from nations like China, India, and ASEAN Countries dominates the global market (Mordor Intelligence, 2021). Renovations and refurbishment in these regions increased financial investments in the building and construction sector – directly influencing the market demand for CHB.

The manual method of producing CHB is the simplest and least expensive, but it is no longer advised due to the process' increased complexity; manual production is non-industrial and too slow for the business. A fully automated block production line is a highly intelligent integrating advanced brick-making equipment with a low labor intensity and high output. However, for microbusinesses with limited capital, adapting these technologies may not be cost-effective. One solution to this is to make the manufacturing process semi-automatic. Semi-automatic concrete block machines use pressure and vibration in the installed molds to produce concrete blocks, producing products with higher quality compared to those that are manually produced (Mousavi, 2022). However, even fully automated systems still depend on the presence of workers for tasks such as maintenance and inspection – meaning that the human workforce remains a necessity no matter how simple or advanced an industry is.

With the goal of designing the working conditions to fit job demands and worker capabilities, workplace ergonomics usually apply physical ergonomics principles dealing with human anatomical, anthropometric, physiological, and biomechanical traits in relation to physical activity. Ergonomic hazards in the workplace are systematically identified to design preventive and control measures to reduce risk factors which are usually associated with the development of musculoskeletal disorders (MSD). As observed in the case study conducted by Gandomi et al. (2021) in Kermanshah Oil Refinery, they have found out that chronic musculoskeletal pain, hyperkyphosis and hyperlordosis, and abnormal joint range of motion experienced by the staffs are all strongly correlated with poor workplace ergonomics. Aside from affecting worker's health, poor workplace design also appears to have direct influence on how productive the workers would be. In a similar study, Liravi and Baradaran (2019) discovered in an Offshore Oil Company that workplace design and body position (material dimensions of ergonomics) have stronger effects on the productivity of employees than the immaterial dimensions (such as job feedback and work freedom). Workers were found to be less productive within undesirable working conditions where there's also less attention from managers. To address this problem, they proposed a revision of the work environment design and a plan to strengthen human resource management and development strategies.

Cognitive ergonomics involves the interaction of humans with tasks, environment, and machinery and is used to maximize cognitive performance and function to enhance usability and minimize human error (Crump, 2019). Human error is a major factor that causes accidents and disrupts productivity. Most systems demand some level of mental or cognitive processing in addition to physical efforts that is why understanding human behavior at work should consider both physical and cognitive demands; according to Mehta (2016), "high cognitive demands can influence physical capabilities, and physical demands can influence cognitive processing". From the same article, we can infer that overloaded cognitive system is more vulnerable to higher mental workload, fatigue, and stress which can directly influence human capabilities and performance. Falling under the cognitive domain, mental workload assessments vary from objective to subjective measurements. Though subjective assessments are ideal given the concept of MWL as a "perceived" task demand, effects of mental workload on workers can also manifest physiologically which can be objectively measured by various methods. Common techniques employed to measure mental workload can be categorized into subjective assessments (e.g., NASA Task Load Index, Workload Profile, and Subjective Workload Assessment Technique), task performance assessments (e.g. error count, cycle time, and reaction time), and physiological assessments (e.g. eye tracking, heart rate measures, and electroencephalogram) (Moustafa et al., 2017; Tao et al., 2019).

3. Methods

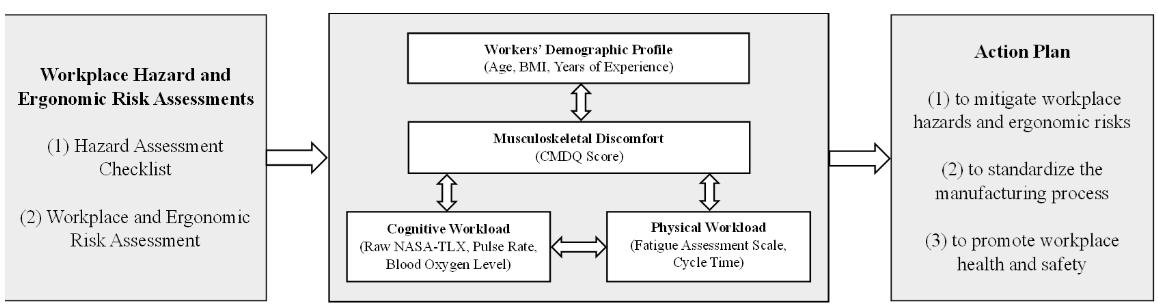

Figure 1. Conceptual paradigm

This study followed an applied research design focusing on determining the relationship of physical and cognitive workload factors to musculoskeletal discomfort experienced by machine operators, to propose ergonomic solutions that aim to minimize, if not completely eliminate, workplace hazards and ergonomic risks in semi-automated hollowblock production sites (refer to Figure 1). Workplace hazard and ergonomic risks were evaluated using Workplace and Ergonomic Risk Assessment and Hazard Assessment Checklist which a scoring system and descriptive checklists, respectively. Musculoskeletal discomfort was recorded using the Cornell Musculoskeletal Discomfort Questionnaire. Physical workload was described and analyzed using the Fatigue Assessment Scale and cycle time measurement, while cognitive workload factors were assessed using the NASA-Task Load Index rating method and physiological measures (heart rate and blood oxygen level) obtained using a commercial pulse oximeter. Statistical analysis using Spearman Rank-Order correlation was used to determine if there is a significant relationship between musculoskeletal discomfort and the components of physical and cognitive workload, as well as the demographic data of workers. Results of the workplace hazard and ergonomic risk assessment and correlation analysis were considered in creating an action plan to promote workplace health and safety.

3.1 Research Environment

The researchers visited three hollowblock manufacturing sites headquartered at Brgy. Silangang Mayao, Lucena City. Each site is open from Monday to Saturday (from 8:00AM to 5:00PM) weekly. A total of 17 workers (seven workers from Site 1, and five workers each from Site 2 and 3) from these manufacturing sites participated in the study. A field observation was conducted by the researchers as preliminary assessment of the workplace and working conditions. All the data gathering procedures were conducted on-site at the time agreed upon by the researchers and the participants involved in the study, with consent from the business owner/manager who runs the production sites.

3.2 Data Gathering Procedures

Preliminary data collection. The researchers conducted an actual observation on the site to understand the processes involved in CHB production. An initial interview with the workers and business owner provided relevant information about the business and their operations. Moreover, related literature and studies were gathered from credible sources and authors to establish the framework, concepts, and methods used as the foundation of the study.

Assessments of Workplace Hazards and Ergonomic Risks. To identify potential hazards and sources of ergonomic risks in the workplace and working conditions, the following assessments were conducted: Workplace Ergonomic Risk Assessment (WERA) and Hazard Assessment Checklist (HAC). WERA was used as an observational tool to assess the workplace and identify risk factors associated with work-related musculoskeletal disorders (WMSDs) (Rahman et al., 2011). It is composed of two parts with a total of nine items: part A which assesses five main body regions (shoulder, wrists, back, neck, and legs) and part B which assesses four physical risk factors (lifting force, vibration, contact stress and task duration). Each item score was computed considering posture as a factor. The final score is the total score of all items, which was used to determine the risk level and the corresponding action that needs to be taken. Meanwhile, HAC is a dichotomous checklist (Health & Safety, 2018; NTWorkSafe, 2021) used by the researchers to identify workplace hazards that are present – with questions tailored according to their relevance to the nature of work and conditions of the production site. Both tools helped in identifying potential solutions to mitigate risks associated with the identified hazards and ergonomic risks.

Measurement of Discomfort Score. Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) was used to measure the musculoskeletal discomfort experienced by workers in the hollowblock manufacturing sites. Each worker was tasked to answer the questionnaire with the assistance of the researchers. To obtain the total CMDQ score per body part, three factors were considered: frequency of experienced pain, ache, or discomfort ("Never" = 0, "1-2 times last week" = 1.5, "3-4 times last week" = 3.5, "Once every day" = 5, "Several times every day" = 10); severity of discomfort ("Slighty uncomfortable" = 1, "Moderately uncomfortable" = 2, "Very uncomfortable" = 3); and interference of discomfort with the ability to work ("Not at all" = 1, "Slighty interfered" = 2, "Substantially interfered" = 3). The scores of these factors for each body part were multiplied to get the final score per body part.

Measurement of Physical and Cognitive Workload Components. A sample of 17 workers participated as respondent in the study. First, they were tasked and assisted to answer the Fatigue Assessment Scale. This described the perceived fatigue symptoms that they have experienced in manufacturing hollowblocks. Then, each worker was tasked to produce three (3) batches of hollowblocks (for repeated trials) which includes the following processes: feeding, molding, demolding, and stacking process. To evaluate the task performance, the cycle time for each worker was computed by dividing the total quantity of hollowblock units produced (constant 12 units) by the total production run time (measured and recorded using a stopwatch). The total production run time begins at the molding process and ends at the stacking process of freshly made hollowblock units. After performing the task, heart rate and blood oxygen level were measured immediately in a non-invasive approach (photoplethysmography) using a commercial pulse oximeter (±2% error window) attached to the worker's finger. Cognitive workload was subjectively assessed using the NASA-Task Load Index, comprised of six linear scales: "mental demand", "physical demand", "temporal demand", "performance", "effort", and "frustration". Each rating scale is set from 0 to 100 with the endpoints described as "very low" and "very high, respectively (except for "performance" which is coded from "perfect" to "failure"). The raw TLX score was calculated based on the average rating for all the six scales – indicating the subjective estimate for mental workload experienced by the workers while performing the assigned task (Lan et al., 2011).

3.3 Data Analysis

With a limited sample size (n<30), the researchers used Spearman rank-order correlation analysis – a non-parametric alternative to Pearson's correlation – to avoid unreliable conclusions based on the assumption that the data gathered in the study are normally distributed (Hoskin, 2012; McDonald, 2022; Weaver et al., 2017). In a study by De Winter et al. (2016), they compare the Pearson and Spearman correlation coefficients across distributions and sample sizes (ranging from N=5 to 1000), concluding that the latter is preferable due to its robustness to the presence of outliers, which is observed in this study. The statistical test was done through the IBM SPSS Statistics v.25 program.

4. Data Collection

The researchers visited three hollowblock manufacturing sites, each site with two (2) stationary semi-automatic hollowblock making machines and one (1) pan type concrete mixer operated by workers (see Figure 2 for reference).

Figure 2. Hollowblock manufacturing sites at Lucena City; (a) stationary hollowblock making machine and (b) pan type cement mixer

Generally, the hollowblock manufacturing process includes the following steps: batching and mixing of cement, molding of the concrete mix, demolding, stacking of fresh blocks, and curing (refer to Figure 3). As observed in the manufacturing sites, two workers usually collaborate during production: an assistant worker who is tasked to batch, mix, and fill the hopper with cement mix and an operator who conducts the feeding, compacting, demolding, and stacking process. In this study, the researchers focused on the interaction of the operator with the hollowblock making machine, that is, starting with the feeding and molding process. Aggregates and cement are mixed consistently by weight to achieve a homogenous mix prior to the molding process. Once the cement mix is prepared, the assistant worker fills the hopper with the mix while operator inspects and cleans the mold to remove any residue that may compromise the quality of the blocks before placing the pallets at the bottom of the molds. The operator then feeds the mix into the mold box using the hopper as the hollowblock making machine vibrates. The mechanical vibration, in addition to manual compacting using the top and bottom compactor installed to the machine, helps in producing tightly compressed blocks. After the molding and compacting process, fresh blocks are demolded and transferred to the stacking area.

Using the hazard assessment checklists adapted from the Occupational Safety and Health (2018) and NT Work Safe (2021), the researchers have identified several hazard types that are common to each site to which the operators are exposed daily (refer to Table 1). Meanwhile, Workplace Ergonomic Risk Assessment (see Figure 4) was used to screen the working task and determine the exposure level of workers to physical risk factors associated with work-related musculoskeletal disorders (WMSDs). The researchers examined the posture of workers during their interaction with the semi-automatic machine as they produce hollowblocks (see Figure 5). Based on observation, the description of each body part were as follows: (1) shoulder is moderately bent with moderate movement; (2) wrists are moderately bent less than 10 times per minute; (3) back is moderately bent forward (at 0-20o) 4-8 times per minute; (4) neck is moderately bent forward (at 0°-20°) with moderate movement; while (5) the legs are moderately bent forward (30°-40°). Other factors such as the lifting force required (weight at between 5-10 kg), vibration (occasional use of vibrating tool/machine, 1-4 hours per day), contact stress (absence of tool handle and hand gloves), and task duration (more than 4 hours per day) were also considered. The final score is 39 which, according to the interpretation table, requires the task to be further investigated prior to the implementation of changes.

Table 1. Types of hazards found in the hollowblock manufacturing sites

Hazard Type	Description
Awkward posture	working with the neck bent forward more than 45° (more than 4 hours total per day) working with the back bent forward more than 30° (more than 4 hours total per day)
High hand force	gripping repetitively more than 3 hours total per day (lever and manual compactor)
Highly repetitive motion	pushing and pulling (of the hopper) more than 2 hours total per day
Repeated impact	using the hand as a hammer more than once per minute (more than 2 hours total per day)
Electrical hazard	poorly maintained electrical leads and cables
Slipping and tripping	poor housekeeping cramped space / presence of obstacles in pathways
Other hazards	noise ventilation temperature

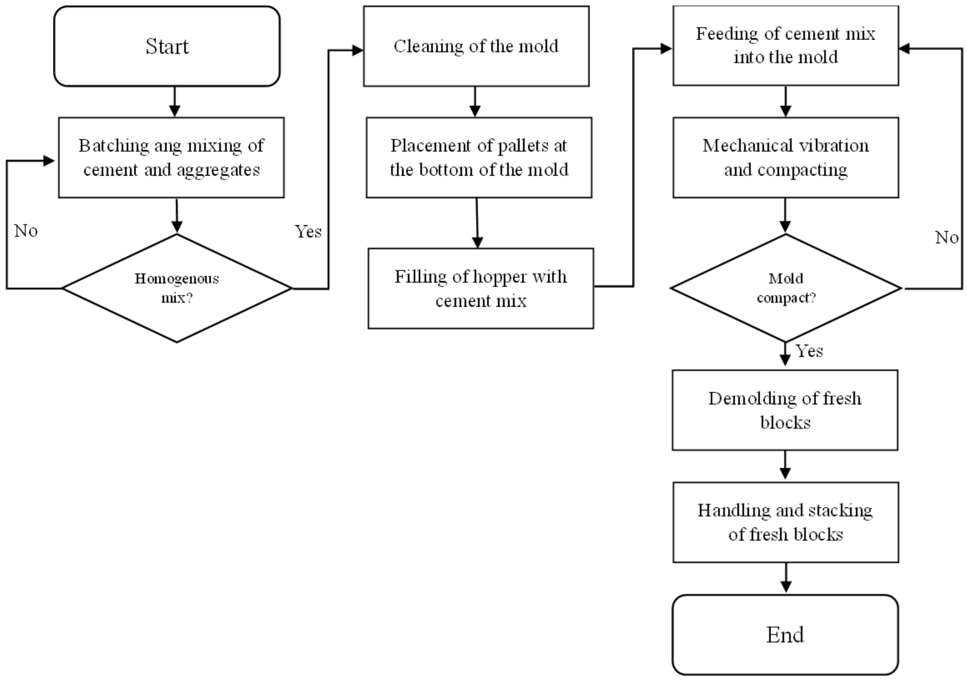

Figure 3. Flow process chart of the hollowblock production process

According to the head operator, there is currently no standard operating procedure being followed by workers at each of their manufacturing site. A pair of workers alternate their roles (either as an assistant worker or as an operator) across their 8-hour shift depending on their own preference. To map the man-machine interaction during the hollowblock production process, the researchers purposively selected two experienced workers as per recommendation of the head operator to act as an operator and as an assistant worker. A man-machine chart was used to visualize the process of creating one batch of hollowblocks (composed of 4 units) – focusing on the interaction of the operator with the semi-automatic hollowblock making machine from molding to the stacking process.

Table 2. Man-Machine chart of hollowblock production process

MAN-MACHINE CHART

OPERATION/PROCESS	One cycle of hollowblocks batch production (molding to stacking)
EQUIPMENT	Stationary, semi-automatic hollowblocks making machine
PRODUCT	Four (4) units of hollowblocks per batch
DATE	January 20, 2023

WORKER 1	WORKER 2	secs	Time	secs	MACHINE
Loading cement mix onto hopper	Loading cement mix onto hopper	3	0:00, 0:01, 0:02, 0:03	20	Idle
Idle	Cleaning the molds	10	0:04, 0:05, 0:06, 0:07, 0:08, 0:09, 0:10, 0:11, 0:12, 0:13		
	Placing the pallets	4	0:14, 0:15, 0:16, 0:17		
	Dragging hopper onto the mold	3	0:18, 0:19, 0:20		
	Turning on the motor	2	0:21, 0:22	2	Power on
	Filling the mold	4	0:23, 0:24, 0:25, 0:26	48	Vibrating
	Inspection	2	0:27, 0:28		
	Compacting	5	0:29, 0:30, 0:31, 0:32, 0:33		
Refilling hopper with cement mix	Idle	3	0:34, 0:35, 0:36		
Idle	Filling the mold	19	0:37, 0:38, 0:39, 0:40, 0:41, 0:42, 0:43, 0:44, 0:45, 0:46, 0:47, 0:48, 0:49, 0:50, 0:51, 0:52, 0:53, 0:54, 0:55		
	Compacting	5	0:56, 0:57, 0:58, 0:59, 1:00		
Refilling hopper with cement mix	Idle	3	1:01, 1:02, 1:03		
Idle	Filling the mold	7	1:04, 1:05, 1:06, 1:07, 1:08, 1:09, 1:10		

WORKER 1	WORKER 2	secs	Time	secs	MACHINE
Idle	Turning off the motor	2	1:11, 1:12	2	Power off
	Compacting	4	1:13, 1:14, 1:15, 1:16	4	Compactor being used
	Demolding	4	1:17, 1:18, 1:19, 1:20	4	Lever being used
	Transferring blocks to stacking area	39	1:21, 1:22, 1:23, 1:24, 1:25, 1:26, 1:27, 1:28, 1:29, 1:30, 1:31, 1:32, 1:33, 1:34, 1:35, 1:36, 1:37, 1:38, 1:39, 1:40, 1:41, 1:42, 1:43, 1:44, 1:45, 1:46, 1:47, 1:48, 1:49, 1:50, 1:51, 1:52, 1:53, 1:54, 1:55, 1:56, 1:57, 1:58, 1:59	39	Idle

TOTAL CYCLE TIME: 119 secs

WORKER 1 TOTAL OBSERVED TIME: 9 secs (8% utilization)

WORKER 2 TOTAL OBSERVED TIME: 110 secs (92% utilization)

TOTAL OBSERVED MAN TIME: 119 secs (100% utilization)

TOTAL OBSERVED MACHINE TIME: 56 secs (47% utilization)

The man-machine chart (see Table 2) reveals that the machine is utilized 47% per cycle of producing one (1) batch of hollowblocks for the purpose of providing mechanical vibration to effectively fill in the molds for better compacting. Even when the machine is turned off, the operator still uses some of its features (manual compactor and lever) to ensure that the mix is tightly compressed into the mold. The assistant worker (with 8% utilization) is only in charge of manually loading cement mix onto the hopper while the operator (with 92% utilization) performs most of the major activities involved such as feeding the mold, compacting, demolding, and stacking the freshly made blocks. In summary, throughout the entire production process, the man element is 100% utilized while the machine element is utilized only 47% of the total cycle time.

Table 3. Demographic profile of workers at the hollowblock manufacturing sites

	Frequency	Percentage
Age (years)		
23-27	4	23.53%
28-32	4	23.53%
33-37	7	41.18%
38-42	1	5.88%
43-47	1	5.88%
Sex		
Male	17	100%
Weight (kg)		
50-55	3	14.85%
55-60	4	21.29%
60-65	2	11.69%
65-70	4	25.39%
70-75	4	26.79%
Height (m)		
1.55-1.6	5	28.17%
1.6-1.65	4	23.39%
1.65-1.7	6	35.97%
1.7-1.75	1	6.18%
1.75-1.8	1	6.29%
BMI (kg/m^2)		
20-22	4	21.28%
22-24	8	46.08%
24-26	3	19.02%
26-28	2	13.62%
Years of Experience		
1-2	3	5.13%
3-4	4	20.51%
5-7	10	74.36%

Table 3 summarizes the demographic profile of workers who participated in the study showing the distribution per age, sex, weight, height, BMI, and years of work experience. They were all male workers – the majority falling under the age bracket of 33 to 37 years old. Most participants also fall under the healthy weight range according to their body mass index. In terms of experience, the majority claimed that they have been working in the hollowblock manufacturing industry for 5 to 7 years.

To obtain the total CMDQ score per body part, three factors were considered: frequency of experienced pain, ache, or discomfort; severity of discomfort; and interference of discomfort with the ability to work. The scores of these factors for each body part were multiplied to get the final score per body part. Based on the results, workers engaged in manufacturing hollowblocks using the semi-automated machine experiences musculoskeletal discomfort more frequently and more severely at their lower back (9.8), upper back (7.32), neck (4.15), and wrist (1.74) which contributes to approximately 80% of the sum of CMDQ scores in all body parts. Neck and back discomfort may be caused by the awkward posture during the molding process while the exposure to excessive vibration and repeated impact during compacting, without the use of proper PPE, may have caused the discomfort that the workers experience at their wrists (refer to Figure 4).

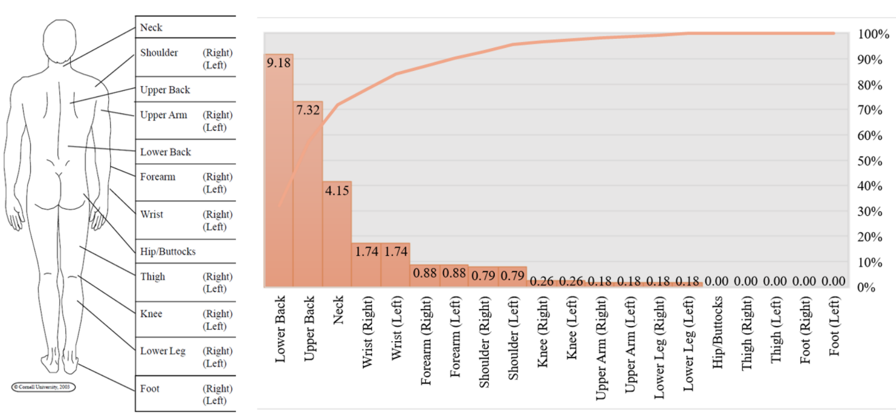

Figure 4. Average CMDQ scores per body part

Table 4. Measurements of physical and cognitive workload components

Operator	**PHYSICAL**		**COGNITIVE**								
	Physiological	**Task-related**	**Subjective**							**Physiological**	
	Perceived Fatigue (FAS Score)	Actual Cycle Time (secs)	Mental Workload (NASA-TLX)							Pulse Rate (bpm)	SpO2 Level (%)
			MD *24*	PD *35*	TD *32*	PF *30*	EF *61*	FR *22*	**AVE**		
1	20	283.32	20	35	25	30	55	15	**30**	104	94
2	21	356.29	25	35	45	30	70	30	**39.17**	116	87
3	21	367.36	15	50	45	20	75	35	**40**	98	90
4	18	339.63	30	30	30	35	60	25	**35**	101	91
5	22	399.67	25	35	45	30	75	30	**40**	95	84
6	21	350.45	25	45	30	30	60	25	**35.83**	104	92
7	18	326.03	35	20	30	40	55	20	**33.33**	107	91
8	18	301.4	20	40	40	25	70	30	**37.5**	111	87
9	19	301.24	25	35	35	30	65	30	**36.67**	111	89
10	18	346.98	20	35	35	25	65	30	**35**	108	95
11	19	275.58	30	25	20	35	50	10	**28.33**	101	84
12	17	304.35	20	35	30	25	60	20	**31.67**	105	93
13	20	353.15	15	50	50	10	80	35	**40**	112	82
14	19	313.63	35	20	20	40	50	10	**29.17**	101	92
15	17	255.24	25	30	15	35	45	10	**26.67**	87	97
16	19	351.32	25	40	25	35	55	15	**32.5**	106	92
17	19	416.68	25	30	20	35	50	10	**28.33**	98	96
Average (sd)	**19.18** (1.47)	**326.60** (42.94)	**34.07** (4.51)							**103.82** (7.09)	**90.35** (4.34)

Table 4 summarizes the measurements of the components of physical and cognitive workload factors. Using the Fatigue Assessment Scale (a 10-item scale), the workers evaluated the symptoms of chronic fatigue that they have experienced. With a maximum score of 50, the average FAS score of the respondents is relatively low (19.18; sd=1.47). Meanwhile, to quantify the task-related component of the physical workload factor, the actual cycle time of each operator in producing three batches (equivalent to 12 units) of hollowblocks was measured. The average cycle time is 326.60 seconds (sd=42.94) which is approximately 27 seconds/unit. The average raw NASA-TLX score is 34.07 (sd=4.51). Furthermore, the highest contributing factors to mental workload score are the following dimensions: effort (ave = 61), physical demand (ave = 35), temporal demand (ave = 32), and performance (ave = 30). This indicates that during the manufacturing of hollowblocks using the semi-automated hollowblock making machine, the workers feel that they need to exert more effort as the task is perceived to be physically demanding (in addition to the pressure due to time and desired quality of the outputs). The average pulse rate of workers is 103.82 bpm (sd=7.09) while the average blood oxygen level is 90.35% (sd=4.34). The normal blood oxygen level of a healthy person is 95-100% (Holland, 2022). Lower oxygen level and rapid heart rate is an indicator of stress (Cox, 2022), which is a physiological manifestation of higher cognitive workload.

5. Results and Discussion

5.1 Statistical Evaluation

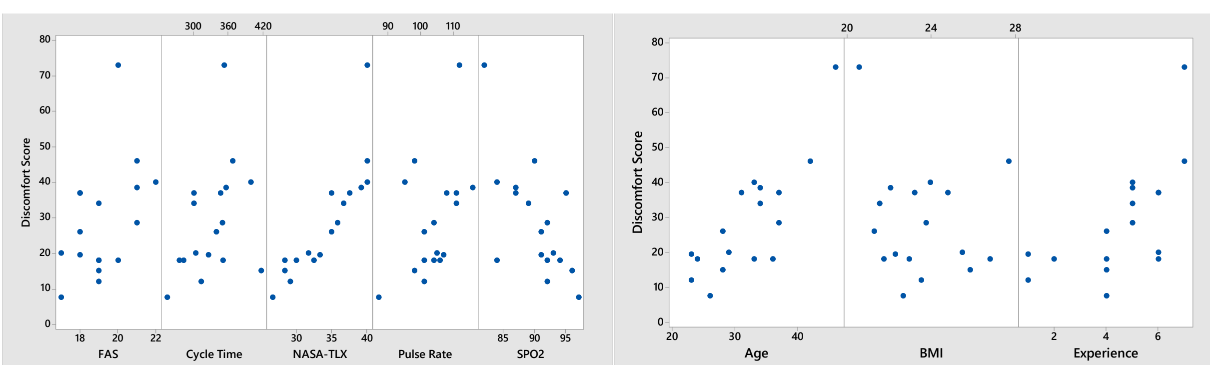

Figure 5. Matrix plot of CMDQ score vs. physical workload, cognitive workload, and demographic data

As can be seen in Figure 5, discomfort scores tend to increase with the increasing FAS score, cycle time, NASA-TLX score, and pulse rate. Meanwhile, discomfort score and blood oxygen level virtually have an inverse relationship. In terms of demographic data, a monotonic relationship was found when CMDQ score is plotted against the age of the workers and their years of experience in the hollowblock manufacturing industry.

Table 5. Nonparametric correlation analysis of CMDQ scores vs. physical workload, cognitive workload, and demographic data using IBM SPSS Statistics v.25

	Physical Workload Factors		**Cognitive Workload Factors**			**Demographic Profile**	
	FAS	Cycle Time	Raw NASA-TLX	Pulse Rate	Blood Oxygen Level	Age	Experience
CMDQ	0.465 (0.06)	0.486* (0.048)	0.959** (0.000)	0.435 (0.081)	-0.650** (0.005)	0.718** (0.001)	0.710** (0.001)

Note: Spearman's rho is displayed followed by the (p-value); significant value at 0.05 (*) and 0.01 (**) level are flagged

Table 5 summarizes the results of the statistical evaluation. It was discovered that the CMDQ score has a moderate positive correlation with FAS score (rs = 0.465), however this relationship is not statistically significant (p = 0.06). A similar study assessing the effect of musculoskeletal problems on fatigue experienced by office personnels supports the result of this correlation by highlighting the severity of discomfort/pain (specifically in neck, shoulders, lower back, and thighs) as correlate to the total fatigue that their respondents have experienced (Daneshmandi et al., 2017). CMDQ score and cycle time, on the other hand, has a statistically significant relationship at 0.05 level (p = 0.048) and a moderate positive correlation (rs = 0.486). This is supported by the study of Finneran and O'Sullivan (2010) which investigated the relationship between discomfort and productivity; their laboratory study showed strong correlation between discomfort and self-pace cycle time of participants in performing repetitive grip exertions. In summary, the results imply that workers who experienced higher discomfort tend to have higher perceived fatigue symptoms and longer cycle time during the hollowblock production process.

Meanwhile, in terms of cognitive workload, CMDQ score has a very strong positive relationship with raw NASA-TLX score (rs = 0.959; p = 0.000) and has a moderate negative relationship with blood oxygen level (rs = -0.65; p = 0.005); both relationships are statistically significant at 0.01 level. CMDQ score and pulse rate has a moderate positive relationship (rs = 0.435), however it is not statistically significant (p = 0.081). High mental workload and low blood oxygen level is an indicator of stress, therefore, suggesting that workers who frequently experience musculoskeletal discomfort during the production process have higher tendencies in experiencing physiological and perceived symptoms of stress. In comparison to another study, significant correlation between musculoskeletal disorder complaints and work-related stress was found among radiographers in three major hospitals in the northern part of Jordan (Alhasan et al., 2014). Meanwhile, in a study analyzing the impact of cognitive workload on physiological arousals on young adult drivers (Mehler et al., 2009), it was found out that heart rate and respiration rate can be very sensitive to changes in workload which suggests that these physiological factors can be used to measure mental workload and therefore be incorporated when designing safety systems.

Workers who are older, and have higher seniority in the field, experience more frequent discomfort. This can be inferred from the correlation coefficient between CMDQ score and age (rs = 0.718; p = 0.001) which implies strong correlation, and between CMDQ score and years of experience (rs = 0.710; p = 0.001) which also implies strong correlation. Both relationships are found to be statistically significant at 0.01 level. There are similar research studying the correlation of age to the development of musculoskeletal disorder, including a cross-sectional study discovering higher frequencies of MSDs on nurses age 45 years and above (Heiden et al., 2013) and a study among Swedish construction workers where MSD was found to increase with age (Holmström & Engholm, 2003).

5.2 Proposed Intervention

To address the problems in the workplace and working conditions at the hollowblock manufacturing sites, the researchers created an action plan with the following primary goals: (1) to mitigate the hazards found in the hollowblock manufacturing sites, (2) to create and employ a standard operating procedure for the hollowblock production process, and (3) to establish health and safety monitoring program in the workplace. The solutions are categorized into engineering controls, administrative controls, and the use of personal protective equipment (PPE), which are among the five general approaches included in the risk control hierarchy (Uzun et al., 2018). It is important to note that implementation of changes shall be applied as deemed necessary while ensuring continuous improvement in the workplace.

6. Conclusion

Physical and cognitive workload factors were found to have correlation to the experienced musculoskeletal discomfort of machine operators in semi-automated hollowblock manufacturing sites – implying the importance of addressing these risk factors to achieve holistic improvements that can promote occupational safety and health during labor-intensive processes. To address the workplace hazards and ergonomic risks associated with the development of MSDs, the researchers recommend the implementation and continuous improvement of hazard mitigation plans applying both the principles of physical and cognitive ergonomics to ensure sustainability.

References

Alhasan, M., Abdelrahman, M., Alewaidat, H., Almhdawi, K., and Nazzal, M., Work-related stress, musculoskeletal disorder complaints, and stress symptoms among radiographers in the northern part of Jordan, Journal of Medical Imaging and Radiation Sciences, 45(3), 291–298, 2014.

Chaure, A. P., Shinde, P. A., Raut, H. M., Dudhal, P. D., and Khotkar, R. G., Hollow concrete blocks, 1, 2018.

Cox, J., Can stress cause low oxygen levels?, Available: https://psychcentral.com/stress/can-stress-cause-low-oxygen-levels, November 5, 2022.

Crump, J., Cognitive ergonomics: how it can transform a safety program, Workplace Testing, Available: https://www.workplacetesting.com/cognitive-ergonomics-how-it-can-transform-a-safety-program/2/4464, November 5, 2022.

Daneshmandi, H., Choobineh, A. R., Ghaem, H., Alhamd, M., and Fakherpour, A., The effect of musculoskeletal problems on fatigue and productivity of office personnel: a cross-sectional study, Journal of Preventive Medicine and Hygiene, 58(3), E252–E258, 2017.

De Winter, J. C. F., Gosling, S. D., and Potter, J., Comparing the Pearson and Spearman correlation coefficients across distributions and sample sizes: A tutorial using simulations and empirical data, Psychological Methods, 21(3), 273, 2016.

Ergonomics, United States Department of Labor, Available: https://www.osha.gov/ergonomics/control-hazards, November 5, 2022.

Finneran, A., and O'Sullivan, L., Force, posture and repetition induced discomfort as a mediator in self-paced cycle time, International Journal of Industrial Ergonomics, 40(3), 257–266, 2010.

Gandomi, F. and Zardoshtian, S., Relationship between workplace ergonomics and musculoskeletal pain, range of motion and spinal deformities in employees: A case study, Kermanshah Oil Refinery, Occupational Medicine, 2021.

Health & Safety, The Hazard Assessment Checklist, Available: https://www.hseblog.com/the-hazard-assessment-checklist/, November 5, 2022.

Heiden, B., Weigl, M., Angerer, P., and Müller, A., Association of age and physical job demands with musculoskeletal disorders in nurses, Applied Ergonomics, 44(4), 652–658, 2013.

Holland, K., Is my blood oxygen level normal?, Healthline, Available: https://www.healthline.com/health/normal-blood-oxygen-level, November 5, 2022.

Hollow concrete block market - growth, trends, covid-19 impact, and forecasts (2022 - 2027). Available: https://www.mordorintelligence.com/industry-reports/hollow-concrete-block-market, November 5, 2022.

Holmström, E. and Engholm, G., Musculoskeletal disorders in relation to age and occupation in Swedish construction workers, American Journal of Industrial Medicine, 44(4), 377–384, 2003.

Hoskin, T., Parametric and nonparametric: Demystifying the terms. Mayo Clinic, 5(1), 1–5, 2012.

Jule, J. G., Workplace safety: a strategy for enterprise risk management, Workplace Health & Safety, 68(8), 360–365, 2020.

Kim, H. G., Cheon, E. J., Bai, D. S., Lee, Y. H., and Koo, B. H., Stress and heart rate variability: A meta-analysis and review of the literature, Psychiatry Investigation, 15(3), 235–245, 2018.

Lan, L., Wargocki, P., Wyon, D. P., and Lian, Z., Effects of thermal discomfort in an office on perceived air quality, SBS symptoms, physiological responses, and human performance, Indoor Air, 21(5), 376–390, 2011.

Lehto, M. and Buck, J., Introduction to human factors and ergonomics, Lawrence Erlbaum Associates, 2008.

Liravi, M. and Baradaran, V., Effects of workplace ergonomics on productivity in an offshore oil company, Archives of Occupational Health, 3, 2019.

Maunahan, B. and Adeba, K., Production of hollow block using waste plastic and sand, American Journal of Science, Engineering and Technology, 6(4), 127, 2021.

McDonald, J. H., Spearman rank correlation, LibreTexts, Available: https://stats.libretexts.org/Bookshelves/Applied_Statistics/Book%3A_Biological_Statistics_(McDonald)/05%3A_Tests_for_Multiple_Measurement_Variables/5.02%3A_Spearman_Rank_Correlation, November 5, 2022.
Mehler, B., Reimer, B., Coughlin, J. F., and Dusek, J. A., Impact of incremental increases in cognitive workload on physiological arousal and performance in young adult drivers, Transportation Research Record: Journal of the Transportation Research Board, 2138(1), 6–12, 2017.
Mehta, R. K., Integrating physical and cognitive ergonomics, IIE Transactions on Occupational Ergonomics and Human Factors, 4(2–3), 83–87, 2016.
Middlesworth, M., Ergonomics 101: the definition, domains, and applications of ergonomics, ErgoPlus, Available: https://ergo-plus.com/ergonomics-definition-domains-applications/, March 7, 2022.
Mousavi, H., Concrete block production, Available: https://bessconcreteblockmachine.com/concrete-block-manufacturing-process.html, November 5, 2022.
Moustafa, K., Luz, S., and Longo, L., Assessment of mental workload: A comparison of machine learning methods and subjective assessment techniques, Communications in Computer and Information Science, 726, 30–50, 2017.
O'Neill, C., and Panuwatwanich, K., The impact of fatigue on labour productivity: case study of dam construction project in Queensland, Proceedings from EPPM, 2013.
Patil, R., Hollow block Available: https://constructionor.com/hollow-block/, November 5, 2022.
Tao, D., Tan, H., Wang, H., Zhang, X., Qu, X., and Zhang, T., A systematic review of physiological measures of mental workload, International Journal of Environmental Research and Public Health, 16(15), 2716, 2019.
Uzun, M., Bilir, S., Gürcanlı, G. E., and Cebi, S., Hierarchy of control measures for common construction activities: A field study, 5th International Project and Construction Management Conference, 2018.
Young, M. S., Brookhuis, K. A., Wickens, C. D., and Hancock, P. A., State of science: mental workload in ergonomics, Ergonomics, 58(1), 1–17, 2015.

Biographies

Roland Emerson Mabuting is a fourth-year student of Bachelor of Science in Industrial Engineering at Manuel S. Enverga University Foundation (Lucena City). He takes interest in studying ergonomics and its diverse applications in different fields, especially in the manufacturing industry. During his Lean Six Sigma Yellow Belt training and certification, he gained significant project management skills, became proficient with quality tools and planning methodologies, and enhanced his leadership and communication skills – further enriching his knowledge and passion in developing relevant and effective solutions using industrial engineering concepts and designs.

Dr. James Louie R. Meneses is an experienced professor, consultant, Industrial engineer, and researcher. In his early professional life, he worked as a Quality control engineer and Management trainee in a Manufacturing company. Currently, he is working as a full-time professor and a research coordinator at Manuel S. Enverga University Foundation, Philippines. His work as a researcher is mainly associated with using the lean six-sigma methodology, ergonomics design, and Partial Least Square Structural Equation Modeling (PLS-SEM). As a consultant, he works in industrial engineering designs, management, quality management systems, and data analysis.

Engr. Luzviminda D. Sinapilo is the former Technical Laboratory Custodial Officer of the University. Being at the forefront of coordinating accreditation and certification activities, she was appointed as the Director of the Office of Quality Improvement for several years now. As a professor in Industrial Engineering program and Internal ISO Auditor, she shares her insights and knowledge on topics related to quality management system, systems engineering, work study and measurement, ergonomics, engineering management, and total productive maintenance, among others. She had been involved in research related to courseware development and laboratory apparatus improvement.