Work System Improvement Using Macroergonomic Analysis and Design (MEAD)

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Abstract

Subur Cracker Factory is an MSME that produces crackers. Observations show four factors that affect the work system: environment, tools/technology, task, and organization. The average production room temperature is 32.7℃ which is above the 30℃ standard, machinery/equipment has risks that can be causing burns and scratches to workers, uncomfortable work postures that cause aches, and disorganized and unfocused workers. This study aims to improve the work system using the Macroergonomic Analysis and Design (MEAD) method to reduce the risk of injury at the Subur Cracker Factory. The research found three key variances in the work system: workers feeling aches, uncomfortable work postures, and dehydrated workers. The procurement of the work tool reduced muscle complaints with a decrease in the Nordic Map (NBM) score of 5.833. Work tool also improved work postures with a decrease in REBA score 9 (before improvement) to REBA score 3 (after improvement) for work posture I and work posture II and REBA score 10 (before improvement) to REBA score 3 (after improvement) for work posture III. The risk of burns and scratches arising from work activities is minimized by using PPE gloves. Workers can also cope with the hot room temperature that causes mild-moderate dehydration by drinking a glass of water regularly. Occupational health and safety displays increase the success of implementation.

Keywords: Work System, Macroergonomic Analysis and Design (MEAD), Work posture, Personal Protective Equipment (PPE), Display

1. Introduction

Subur Cracker Factory is an MSME that produces crackers and markets them in the Yogyakarta area. The production process of crackers includes the process of making spices, boiling porridge, grinding dough, pressing the dough, molding dough, steaming, drying, roasting, and frying. Observations at the Subur Cracker Factory found that at least four factors affect the work system in this MSME. These factors include the environment, tools/technology, task, and organization. The environmental factors identified that the condition of the production room has an average room temperature of 32.7℃ an average humidity of 69.3%. This production room temperature is above the acceptable temperature standard of 30℃ (Hiperker Standardization Workshop, 1974). The tools/technology factor is identified as having a risk of causing burns and scratches to workers where this condition is exacerbated by the unavailability of Personal Protective Equipment (PPE) for workers. The task factor identified several jobs with non-ergonomic work postures. Workers must work bent over which causes aches in the back and waist if done repeatedly. The organizational factors were identified as disorganized and unfocused workers, non-ideal working conditions, and other factors that caused workers to feel uncomfortable at work.

The description of these problems shows that the existing work system is not good. One of the efforts that can be taken to improve the work system of the Subur Crackers Factory is to use Macroergonomic Analysis and Design (MEAD). MEAD can clearly describe the stages of implementing macro ergonomics to evaluate and design the work system. MEAD) is expected to be able to analyze problems that significantly affect the work system. The results of the analysis of the four factors of the work system become the basis for designing improvement proposals that can be implemented. The expected result is a work system that can be accepted or tolerated within certain limits with a work system with no risk of endangering human health and life.

2. Literature Review

2.1 Work system

The work system is a unit composed of human elements, materials, equipment and equipment, work methods, and work environment for a specific purpose (Sutalaksana et all., 1979). Ergonomic work systems are oriented towards effective, comfortable, safe, healthy, and efficient work. Purnomo (2012) explains that work system design must be done by adjusting the needs of workers and companies to create a working system that is safe, comfortable, and able to increase work productivity.

2.2 Ergonomic

Ergonomics is known as Human Factor Engineering or Human Engineering¸ which is a scientific discipline that regulates how work should be done by humans. Ergonomics is a scientific discipline that focuses on studying the limitations, strengths, and characteristics of humans and information used for the process of designing products, machines, facilities, environments, and even work systems so that the best quality work can be realized without getting rid of aspects of health, safety, and comfort of human users (Iridiastadi & Yassierli, 2014). One of the ergonomics disciplines is macro ergonomics. Iridiastadi & Yassierli (2014) explain that macro ergonomics is a top-down sociotechnical approach to analyzing, designing, or improving work systems and work organizations and then aligning the design into its elements.

2.3 Macroergonomic Analysis dan Design (MEAD)

Macroergonomic Analysis and Design (MEAD) is one of the most frequently used methods in the discipline of macro ergonomics. MEAD consists of 10 steps used to evaluate and design the overall work system. The general framework of MEAD developed by Emery & Trist (1978) in Hendrick and Kleiner (2001) can be found in Table 1.

Table 1. Steps of MEAD

No.	Step	Subsystem
1.	Scanning analysis	Environment and organization
2.	System type and performance analysis	Technology
3.	Technical work process analysis	Technology
4.	Variance data collection	Technology
5.	Variance matrix analysis	Technology
6.	Variance control and role analysis	Task
7.	Organizational, joint, and function design	Task, technology, and organization
8.	Responsibility perception analysis	Task
9.	Support system and interface design	All subsystem
10.	Implement, iterate, and improve	All subsystem

2.4 Nordic Body Map (NBM)

According to Corlett & Wilson (1995), the Nordic Body Map (NBM) is one of the subjective measurement methods to measure muscle pain in workers. The NBM questionnaire includes 28 parts of the body's right and left skeletal muscles. NBM can help find out which parts of the muscles experience discomfort or complaints from low levels (no complaints/injuries) to high-level complaints (very painful complaints) (Tarwaka, 2010: 329).

2.5 Work Environment

The work environment is one of the factors that support the success of a work system. Isyandi (2014) argues that the work environment is things that exist in the environment of workers that can affect them when doing work such as temperature, humidity, ventilation, lighting, noise, workplace cleanliness, and the availability of work equipment.

2.6 Work Posture

Work posture is the attitude of the body when performing work activities. Some ergonomic considerations to overcome work posture problems (Ghiffara, 2019): reducing the need for workers to work in a bent position with a high frequency of activities or for a long period of time, using the maximum reach range, sitting, or standing for a long duration of time, and using hands or arms in a position above the normal elbow level.

2.7 Rapid Body Assessment (REBA)

Rapid Entire Body Assessment (REBA) is one method that can be used to assess work postures semi-quantitatively. This method aims to evaluate work postures in relation to Musculoskeletal Disorders/Work-Related Musculoskeletal Disorders (WDMs) for various risky jobs. The development of REBA as a method was based on the need for an analytical tool that requires sensitivity to unexpected types of postures in the healthcare sector and other industries (Highnett & McAtamney, 2000).

2.8 Anthropometry

Anthropometry comes from two words, namely anthro, which means human, and metric, which means size. Based on the meaning of these two words, anthropometry can be defined as a study related to measuring human dimensions (Wignjosobroto, 2001). A good understanding and proper use of anthropometry can help design work tools that suit users so that the risk of work accidents can be minimized.

2.9 Personal Protective Equipment (PPE)

Personal Protective Equipment (PPE) is a tool used as a protective measure for workers when carrying out work activities (Arpian, 2018). PPE plays an important role as a form of control based on the occupational risk control hierarchy where the hierarchy includes elimination, substitution, technical control (engineering), administration, and PPE.

2.10 Display

The display is part of the environment that conveys information to workers so that their tasks become easy to do (Nurmianto, 2004). Display design requires ergonomic considerations so that information can be conveyed clearly. Ergonomic considerations are closely related to the concept of "Human Centered Design" in which the concept of display design will be centered on human capabilities by considering human traits as "seers and understanders of cues".

3. Methods

This research was conducted at the Subur Crackers Factory located in Bantul Regency, Yogyakarta. The research took place from February to September 2022. The focus of the research was the production department. The research was limited to factors affecting the work system, including the environment, tools/technology, task, and organization. The most significant factors affecting the work system became the basis for evaluating and designing improvement. Evaluation and improvement were carried out using Macroergonomic Analysis and Design (MEAD), which consists of 10 steps. The evaluation is carried out by identifying key factors following steps one to five. If the key factors have been found, a proposed work system improvement can be designed based on the selected key factors by following steps six to ten.

4. Data Collection

Data collection was carried out by considering the type of data. Primary data is data obtained directly from the object of research by conducting interviews or surveys directly with related parties. The primary data needed in this study are as follows: problems that occur in the production section, questionnaires to find out key variants, the production process of canned crackers, workplace temperature and humidity, complaints of pain in workers' body parts through the Nordic Body Map questionnaire, work posture, anthropometric measurements of workers, and dimensions of the production room. Meanwhile, secondary data is power obtained indirectly from the object of research. Secondary data in this study includes general data about the Subur Crackers Factory such as organizational structure, working hours, production processes, and other data related to the research theme.

5. Results and Discussion

The research began with the identification of key factors. This identification was carried out with steps one, two, and three of MEAD, namely scanning analysis on environmental and organizational factors, then the system type and performance analysis stage on technological factors, and technical work process analysis on technological factors. The results of the analysis are the basis for identifying variances that occur in the work system. Variant data collection is carried out by submitting questionnaires to workers to see which variances occur in the work system. Variances that have been identified are analyzed with the help of a variance matrix so that the correlation between variances that can increase their influence can be known with certainty. Factors with variances that correlate the most with other variances so that they can increase their influence become key factors. The variance matrix can be found in Table 2.

Table 2. Variance matrix

Key Factor	Variance	1	2	3	4	5	6	7	8	9	10	11	12	Score
Environment	High workplace temperatures (1)						X				X	X		3
Tools/ technology	Machines are maintained only when broken (2)									X				1
	No specialized technicians to repair machines/equipment (3)		X											1
	Machinery/equipment poses risks to worker health and safety (4)					X			X		X	X		4
	Personal protective equipment (PPE) is not provided (5)				X			X	X					3
Task	Workers get tired easily during and after work (6)	X									X			2
	Workers feel aches (7)					X			X	X	X	X		5
	Uncomfortable work postures (8)				X	X		X		X		X		5
	Production targets are hard to meet (9)		X					X	X					3
	Workers are dehydrated (10)	X			X		X	X				X		5
Organization	Unkempt workplace conditions (11)	X			X			X	X					4
	Lack of appreciation (12)									X				1

The identified key variances are then analyzed in terms of how they are controlled under the current work system conditions. Variance control and role analysis can help develop proposals for work system improvements by adjusting the actual conditions of the work system. The control and role analysis and key factors can be seen in Table 3.

Table 3. Control and role analysis

	Key Factor	Key variance	Place	Responsible party	Directly involved party	Supporting activities
1.	Task	Workers feel aches	Production department	Production head	Production workers	Breaks and rest areas
2.		Uncomfortable work postures	Production department	Production head	Production workers	-
3.		Workers are dehydrated	Production department	Production head	Production workers	Breaks and rest areas

The improvement proposal is designed to consider the identified key variance and the gaps that cannot be filled by the existing supporting activities. The improvement proposal consists of several alternatives structured with an organizational, joint, and functional design that aims to determine the functional allocation of the effort and resources required to realize the alternative improvement designs. All these allocations can be translated into an objective tree/activity tree format which can be found in Figure 1.

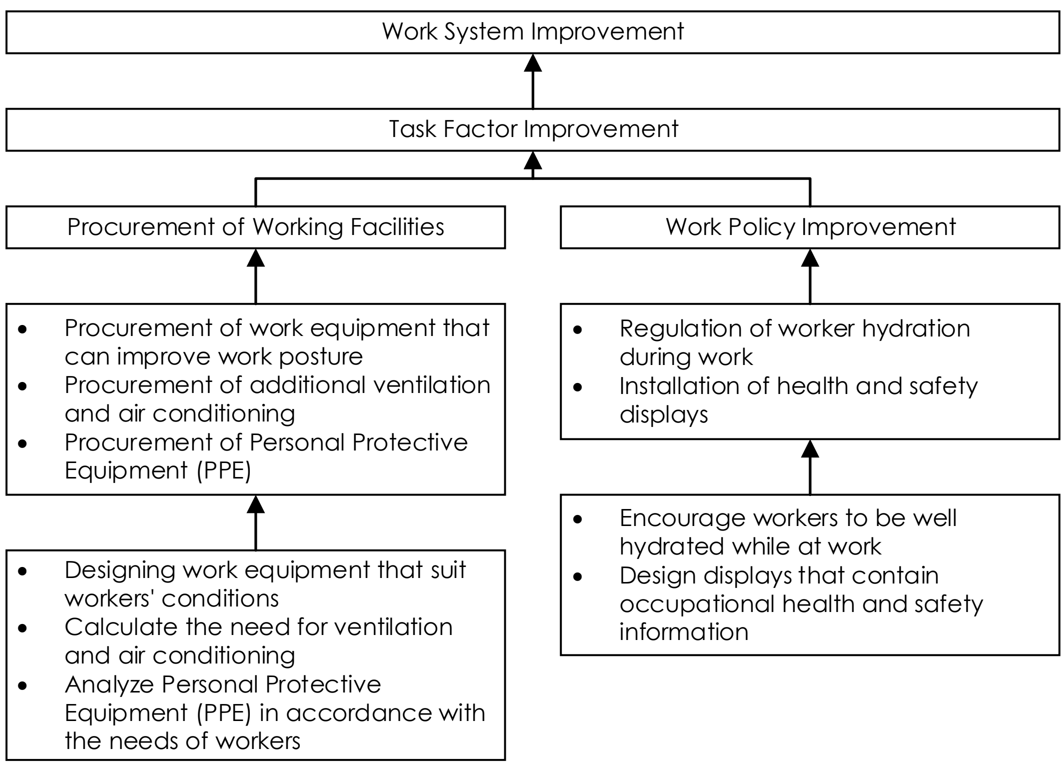


Figure 1. Objective tree alternative improvement design

The proposed improvement alternatives are analyzed in terms of their perceived responsibility. Analysis of the role of responsibility is carried out by evaluating and scoring each proposed improvement alternative. The score is based on criteria that MEAD has determined. The results of scoring each alternative can be found in Table 4.

Table 4. The score for each alternative

Alternative	Outreach to the organization	Imminent risks	Advantages	Effect on cost expenditure	Total scores
Procurement of work facilities	2	-3	8	-1	6
Work policy improvement	2	-2	8	-2	6

The acquisition of the same score means that each alternative proposed has approximately the same chance of success if the implementation stage is carried out. The improvement alternatives are then designed to become supporting sub-systems. The redesign of each proposed improvement can be seen as follows:

a. Procurement of work tool

The procurement of work tool aims to improve uncomfortable work postures felt by workers that cause pain in certain parts of the body. The work postures include arranging the cracker dough on the shelf (I), arranging the cracker dough on the bamboo board (II), and placing the bamboo board in the drying area (III). Muscle complaint assessment and work posture assessment are required before designing work tools. The assessment can be a basis for consideration of work tool design as well as a parameter for the effectiveness of work tool function. The results of muscle complaint assessment using NBM before improvement can be found in Figure 2 and work posture assessment using REBA before improvement can be found in Table 5.

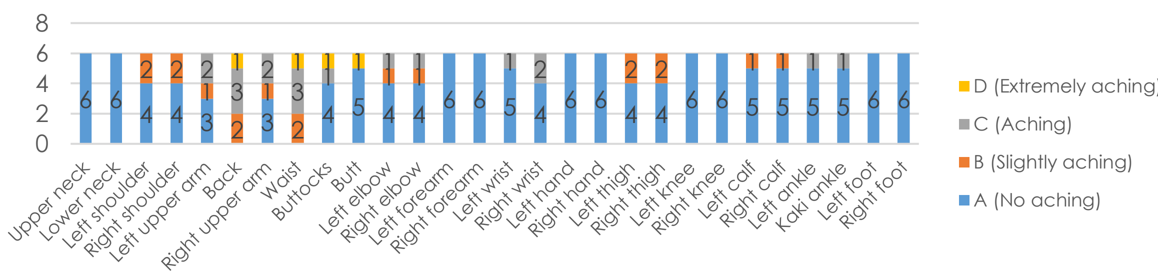
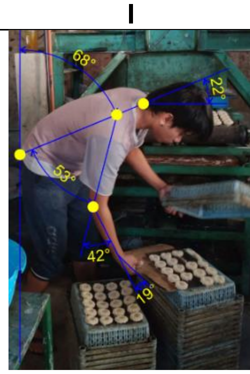
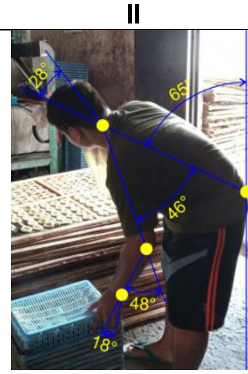
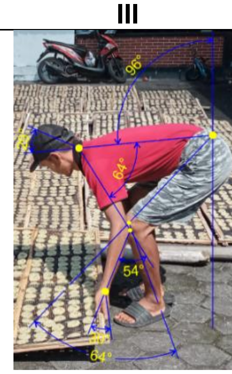


Figure 2. NBM questionnaire results before improvement

Table 5. REBA score of each work posture before improvement

	I	II	III
Work posture			
REBA Score	9	9	10
Risk	High	High	High

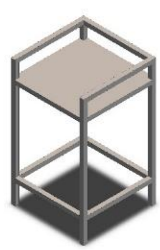
The average NBM score obtained from the assessment of muscle complaints is 39. The REBA score of each work posture also provides information that the risk level of the work posture before improvement is high and improvements need to be made immediately. Assessment of muscle complaints and work postures showed that the design of work tools would be focused on reducing the need for workers to bend repeatedly causing back and waist aches. The work tool designed are tables to improve work postures I and II and support poles to improve work posture III. The specifications of the work tool were determined by interpreting workers' desires for work tool. The interpretation can be found in Table 6.

Table 6. Wishes interpretation

	Table	Support poles
Wishes nteripretation	Made with lightweight steel	Made with lightweight steel
	Coated with rust-proof paint	Coated with rust-proof paint
	Size fits body dimensions	Sturdy design that can support bamboo boards
	Fits with the available space	Size fits body dimensions
	Fits to budget	Easy to relocate
		Fits to budget

The process of designing work tool is continued by processing anthropometric data. The anthropometric data used in the process of designing work tool are Spinal Height to determine the height of the table, Elbow Height to determine the height of the support pole, Elbow Span as a consideration for the width of the support pole, and Hand Width for allowance for hand use on the length and width of the table. Anthropometric data processing involves statistical tests including data uniformity tests, data adequacy tests, and percentile calculations. Statistical tests show that the data used is uniform and sufficient. The results of the work tool design can be found in Figure 3.

Table 7. Design of work tool

Design of work tool	Specifications
	Length: 54 cm, Width: 54 cm, Height: 94 cm. The table is made with a lightweight iron frame with a size of 3 cm and coated with anti-rust paint. Table dimensions are determined by anthropometric data of workers. The height of the table uses Spinal Height data with the 5th percentile and the allowance for the use of the left and right hands at the table using Hand Width (HW) data with a 95-th percentile.
	Length: 120 cm, Width: 70 cm, Height: 94 cm. The support poles are made with a lightweight iron frame with a size of 3 cm and coated with anti-rust paint. Support pool dimensions are determined by anthropometric data of workers. The height of the support pole utilizes the Elbow Height data with a 5-th percentile and the distance between the poles supporting the bamboo must exceed the Length of Elbow Span (ES) data with a 95-th percentile.

b. Procurement of additional ventilation and air conditioning
Providing additional ventilation and air conditioning aims to reduce the temperature of the production room to reduce the level of sweat excretion so that workers are no longer dehydrated. The ideal ventilation requirement can be calculated as follows:

$$\text{Ideal ventilation requirement} = 110{,}6\ m^2 \times 10\% = 11{,}06\ m^2 \quad (1)$$

The production room now has total ventilation and door area of 11.62 m^2. These results show that the ventilation in the production room is sufficient and in line with the ideal ventilation requirement. While the calculation of the proposed fan requirements can be done using the Cubic Feet per Minute (CFM) equation. Fan requirements can be calculated as follows:

$$\text{CFM} = 17770{,}75\text{x}\,\frac{10}{60} = 2961{,}79 \quad (2)$$

The production room is a smoky and humid factory building, so the ACR value for this type of room is 10. The fan proposed for use is a Sekai IWF 2639 with a water volume of 1440 CFM.

$$\text{Fan requirements} = \frac{2961{,}79}{1440} = 2{,}0568 \approx 3 \text{ unit} \quad (3)$$

The calculation results show that the production room requires 3 units of fans.

c. Procurement of Personal Protective Equipment (PPE)
   The use of Personal Protective Equipment (PPE) is one form of accident risk control based on the risk control hierarchy. Based on observations and workers' statements, the most common workplace accidents are burns to the hands due to splashes of cooking oil and scratches due to the sharp edges of bamboo boards scratching the hands. The PPE proposed to be procured are chemical gloves that can be used by workers when frying and cooking cracker dough and safety gloves that can be used when carrying bamboo boards.
d. Regulation of worker hydration during work
   Improvements in worker hydration regulation are based on OSHA-recommended administrative fluid and heat control techniques. Workers are encouraged to drink a glass of water without electrolytes every 20 minutes. This activity should be encouraged until it becomes a habit for workers.
e. Installation of health and safety displays
   The installation of occupational health and safety displays aims to support the proposed improvements in the provision of Personal Protective Equipment (PPE) and regulation of worker hydration while working. The proposed display to be installed in the production room can be found in Figure 3.

Figure 3. Health and safety displays

The last stage of the Macroergonomic Analysis and Design (MEAD) method is the implementation of the proposed improvements. Proposed improvements that can be implemented include procurement of work tools in the form of tables and support poles, procurement of Personal Protective Equipment (PPE) in the form of chemical gloves and safety gloves, regulation of worker hydration while working, and installation of displays. The implemented improvements have an impact on reducing the risk of injury in the work system. The results of muscle complaint assessment using NBM after improvement can be seen in Figure 4 and work posture assessment using REBA after improvement can be seen in Table 8.

The average NBM score after improvement is 33.16 with a decrease in score of 5.83. This significant decrease in the NBM score indicates a reduction in muscle complaints by workers, especially in the back and waist. Improvements in work posture also occur with the results of work posture assessment after improvement using REBA showing a low level of risk and improvement needs to be made but not anytime soon.

The provision of Personal Protective Equipment (PPE) helps reduce the burns and scratches that workers receive, so workers now feel safer and more comfortable while working. Workers also stated that the hydration arrangements helped workers to cope with hot room temperatures that caused workers to experience mild-moderate dehydration, although workers needed a lot of encouragement and time to get into the habit of being compliant and drinking a glass of water regularly. The improved displays directly influence the success of improving workers' compliance with PPE and hydration in the production room. The displays installed in the production room can be seen clearly, and information about worker safety and health is conveyed to workers well.

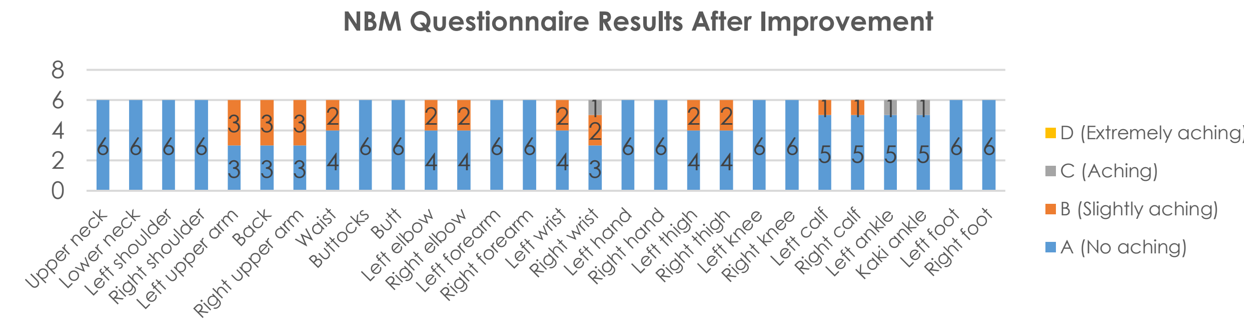
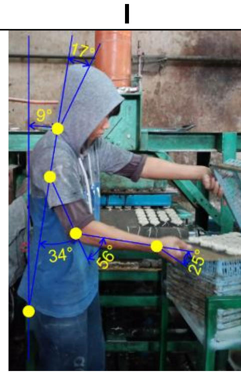


Figure 4. NBM questionnaire results after improvement

Table 8. REBA score of each work posture after improvement

	I	**II**	**III**
Work posture			
REBA Score	3	3	3
Risk	Low	Low	Low

6. Conclusion

The results of the implementation of improvements show a reduction in the risk of work accidents that can endanger the safety and health of workers. Procurement of work tools has an impact on reducing muscle complaints, especially on the back and waist of workers. This decrease in muscle complaints is validated by a decrease in the average Nordic Map (NBM) score after an improvement of 5.833. This work tool also improves work postures which are validated by a decrease in risk levels from high to low for all work postures. The risk of burns and scratches arising from work activities is minimized by using PPE in the form of chemical gloves and safety gloves during work. Workers also stated that they can cope with the hot room temperature that causes mild-moderate dehydration by drinking a glass of water regularly. The installation of occupational health and safety displays also encourages the successful implementation of improvements in the use of PPE and regulation of worker hydration during work.

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