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ORIGINAL RESEARCH PAPER

Home Science

ANALYSIS OF PHYSIOLOGICAL COST OF FORGING WORKER'S

KEY WORDS: Physiological cost, ergonomics, cardiac cost, Stress, Forging

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ABSTRACT

The forging process is significant and holds a crucial position within various manufacturing operations commonly conducted in workshops. While forging activities, workers may encounter notable hazards related to lacerations when handling forged parts or removing excess material. Moreover, in high-impact forging, there exists a potential for the expulsion of fragments, scale, or tools, thereby presenting an injury risk. Certain forging tasks involve the forge smiths working in standing, sitting, squatting positions, often requiring them to bend over while working on metal pieces and engaging in heavy lifting. They also utilize power tools like power hammers and drills, which contribute to the physical demands on workers. Consequently, the physiological impact on workers was assessed in a study involving 120 forging workers, focusing on parameters such as heart rate (HR), energy expenditure rate (EER), and total cardiac cost of work (TCCW). The study revealed that workers engaged in striking activities faced the highest risk, as the physiological cost of work was found to be the greatest during striking tasks. These workers not only deal with awkward postures during their activities but also work with heavy tools while performing repetitive motions. The study recommended the implementation of ergonomics interventions programs coupled with awareness and training initiatives among forging workers to mitigate the associated risks effectively.

INTRODUCTION

Small and Medium-sized Enterprises (SMEs) are recognized as the cornerstone of economic growth in every nation. They play a crucial role in sustaining the country's economy and establishing a robust supply chain system **(Kristenson, 2004).** One of the crucial SMEs is the forging industry which plays a critical role in the manufacturing sector, supplying essential components for various industries, including automotive, aerospace, construction, oil and gas, and power generation. Forging is a metalworking process that utilizes compressive forces to shape metal. This involves heating the metal to a specific temperature, applying pressure to deform it, and allowing it to cool in the desired shape. The significance of the forging industry lies in its ability to produce components with superior mechanical properties, such as strength, toughness, and fatigue resistance. However, this production process also exposes workers to a range of occupational health hazards, adversely affecting their physical and mental well- being. These chronic health hazards can arise from persistent anxiety related to factors like low income, job insecurity, unstable housing, social isolation, and a lack of control over work and personal life (**Krause *et* al.,2014).** Experiencing multiple stressors can increase the expectation of negative outcomes, leading to feelings of hopelessness, diminished coping abilities, and heightened vulnerability to future stressors **(Neill, 2011).** Additionally, the physically demanding nature of forging tasks, coupled with poor working conditions and repetitive operations, can cause physical and mental exhaustion, as highlighted by **(Charles & Nixon, 2019; DiDomenico & Nussbaum,2011)** When faced with any physical and mental exhaustion, the body activates its physiological systems to adapt and respond to imminent challenges. This response is characterized by elevated heart rate, blood pressure, pulse rate, and increased energy expenditure. However, prolonged, or repeated exposure to stress can lead to dysregulated and recurrent physiological responses, which can have detrimental effects on the body, causing a state of biological "wear and tear". Therefore, the need was felt to assess the different physiological stress parameters of the forging workers engaged in various activities.

MATERIALS AND METHODS

Selection of Respondents:

The study was carried out in the state of Uttarakhand. The sample size of 120 male workers were selected through snowball technique. The main reason for selection of male workers is that they were mainly involved in forging activities.

Standardization of activities:

Based on the preliminary survey conducted prior to the experiment, three activities in which the respondents faced problems were selected. These activities include Hammering, striking, and cooling as shown in table 1. Each activity was performed for 15 minutes.

Collection of data:

A specially designed Performa used to record readings during experiments. Readings were taken while the workers performed the planned tasks. Workers are encouraged to work in an ordinary way and not to be swayed by the investigator presence.Before starting every activity, workers were rested for 15 minutes at this point resting heart rate was recorded. Workers were asked to perform each activity for 15 minutes using the existing tools and equipment. Working heart rate was noted for 15 minutes at the interval of 5 minutes. The resting heart rate was recorded for 5 minutes at the interval of 1 minute each.

Calculation of Physiological cost of work:

The following parameters were calculated by using heart rate.

1. Average heart rate during rest, work and recovery period.
2. The energy expenditure per minute was estimated from heart rate using the following formula and the classification of workload was done as per Varghese et al. (1994). Energy Expenditure (kJ/min) = 0.159 x Average Heart rate (bmin-1) – 8.72
3. The Total Cardiac Cost of Work (TCCW) was also estimated for the whole day based on the cardiac cost of work and cardiac cost of recovery.

Cardiac Cost of Work (CCW) = Increased Average heart rate x Duration of work Increased Average heart rate during work= Average working heart rate – Average heart rate during rest

Cardiac Cost of Recovery (CCR) = Increased average heart rate during recovery x Duration Increased average heart rate during recovery = Average recovery heart rate – Average resting heart rate

Statistical Analysis of Experimental Data: Simple averages, percentages were calculated.

Table 1. Categories of workers according to activities

Groups	Activity	Pictures	POSITION	No. of workers
I	Hammering		Sitting	40
II	Striking		Bending	40
III	Cooling		Squatting	40

RESULT AND DISCUSSION

1. Physiological illness

Various type of common illness as cough, cold and fever, headache, body ache, skin rashes and allergy, eye irritation, nose and throat irritations etc and chronic illness like diabetes mellitus, respiratory disease, BP problem, stiffness in hand; cuts and wounds, burns, numbness in body and tingling in hand were reported by workers in last one year.

Common Illness

It was evident from the table 2 majority of the total workers i.e. 93.33 percent had reported body ache as the main common illness faced by them which was due to poor working posture for longer duration, and rest reported illness was cough, cold and fever i.e. nearly by 40 percent of workers.

When comparison was made among the different groups of workers, it was found that all workers in group I and group II who were involved in hammering and striking of metals to give it a desired shape had reported body ache as their major common illness and the reason might be long hour work in awkward position. The result were supported by finding of (**Burdort et al.,1991**)that the main contributing factor for body ache is poor working posture. Whereas among the group III workers who were engaged in cooling operation the main common illness reported by majority of workers i.e. 92.5 percent was eye irritation, the reason might be the fumes/smoke/gas produced when hot metal comes in contact of cold water while cooling operation.

Table 2. Medical History of forge smith workers during last one year N=120

S.No	Occurrence Illness/ symptoms	Group I	Group II	Group III	TOTAL
Common illness					
1.	**Cough, cold, fever**	15 (37.5)	10 (25.0)	22 (55.0)	47 (39.16)
2.	**Headache**	37 (92.5)	32 (80.0)	17 (42.5)	86 (71.66)
3.	**Body-ache**	40 (100)	40 (100)	32 (80.0)	112 (93.33)
4.	**Skin rashes, allergy**	20 (50.0)	11 (27.5)	28 (70.0)	59 (49.16)
5.	**Eye irritation**	38 (95.0)	27 (67.5)	37 (92.5)	102 (85)
6.	**Nose and throat irritation**	20 (50.0)	6 (15.0)	28 (70.0)	54 (45.00)
Chronic illness					
1.	**Diabetes mellitus**	-	2 (5.0)	3 (7.5)	5 (4.16)
2.	**Respiratory disease**	10 (25.0)	-	12 (30)	22 (18.33)
3	**BP problem**	14 (35.0)	16 (40.0)	7 (17.5)	37 (30.83)
4.	**Stiffness in hands**	33 (82.5)	35 (87.5)	3 (7.5)	71 (59.16)
5.	**Cuts and wounds**	40 (100)	30 (75.0)	6 (15.0)	76 (63.33)
6.	**Burns**	40 (100)	20 (50.0)	36 (90.0)	96 (80)
7.	**Numbness in body**	38 (95.0)	40 (100)	9 (22.5)	87 (72.50)
8.	**Tingling in hand**	33 (82.5)	36 (90.0)	-	69 (57.50)

Figures in parentheses indicate the percentage values

Chronic illness

Various type of chronic illness as diabetes mellitus, respiratory disease, BP problem, stiffness in hand; cuts and wounds, burns, numbness in body and tingling in hand were reported by workers in last one year.

Data revealed that most of the workers i.e. 80 percent had reported burns as the major chronic illness and least common was diabetes mellitus which was reported by only 4.16 percent. A commendable proportion of total workers i.e. 18.33 percent, 59.16 percent, 63.33 percent, 72.50 percent, and 57.50 percent complained that they suffered from respiratory problem, stiffness in hand, cuts and wounds, numbness in body and tingling in hand, respectively.

It can depicted from the table 2. that group I workers who were involved in hammering operation had reported cuts/wounds and burns as their main chronic illness, as they had to deal with direct heat and heavy tools while performing their tasks. Among group II workers the majorly reported chronic illness by all workers was numbness in body, as their work involved striking of metal by heavy tools which required continuous forceful motion to give the metal a desirable shape. Whereas among group III workers the mostly reported (i.e. by 90 percent) chronic illness was burns the reason might be the hot melted metal and fumes which produced while cooling of metal.

2. Physiological cost of workers

Physiological factors like heart rate, maximal oxygen consumption, and energy expenditure linked to metabolism serve as the primary parameters for evaluating the physiological workload **(Balderrama *et* al., 2010; Charles & Nixon, 2019 ; Uusitalo *et* al.,2011)** So, to assess the physiological cost of work, a total of five replications were conducted, measuring Heart Rate (HR), Energy Expenditure Rate (EER), and total cardiac cost of work (TCCW)

2.1 Physiological cost of work in term of Heart Rate (beats/minute) The results of experiments conducted on workers with different activity profiles were analysed and presented in Table 3 and Figure 1,

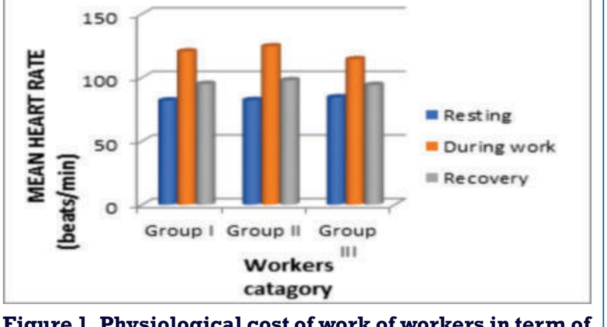

Figure 1. Physiological cost of work of workers in term of Heart Rate (beats/minute)

depicting the mean Heart Rate (HR) and the percentage increase from the resting level. Work performance led to an increase in Heart Rate, with the mean resting heart rate ranging from 82 to 85 beats per minute for various activities. The subsequent section describes the variations in these responses for different activities.

In Group I, the mean Heart Rate at resting level was 82.3 beats per minute, increasing to 120.6 beats per minute during work, resulting in a percentage increase of 15.43.

In Group II, the mean resting Heart Rate was 82.5 beats per minute, which rose to 124.6 beats per minute during performance. The percentage increase in Heart Rate in Group II workers was found to be 18.66, the highest among all groups when compared.

In Group III, the mean Heart Rate before work, during work, and the recovery period was 84.5, 114.4, and 94.2 beats per minute, respectively, with a percentage increase in Heart Rate of 11.47.

Overall, it can be concluded that there was a notable difference in the percentage increase in heart rate for various activity groups. Group II workers, engaged in striking operations with heavy tool handling like long hammers and repetitive work motion in awkward positions, showed the highest percentage increase in heart rate.

Table 3. Physiological cost of work of worker in term of Heart Rate (beats/minute) N=120

S.No	Activity Profile	Mean Heart rate (beats/ min)			Percent increase in HR
		Resting	During work	Recovery	
1.	Group I(n=40)	82.3	120.6	95	15.43
2.	Group II (n=40)	82.5	124.6	97.9	18.66
3.	Group III (n=40)	84.5	114.4	94.2	11.47

Percent increase =(After Activity-Before Activity) X 100
(Before Activity)

2.2 Physiological cost of work of worker in term of Energy Expenditure Rate

Based on the data presented in Table 3 and Figure 2, the mean Energy Expenditure Rate (EER) in

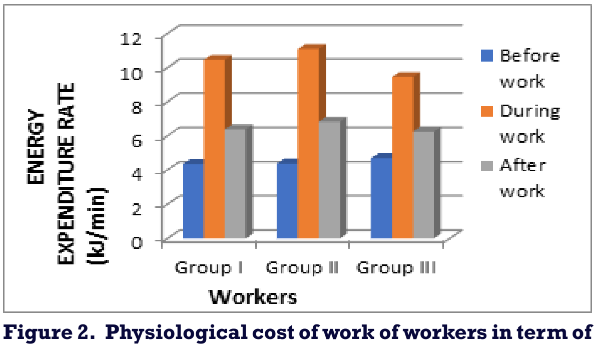

Figure 2. Physiological cost of work of workers in term of Energy Expenditure Rate (kJ/min)

kJ/min and the increase in EER from resting levels were analysed for various activities performed by selected forging workers, leading to the following findings:

In Group I (hammering), the EER at resting, during work, and in the recovery, period was 4.36, 10.45, and 6.38 kJ/min, respectively, resulting in a percentage increase of 46.97.

Group II workers (striking) had an EER of 4.39 kJ/min before work, which increased to 11.09 kJ/min during work, indicating a percentage increase of 56.80.

Group III workers (cooling) experienced a percentage increase in EER of 32.69, with EER levels ranging from 4.71 before work to 9.46 kJ/min during work.

To summarize, Group II workers (engaged in striking tasks) exhibited the most strenuous activity in terms of energy expenditure, leading to high metabolic demand. This heightened demand can result in physical and mental fatigue, an increased risk of work injuries, decreased work performance, and a higher likelihood of cardiovascular diseases and early retirement **(Karpansalo *et* al., 2002; Krause *et* al,2014; Krause *et* al., 2007; Tornqvis, 2011; Wultsch *et* al.,2012).**

Table 4. Physiological cost of work of worker in term of Energy Expenditure Rate N=120

S. No	Activity Profile	Energy Expenditure Rate (kJ/ min)			Percent increase in EER
		Resting	During work	Recovery	
1.	Group I(n=40)	4.36	10.45	6.38	46.97
2.	Group II (n=40)	4.39	11.09	6.84	55.80
3.	Group III (n=40)	4.71	9.46	6.25	32.69

Percent increase =(After Activity-Before Activity) X 100
(Before Activity)

2.3 Physiological cost of work of worker in term of total cardiac cost of work (TCCW)

According to the data presented in Table 4, the mean cardiac cost of work (CCW), mean cardiac cost of recovery (CCR), and the total cardiac cost of work (TCCW) were analysed for various activities performed by selected forging workers, resulting in the following observations:

In Group I (hammering), the mean CCW, mean CCR, and TCCW were 574.5 (beats/min), 63.5 (beats/min), and 638 (beats), respectively. This group of workers faced a physiological cost of 42.53 beats.

For Group II (striking), the mean CCW, mean CCR, and TCCW were 631.5 (beats/min), 77 (beats/min), and 708.5 (beats), respectively. The physiological cost faced by this group of workers was 47.23 beats.

In the case of Group III (cooling), the mean CCW, mean CCR, and TCCW were 448.5 (beats/min), 48.5 (beats/min), and 497 (beats), respectively. The physiological cost faced by this group of workers was 33.13 beats.

In summary, based on the TCCW, Group II workers (striking) were engaged in the most strenuous activity, with the highest physiological cost of work being 47.46 beats. Conversely, Group III workers (cooling) were involved in the least exhaustive activity.

Table 5. Physiological cost of work of worker in term of total cardiac cost of work (TCCW) N=120

S.No	Activity Profile	Cardiac cost of work (CCW)	Cardiac cost of recovery (CCR)	Total cardiac cost of work (TCCW) (beats)	Physiological cost of work (PCW) (beats)
1.	Group I (n=40)	574.5	63.5	638	42.53
2.	Group II (n=40)	631.5	77	708.5	47.23
3.	Group III (n=40)	448.5	48.5	497	33.13

The comprehensive data analysis from tables 2 to 5 highlights that Group II workers engaged in striking tasks showed the most strenuous activity, incurring the highest physiological cost of work in terms of blood pressure, heart rate, energy expenditure rate, and total cardiac cost. This finding is consistent with the research by **(Tirthankar *et* al.,2011)** which attributes various factors to this observation, including the forceful motions and prolonged use of heavy tools in awkward positions inherent to striking operations. These factors contribute to the heightened physiological cost of work for Group II workers, impacting their health, productivity, and overall work performance.

CONCLUSION

The forging industry plays a vital role in the Indian economy, providing employment to numerous workers who are exposed to constant risks of musculoskeletal disorders (MSDs) like strains, sprains, and back injuries. These hazards are primarily attributed to the repetitive nature of forging tasks, coupled with inadequate ergonomic design and workstations, which increase the likelihood of such injuries. The study's findings indicate that workers engaged in striking activities face a high risk of these hazards, experiencing the highest physiological cost of work. Therefore, the study strongly recommends the urgent implementation of appropriate safety measures to mitigate these risks. Such measures may include the use of engineering controls, providing personal protective equipment (PPE), conducting regular risk assessments, organizing training programs on hazard recognition and prevention, and ensuring compliance with local occupational health and safety regulations.

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