



Ergonomic evaluation of tea leaf plucking in Assam

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ABSTRACT

Plucking of tea leaves is the most laborious operation in the tea garden which is accomplished by engaging a large number of women workers. It involves repetitive hand movements with body tilting frontward from natural alignment for a long time. The fatigue developed due to working posture may lead to occupational health hazards. Ergonomic evaluation of the work and workload of the women workers engaged in tea leaf plucking were investigated in the present study. Fifteen female workers in the age group of 18 to 53 years of a private company owned tea garden in Assam (India) with work experience of more than one year were selected as subjects for the evaluation. Heart rate of the subjects during the whole day activity was recorded. The average working heart rate and increase in heart rate during tea leaf plucking was 106.95 ± 1.87 beats/min and 28.15 ± 3.39 beats/min, respectively. The oxygen consumption rate and energy expenditure rate were 0.54 L/min and 8.28 kJ/min, respectively. The physiological cost for one bout of work was 27.27 beats/min. The average overall discomfort rate was 2.53 indicating that the tea leaf plucking on psychophysical basis is light to moderately heavy work. The workers perceived maximum discomfort at the neck, wrists, back and upper arms. The discomfort associated with tea leaf plucking can be attributed to repetitive hand movement in bending posture during plucking while carrying the load of the basket with plucked tea leaves on the back.

1. Introduction

India is the second largest producer and fourth largest exporter of tea in the world. Tea industry is the second largest agro-based industry in India. Tea production in India was about 1322 million kg in the year 2017, which is about 23% of total tea production in the world (Tea Board of India, 2018). Assam is graced by favourable soil and agro-climatic condition for the production of tea.

There are two methods plucking tea leaves plucking is not viz., manual and mechanical. Mechanical production of tea in Assam was 645.14 million kg in the year 2018, which was nearly 49% of total tea production in India (Tea Board of India, 2018) popular in India. Manual plucking involves repetitive dynamic hand movements on standing posture while tilting forward (bending back and neck) from the natural alignment. The manual plucking operation is

laborious and drudgery-prone. The output of the work decreases with time, and the health of the workers also get affected (Bihari *et al.*, 2011).

Women play a pivotal role as field workers in tea estates. Majority of workforce in plucking operation are women. In a study on the occupational health hazards and safety measures conducted on the tea plantation workers of Kerala, it was revealed that the workers in tea garden have to work for 41 to 50 hours per week (Nair and Priyadarshan, 2018). Long working hours and inappropriate rest breaks add to the risk of occupational health hazard. The repetitive hand movement in bending posture during plucking increases the drudgery and decreases the productivity of women workers. Repetitive movement in an awkward posture has been described as causal factor to different musculoskeletal disorders (Piligian *et al.*, 2000). Sufficient rest allowance is necessary between two work bouts to avoid work related health problem.

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In Assam, tea production season starts from April and prevails up to December every year. However, maximum production of tea is during the months of May to October. In peak season, the management of tea estate assigns certain higher target to each worker with additional monetary incentives. To achieve the target, workers try to pluck tea leaves quickly neglecting the fatigue, discomfort and its impact on health. This may further lead to permanent discomfort.

Research on ergonomics of tea leaf plucking operation is very limited. Sen *et al.*, 1983 studied physiological cost of tea leaf plucking operation. They reported the heart rate of 115.2 ± 8.75 beats/min and energy expenditure rate of 13.91 kJ/min during tea leaf plucking with full basket. Mirbod *et al.*, 1995 studied the health and safety condition of green tea workers in Japan. The workers used tea harvesting machine. The study revealed that, 72.2% males and 63.0% females suffered pain in the lower back during mechanical harvesting of tea. Kishtwaria *et al.*, 2004 reported the peak heart rate of 110.13 and 111.67 beats/min and average heart rate of 99.07 and 101.12 beats/min in morning and evening, respectively for tea leaf pluckers in the age group of 25 to 35 years. The peak heart rate of 106.20 and 109.33 beats/min and average heart rate of 97.80 and 99.00 beats/min in morning and evening, respectively was observed for the tea leaf pluckers in the age group of 35 to 45 years. The workload was found to be high and stressful for the pluckers in the age group of 35 to 45 years. Chattopadhyay *et al.*, 2006 studies posture- comfort-performance interrelationships in plucking operation in a tea estate. Performance of the workers was found to correlate with both stature bush height ratio and body part discomfort frequency and severity. Body part discomfort frequency and severity increased with progression of working duration. Dewangan and Dihingia, 2011 conducted a research on musculoskeletal symptom among tea pluckers in India. They reported the occupational pain at the shoulders (71.8%) followed by the neck (66.4%), upper back (65.6%), wrists/hands (50.4%), lower back (47.2%), elbows (39.4%), knees (10.0%), hips/thighs/buttocks (5.4%) and ankles/feet (2.6%). Bhattacharyya and Chakrabarti, 2012 reported that the workers during plucking operation were found to assume unnatural posture which was static as well as highly dynamic with a load (tea leaf collecting basket up to weight of 30 kg when filled with plucked leaves) at back. With gradual increment of load, pain through the load is released intermittently, and the strain level was found to remain at a high level.

Women labourers have occupied forefront position in employment across plantations sector. Labour Bureau, 2012 reflected that 53.27% of women are employed across all plantations (coffee, tea, rubber and others) in 2008. Participation of women in tea plantation increased from 48.88% in 1995 to 53.43% in 2008. Keeping these facts in view, the present study was conducted to investigate the ergonomics and workload of workers engaged in tea leaf plucking in a renowned tea garden of Assam.

2. Materials and Methods

Experiment site

The experiment was conducted in M/s Saikia Tea Garden located in the Sonitpur district of Assam during 3rd and 4th weeks of May, 2019. The maximum and minimum dry bulb temperature in the tea garden during the period of study varied in the range of 28–35°C and 23–24°C, respectively. Relative humidity varied in the range of 76–95%. The Sonitpur district is one of the leading producers of tea in Assam. There are altogether 73 tea gardens in Sonitpur district, established by the renowned companies excluding registered small size tea gardens (Census of India, 2011). Hence, majority of agricultural labourers are employed in tea estates. Plucking of tea leaves being repetitive work, it is accomplished in the selected tea garden by employing a large number of women workers. Permission to conduct the research work was taken from the estate management authorities.

Subjects

Thirty women workers in the age group of 18 to 53 years who were engaged in tea leaf plucking for more than one year in the selected tea garden were randomly selected. They were educated about the research and persuaded to cooperate during the experiment. After the discussion, only 15 women workers who were free from cardiovascular disease, respiratory problems, movement restrictions and physical deformity were selected as subjects for the study. Physical characteristics of the subjects are given in Table 1. The mean \pm standard deviation of age, stature and weight of the subjects was 37 ± 11.4 years, 145.13 ± 8.61 cm and 39.93 ± 6.28 kg, respectively. The subjects were allowed to take sufficient rest before starting the activity to determine the resting heart rate. The resting heart rate of the subjects varied in the range of 74.0 to 82.7 beats/min, and the mean resting heart rate of the subjects was 78.82 ± 2.71 beats/min.

Experiment design

The experiment was divided in two parts viz., ergonomic evaluation associated with tea leaf plucking operation and workload of the subjects. The experiment was conducted in randomized block design (RBD) with total 15 subjects as replications of the experiment. The test locations were randomly chosen in the garden to minimize the variation due to the effect of environment, site condition and plant size. The ergonomic evaluation of women labourers engaged in tea leaf plucking was conducted during the period from 7.00 a.m. to 5.00 p.m. Heart rate was measured under 4 different circumstances viz., during forward (onward) journey from residence to the work place (tea garden), during plucking of tea leaves, during backward (return) journey from tea garden to the residence, and during whole work day. Heart rate monitor (Polar electro, Finland) consisting transmitter, receiver and interface was used to measure heart rate of the subjects (Figure 1).

Ergonomics evaluation

Ergonomics associated with the tea leaf plucking was evaluated using the heart rate data obtained from the heart rate monitor. Oxygen consumption rate (OCR) of the subjects during work was computed from the heart rate of the subjects using equation (1) as proposed by Singh *et al.* (2008).

$$\text{OCR} = 0.0114 \text{ HR} - 0.68 \quad (1)$$

where, OCR = Oxygen consumption rate, L/min

HR = Heart rate, beats/min

Energy expenditure rate (EER) and total cardiac cost of work (TCCW) were calculated using equations (2) to (5) as proposed by Verghese *et al.* (1994).

$$\text{EER} = 0.159 \text{ AHR} - 8.72 \quad (2)$$

where, EER = Energy expenditure rate, kJ/min

AHR = Average heart rate, beats/min

$$\text{TCCW} = \text{CCW} + \text{CCR} \quad (3)$$

where, CCW = Cardiac cost of work, beats

CCR = Cardiac cost of recovery, beats

$$\text{CCW} = \Delta\text{HRA} \cdot t_A \quad (4)$$

where, ΔHRA = Mean working heart rate – Mean resting heart rate

t_A = Duration of activity, min

$$\text{CCR} = \Delta\text{HRR} \cdot t_R \quad (5)$$

where, ΔHRR = Mean recovery heart rate – Mean resting heart rate

t_R = Duration of recovery, min

$$\text{Physiological cost of work (PCW)} = \text{TCCW} / t_w \quad (6)$$

where, t_w = Total time taken for the activity, min

Plucking of tea leaf in unnatural body posture was categorized according to workload categorization (Table 2) as proposed by Varghese *et al.*, 1994. Categorization of workload was based on the average energy expenditure and average heart rate during execution of work.

Body part discomfort rating

The effect due to working posture was measured in terms of overall discomfort rate and body part discomfort rate techniques. The subjects were asked to indicate her exertion/discomfort on a 5-point Rating on Perceived Exertion (RPE) scale at the end of day's work. Work related body part discomfort for 27 body regions and overall discomfort score was collected at the site.

Data Analysis

After completion of each day's work, the heart rate data recorded during experiment was downloaded from heart rate monitor (receiver) to a computer with the help of an interface (Polar electro, Finland) and software for further analysis. Microsoft Excel software package was used for the statistical analysis. Heart rate data of each subject was obtained for every minute of the activity. Data from 6 minute into work to till the completion of work was averaged to get mean heart rate value of the subject. Mean values of the overall discomfort and work related body part discomfort was calculated.

3. Results and Discussion

Heart rate response in a day long work

Typical heart rate pattern of a subject for a day long work is shown in Figure 2. The heart rate of the subject increased

rapidly from resting heart rate at the beginning of forward (onward) journey upto the working spot. After reaching the work site, the women workers refresh their mood and mentally prepare for working, and then start the activity (plucking). The entire activities consume about 5 to 10 min. During this period the heart rate of the subject decreases. This is because, preparation for working is lighter as compared to walking. As soon as the women workers initiate the plucking, the heart rate increases, and it remain almost constant during a bout of tea leaf plucking. The heart rate of the subjects decreases from the working heart rate level when they take tea break. The tea break is generally of 10 minutes duration. The tea break is followed by plucking, and it continues till the bamboo basket carried by the workers is fully filled with green leaves. The women workers have to carry the plucked leaves to the weighing room. After weighing the leaves, the plucker goes for 45–60 minutes lunch break. The heart rate of the subjects decreases from the working heart rate level during lunch break. The lunch break is again followed by tea leaf plucking. The heart rate of the subjects again starts increasing, and it remains almost constant during a bout of tea leaf plucking. At the end of the day's work, the pluckers again go to the weighing room. Afterward, all the subjects change their working dress, collect their basket, umbrella, tiffin box, etc. and proceed to home which is termed as backward (return) journey. After reaching home, the plucker was asked to relax for 15 minutes.

In a day long work, the average duration of tea leaf plucking was 5.8 ± 0.3 h and average duration of rest was 2.0 ± 0.2 h. The summary of average working and recovery heart rate of all the subjects in a day long work is presented in Table 3. The highest and the lowest values of average heart rate during plucking operation was 111.5 and 104.1 beats / min, respectively. The average working heart rate was 106.95 ± 1.87 beats/min. The average increase in heart rate during plucking from the rest was 28.15 ± 3.39 beats/min. The recovery heart rate of the subjects varied in the range of 81.4 to 91.2 beats/min. The average recovery heart rate was 85.53 ± 3.07 beats/min.

The average heart rate reported by Sen *et al.*, 1983 during tea leaf plucking (115.2 ± 8.75 beats/min) was higher than that observed in the present study. The average heart rate of

women workers engaged in tea leaf plucking in the morning and evening as reported by Kishtwaria *et al.*, 2004 was less than that observed in the present study.

Oxygen consumption rate and energy expenditure rate Substituting the value of average heart rate during plucking (106.95 beats/min) in equations (1) and (2), the oxygen consumption rate was found to be 0.54 L/min and energy expenditure rate was found to be 8.28 kJ/min. Referring to Table 2, for the obtained values of energy expenditure and heart beats during work, the plucking operation was classified as moderately heavy. The energy expenditure rate for tea leaf plucking with full basket (13.91 kJ/min) reported by Sen *et al.* (1983) was much higher than that observed in the present study.

Total Cardiac Cost

Substituting the value of average heart rate during resting (78.82 beats/min) in equation (4), and taking duration of activity for one bout of work as 120 minutes, the cardiac cost of work was found to be 3375.20 beats. Putting the value of average heart rate during recovery (85.53 beats/min) and duration of recovery (5 min) in equation (5), the cardiac cost of recovery was found to be 33.53 beats. Substituting these values in equation (3), the total cardiac cost for one bout of work was found to be 3408.73 beats. The physiological cost of work was computed using equation (6), and it was 27.27 beats/min.

Discomfort rating during tea leaf plucking

The overall discomfort ratings of the subjects on the 5-point RPE scale after the day's work is presented in Table 4. The overall discomfort score varied from 2 to 3 with eight subjects rating tea plucking as moderately heavy (3 point) and seven subjects rating it as light (2 point). Hence, on the psychophysical basis, tea leaf plucking activity was found to be either light or moderately heavy job. Kishtwaria *et al.* (2004) reported the workload to be high and stressful for the pluckers in the age group of 35 to 45 years. Body part discomfort rating by the subjects on the 5-point RPE scale for the discomfort at 27 various body parts is presented in Table 5. Subjects gave the highest discomfort rating of 2.6 to neck, followed by upper back, right wrist (2.53), right upper arm, left wrist, lower back (2.47), left shoulder, left upper arm and midback (2.40). Overall, discomfort perceived at the neck,

wrists, back and upper arms was higher than the discomfort perceived at other body parts (left knee, left elbow, chest and buttock).

The body part discomfort was mainly due to repetitive hand movement in bending posture during plucking while carrying the load of the basket with plucked tea leaves on the back. The comfort of women workers engaged in tea leaf plucking can be improved by introducing plucking gloves which is expected to minimize the injury to fingers, and increase the grasping power of fingers to tea leaf and minimize the energy required for detaching leaf from the tea bush. The findings of the present study suggest that tea leaf pluckers in Assam, India are at high risk of musculoskeletal disorders. Risk of musculoskeletal disorders due to discomfort may be reduced by implementing ergonomic interventions like, reduction of load carriage, improved work organization with job rotations and sufficient rest during work to the tea pluckers (Dewangan and Dihingia, 2011).

4. Conclusions

Ergonomic evaluation of tea leaf plucking by representative female workers in a private company owned tea garden in Assam (India) indicated that the tea leaf plucking is light to moderately heavy work. Due to discomfort associated with repetitive hand movement in bending posture while carrying the load of the basket with plucked tea leaves on the back, the workers perceived maximum discomfort at the neck, wrists, back and upper arms. The work stress on the women workers may be reduced by implementing ergonomic interventions like, reduction of load of plucked tea leaves being carried in the basket and sufficient rest during the work.

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Table 1. Physical characteristics of the selected subjects

Subject No.	Age, years	Stature, cm	Body weight, kg	Resting heart rate, beats/min
S1	37	142	33	80.8
S2	38	151	41	80.0
S3	18	152	41	82.2
S4	45	146	34	77.6
S5	50	151	40	81.0
S6	35	150	38	82.7
S7	50	135	37	81.2
S8	18	124	44	81.3
S9	35	145	37	74.4
S10	40	147	36	77.7
S11	36	133	38	77.6
S12	18	155	51	76.9
S13	53	153	56	77.3
S14	45	143	35	74.0
S 15	37	150	38	77.6
Mean	37.00	145.13	39.93	78.82
Standard deviation	11.41	8.61	6.27	2.71
5 th percentile	18.22	130.97	29.61	74.36
95 th percentile	55.78	159.30	50.25	83.28

Table 2. Categorization of workload

Physical work load	Physiological variables	
	Energy expenditure, kJ/min	Heart beats, beats/min
Very light	Up to 5.0	Up to 90
Light	5.0–7.5	91–105
Moderately heavy	7.6–10.0	106–120
Heavy	10.0–12.5	121–135
Very heavy	12.6–15.0	136–150
Extremely heavy	< 15.0	Above 151

Source: Varghese *et al.*, 1994

Table 3. Summary of working, increase in heart rate from rest and recovery heart rate for the selected subjects

Subject No.	Working heart rate, beats/min	Increase in heart rate, beats/min	Recovery heart rate, beats/min
S1	105.4	24.7	85.5
S2	107.5	27.6	86.0
S3	111.5	29.3	87.1
S4	105.5	27.9	82.5
S5	106.7	25.7	88.1
S6	104.1	21.4	89.2
S7	108.0	26.8	90.2
S8	104.8	23.5	91.2
S9	105.5	31.1	82.5
S10	106.9	29.3	81.4
S11	108.2	30.6	82.6
S12	108.0	31.1	83.3
S13	106.1	28.8	85.5
S14	108.9	34.9	84.7
S15	107.1	29.5	83.1
Mean	106.95	28.15	85.53
Standard deviation	1.87	3.39	3.07

Table 4. Overall discomfort rating of the subjects during tea leaf plucking

Subject No.	Overall discomfort rating
1	3.0
2	2.0
3	3.0
4	2.0
5	3.0
6	3.0
7	2.0
8	3.0
9	2.0
10	3.0
11	2.0
12	3.0
13	2.0
14	2.0
15	3.0
Mean	2.53
Standard deviation	0.52

**Figure 1.** Heart rate monitor (transmitter, receiver and interface) (Polar electro, Finland)

Table 5. Work related body part discomfort score in 5-point RPE scale during tea leaf plucking

Sl. No.	Body part	Perception by subjects															Mean	SD
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
1	Neck	3	2	3	2	3	2	3	3	2	3	2	3	2	3	3	2.60	0.51
2	Left shoulder	2	2	3	2	3	2	2	3	2	3	2	3	2	2	3	2.40	0.51
3	Right shoulder	3	2	2	2	3	2	2	2	2	2	2	3	2	2	2	2.20	0.41
4	Left upper arm	3	2	2	3	3	3	3	2	3	2	2	2	2	2	2	2.40	0.51
5	Right upper arm	2	3	3	2	3	2	2	3	3	2	2	3	2	2	3	2.47	0.52
6	Left elbow	1	1	1	1	1	2	1	1	2	1	1	1	1	1	1	1.13	0.35
7	Right elbow	1	1	2	1	1	1	1	2	1	1	1	1	1	1	2	1.20	0.41
8	Left fore arm	2	3	2	2	3	2	2	3	2	3	3	2	2	2	2	2.33	0.49
9	Right fore arm	2	3	2	2	2	2	3	3	2	2	2	2	2	2	2	2.20	0.41
10	Left wrist	3	2	3	2	3	3	2	3	2	2	2	3	2	2	3	2.47	0.52
11	Right wrist	3	2	3	2	3	3	2	3	2	3	2	3	2	2	3	2.53	0.52
12	Left hand	3	2	2	2	3	2	2	2	2	2	2	3	2	2	2	2.20	0.41
13	Right hand	3	2	2	2	3	2	2	2	2	2	2	3	2	2	2	2.20	0.41
14	Chest	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1.13	0.35
15	Abdomen	1	2	1	1	2	1	2	1	1	1	2	1	1	2	1	1.33	0.49
16	Upper back	3	2	3	2	3	3	2	3	2	3	2	3	2	2	3	2.53	0.52
17	Mid back	3	2	3	2	3	3	2	3	2	2	2	3	2	2	2	2.40	0.51
18	Lower back	3	2	3	2	2	3	2	3	2	3	2	3	2	2	3	2.47	0.52
19	Buttock	1	1	1	2	1	1	1	2	1	1	1	1	1	1	1	1.13	0.35
20	Left upper leg	1	1	2	1	2	2	1	1	1	1	1	1	1	1	2	1.27	0.46
21	Right upper leg	1	1	2	1	1	2	2	1	1	2	1	2	1	2	1	1.40	0.51
22	Left knee	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1.07	0.26
23	Right knee	1	1	1	1	1	2	1	1	2	1	1	2	1	1	1	1.20	0.41
24	Left lower leg	2	1	2	2	1	2	2	1	2	1	2	1	2	1	2	1.60	0.51
25	Right lower leg	2	1	2	2	1	2	2	1	2	1	2	1	2	1	2	1.60	0.51
26	Left foot	1	2	2	1	2	2	2	2	2	1	2	2	1	2	2	1.73	0.46
27	Right Foot	2	2	2	2	1	2	1	1	2	1	2	2	2	2	2	1.73	0.46

SD: Standard deviation

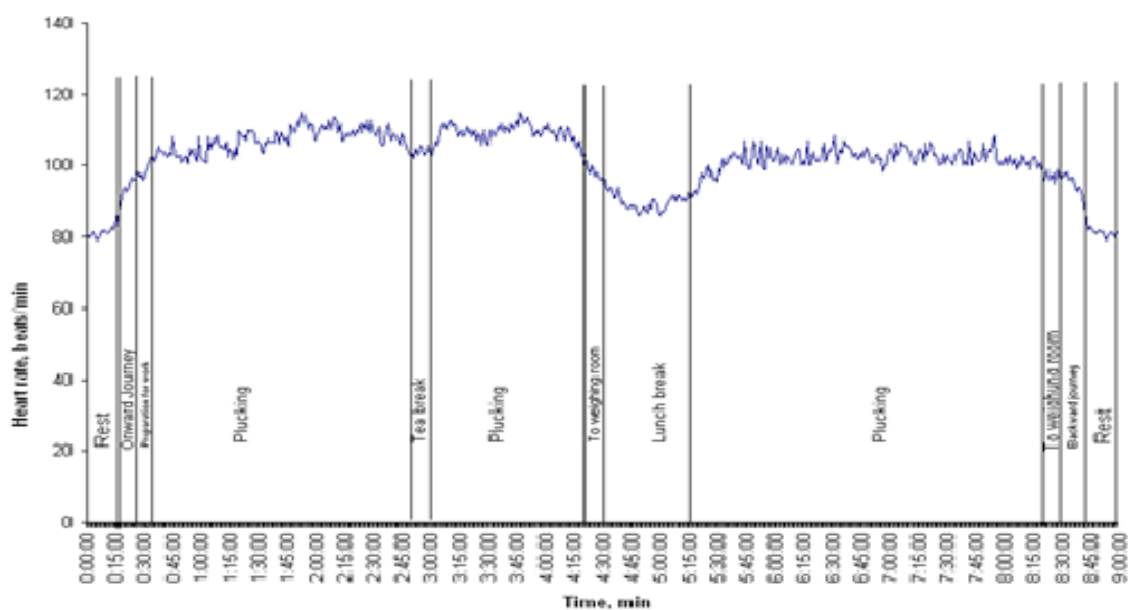


Figure 2. A typical heart rate pattern of subject for a day long