Ergonomics of Farm Women in Manual Paddy Threshing

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ABSTRACT

A study was taken up to have a comparative study on the ergonomics of farm women in pedal threshing with single and double operators (N =15) and to suggest modifications for further reduction of human drudgery. The mean HR_{work} was found to be 135.9 ± 1.3 and 121.2 ±1.0 beats/min respectively with single and double operators; a significant ($P<0.01$) reduction of 10.82 %. The corresponding work pulse (Δ HR) was 65.7 ± 0.9 and 51.5 ± 1.6 beats/min. The Δ HR was more than the allowable limit of 40 beats/min. HR_{work} steadied after 6 minutes of threshing and there was complete recovery of HR after 6 minutes with double operators and 8 minutes with single operator. The increase in HR/kg of grain threshed was found to be 146.4 ± 4.4 and 76.0 ± 4.1 in case of single and double operators respectively; a significant reduction of 48 %. The workload decreased by 13.5 % with double operators but was still higher than the allowable limit of 35 % of $VO_{2\ max}$. The energy expenditure rate (ERR) was 18.9 ± 0.4 kJ/min with single operator and reduced to 16.6 ± 0.3 kJ/min with double operators. The total cardiac cost of work (TCCW) and physiological cost of work (PCW) reduced by 19.84 and 20 % with double operators. No significant variation of blood lactate accumulation between single and double operators was observed. The pedal force required was 232.3 ± 7.0 N and 199.7 ± 5.8 N in case of single operator and double operators respectively but was higher than the mean leg strength of the women of the eastern region of India. Higher pedal force application with double operators increased the number strokes/min (96/min) leading to a 51.15 % increase in output capacity of the thresher per hour per person. An increase of length of the pedal by 2 cm was suggested to reduce the force requirement. The length of the threshing drum can be reduced from 60.5 cm to 40 cm to be used by single operator or it can be increased to 75 cm to comfortably accommodate two persons.

Keywords: Ergonomics, farmwomen, pedal thresher, pedal force, India

1. INTRODUCTION

Rice is one of the important crops of the world and is grown between latitudes 45^0N and 40^0S. In India, paddy occupies about 44 million hectares, which is nearly 40 per cent of the total cereals. India with highest area under the crop is the second largest producer of rice in the world after China but ranks 35th with respect to its productivity. More than 90 per cent of the world's production of rice comes from China and India. Rice is cultivated in almost all the states of India but most of its cultivation is concentrated in the river valleys, deltas of rivers and coastal plains. The main rice producing states are Tamil Nadu, West Bengal, Andhra Pradesh, Bihar, Punjab, Orissa, Uttar Pradesh, Karnataka, Assam and Maharashtra. Paddy is the major crop of eastern Indian states like Orissa, West Bengal and Assam covering an area of 30 % of total cultivated land under paddy in India (Annon, 2001). These states are not so advanced agriculturally like some northern and southern states of India where paddy threshing is completely mechanized. Threshing consumes 25 % of the total energy utilized in

paddy cultivation (Kathrivel and Sivakumar, 2003). Bullock treading and beating of paddy bundle on wooden or stone platform are the two methods farmers still practice in these states although it has low output, higher grain damage and involved more drudgery to the farmers. The heart rate and oxygen consumption rate required for paddy threshing by beating the crop on stones or wooden block were 135.8 beats/min and 0.920 l/min (Nag and Dutta, 1980) and 132 beats/min and 1.01 l/min (Karunanithi and Tajuddin, 2003). The energy consumption is 17-21.5 kJ/min that can be termed as a 'heavy' work as proposed by Nag and Nag (2004). Paddy threshing by pedal thresher and hold on type electric motor operated threshers are gaining popularity among the farmers of these states. At present, there are about 1 million manually operated threshers working in the states of Orissa, West Bengal and Assam with Orissa has the highest number (0.69 million). Compared to this the population of power paddy thresher in Orissa, West Bengal and Assam is only13, 400 (Seventeenth Livestock Census, 2003). Since, 57.7 % of the cultivated land is under the category of small and marginal farmers (Agricultural Statistics at a Glance. 2004), their threshing requirement is less and can be met with a low capacity thresher. Moreover, the economic condition does not permit to own a power thresher (hold on type) costing about Rs.13,200 (334 US $) whereas the pedal thresher costs Rs.4000 (101 US$). Limited requirement, low cost of the pedal thresher and erratic electric supply in the rural areas create a huge potential for large scale adoption of pedal thresher in the eastern states of India.

Pedal threshing requires both leg and hand coordination. During threshing, pedal operation is continuous, one leg on the pedal and the other leg on the ground. In addition to that, the operator keeps on spreading the crop bundle on the threshing drum so that ear heads get detached. This requires suitable hand orientation to keep the crop spreading. Further, the operator needs to adjust the bodyweight between his two legs to maintain a static position. The operator has to exert leg force on the pedal on its downward movement and has to lift the leg when the pedal moves upward so that the retardation of the pedal by the weight of the leg is less. However, small retardation cannot be avoided, as the pedal movement is very fast. Separation of grain from the ear head is faster at higher peripheral speed of the threshing drum that requires application of more force at the pedal. If the weight of the leg alone is not sufficient to apply the required force, the operator has to move the entire torso forward to shift the bodyweight on the leg. This happened in the downward movement of the pedal and is followed by a backward movement of the torso when the pedal moves upward. The body discomfort is induced not only by muscle movement but also by the effort to maintain static body posture while operating the thresher. This makes pedal threshing a complex work and its ergonomics need to be studied.

Studies on pedal thresher by Nag and Dutta (1980), Annon. (2004), and Nag and Nag (2004) have been limited to only assessment of change in heart rate and oxygen consumption rate. The physiological cost involved in threshing has been expressed in term of energy expenditure rate. All the above studies have been conducted using a single operator whereas pedal threshing using two operators has not been explored.
Since, women constitute a major task force in agricultural operations in India and eastern India in particular, it becomes necessary to study the ergonomics of women operators involved in pedal paddy threshing with single and double operators and to suggest modifications for further reduction of human drudgery.

2. MATERIALS AND METHODS

The ergonomical evaluation of pedal thresher was conducted with female agricultural operators of the farm of Orissa University of Agriculture and Technology, Bhubaneswar, India. The pedal thresher was operated with single and double operators for 20 minutes for paddy from 800 to 1200 h in the month of December. One person was engaged for supplying the crop bundle to the operators. The ambient temperature and relative humidity during experiments period were 20.6 ± 0.75 ^{0}C and 45 ± 6.8 % respectively. At the end of each experiment, the subjects were given 30 minutes rest so that all the physiological parameters regained to their resting level. The detail specification of the thresher is given in Table 1.

Table 1. Salient specifications of the thresher

Sl No.	Specifications	Dimension
1	Length of the threshing drum, cm	60.5
2	Diameter of the threshing drum, cm	43
3	Number of slats	12
4	No of wire loops/slats	12
5	Height of the wire loop, cm	6.5
6	Feeding height, cm	75
7	Length of the pedal, cm	44
8	Gear ratio (driver: driven)	1:4

2.1 Selection of Subjects

The subjects selected were in the age group of 18-45 years because they usually attain their highest strength level between 20-45 years (Mc Ardle et al., 2001) and were chosen in such a way that the physical characteristics lie between the 5th and 95th percentile values of the female operators of eastern India. The details of the physical measurements of these subjects are placed in table 2. All the subjects were right handed.

Table 2. Anthropometric data of the female workers (N=15)

Sl No.	Body dimension	Female subjects of West Bengal (Tewari et al., 2007)			Female subjects of Orissa (Satapathy and Mohanty, 2005)			Female subjects under study		
		5th	Mean	95th	5th	Mean	95th	5th	Mean	95th
1	Height, cm	141	150	159	142	152	161	140	152	165
2	Weight, kg	34	43	55	34	44	54	35	52	56
3	Elbow height, cm	90	96	103	88	96	104	90	97	103
4	Olecranon height, cm	85	91	98	86	94	101	89	95	106
5	Illiocrystale height, cm	83	89	97	80	88	96	79	91	103
6	Illiospinal height, cm	79	87	94	75	83	90	77	85	97
7	Knee height, cm	38	42	46	37	44	50	39	45	51
8	Arm reach from wall, cm	-	-	-	68	77	85	70	78	87
9	Right foot length, N	115	129	143	41	164	288	45	170	295

2.2 Calibration of the Subjects

The subjects were calibrated in the laboratory with a treadmill to determine their maximum sustainable heart rate (HR_{max}) and oxygen consumption rate ($VO_{2\ max}$). The resting heart rate (HR_{rest}), oxygen consumption rate at rest ($VO_{2\ rest}$) and the blood pressure were measured at rest and 15 minute prior to any experiment.

2.3 Measurement of HR, OCR, Blood Pressure and EER

The HR_{work} and the OCR ($VO_{2\ work}$) was measured between 6^{th} to 20^{th} minute of work of each subject as it is considered that the heart rate gets stable after $3\text{-}5^{th}$ minute of the work (Astrand and Rodahl, 1977). The average HR and OCR were taken as representative value for each subject for the working duration. The HR was measured by polar heart rate monitor (Model S-810) of Polar make with an accuracy of ± 1 beat/min. The polar transmitter detects the HR and transmits it to the wrist receiver. Twenty observations were taken between $6\text{-}20^{th}$ minutes and the average was taken as the representative HR.

The OCR was measured by Metamax – II having volume transducer, oxygen and CO_2 analyzer, temperature and pressure sensors. The accuracy of the oxygen analyzer is 0.1 % by volume. Twenty observations were taken between $6\text{-}20^{th}$ minutes and the average was taken as the representative OCR.

The blood pressure was measured by a sphygmomanometer (Novaphon-300). The energy expenditure rate was measured by multiplying the OCR (l/min) with 20.93 kJ (1 litre O_2 = 20.93 kJ). The increase in heart rate per kg of grain threshed was determined by the following formula (Solanki et al., 2006):

$$\Delta HRKG = [\Delta HR / C].60 \quad \text{---------- (1)}$$

Where,

Δ HRKG = Increase HR/kg of grain threshed, beats/kg

ΔHR = (Mean working HR – Resting HR), beats/min

C= Capacity of the thresher, kg/h

2.4 Measurement of Blood Lactate Accumulation

The blood lactate accumulation (BLA) of each female subject was measured with the help of a digital blood lactate analyzer before the trial and just after completion of the trial. Before drawing blood from the finger strips the workers were asked to wash their hand with soap and their hands were dried. The calibration strip of blood lactate analyzer was inserted into the strip inlet as a result the function number appeared on display. The function number was checked with the number printed on the box. The calibration strip was removed and stored for future use. A test strip was inserted into the strip inlet to confirm the display of the function number and the last measured test result alternately. A drop of blood was collected with the

help of a lancing device. The blood was drawn automatically into the strip's reaction space and the reading was recorded (Fig. 1)

Figure1. Measurement of blood lactate accumulation by digital blood lactate analyzer

2.5 Measurement of Pedal Force

The effort required for pedaling operation was measured using a universal 'S' type Novatech load cell (F 256) with 40 kg capacity and 1 % accuracy. The load cell was mounted in the foot pedal of the thresher and the worker applied the foot force over the load cell. The applied force is displayed in the TR-100 transducer read out which is a microprocessor based portable instrument. Twenty observations were taken during the threshing operation and the average was considered as the representative pedal force for an experiment (Fig. 2).

Figure 2. Measurement of applied force on the pedal of the thresher by Novatech load cell

2.6 Physiological Cost of Work

Circulatory stress was evaluated from the cardiac cost of work and cardiac cost of recovery. The cardiac cost of recovery is the total number of heartbeats above the resting level occurring between the end of the work and return to the resting state (Saha, 1976). Following formulae were used to calculate the total cardiac cost of work (TCCW) and physiological cost of work (PCW) (Singh et al., 2007).

$CCW = \Delta HR \cdot t_A$ ---------- (2)

Where,
CCW = Cardiac cost of work
Δ HR = Mean working heart rate – Mean resting heart rate
t_A = duration of activity

$CCR = (AHR_{recovery} - AHR_{rest}) \cdot t_R$ ---------- (3)

Where,
CCR = Cardiac cost of recovery
$AHR_{recovery}$ = Average recovery HR
AHR_{rest} = Average resting HR
t_R = duration of recovery

$TCCW = CCW + CCR$ ---------- (4)

Where,
TCCW = Total cardiac cost of work

$PCW = TCCW/t_A$ ---------- (5)

Where,
PCW = physiological cost of work

2.7 Overall Discomfort Rating

Overall discomfort rating (ODR) was measured on a 10-point visual analogue scale (0- no discomfort, 10-extreme discomfort) that is an adoption of a technique developed by Corlett and Bishop (1976). A scale of 70 cm length was fabricated having 0 to 10 digit marked on it equidistantly. A movable pointer was provided to indicate the rating. At the end of each trial, the subjects were asked to indicate their overall discomfort rating on the scale.

2.8 Statistical Analysis

In case of two subjects operating the thresher simultaneously, the mean values of the measured parameters of the two subjects were taken as representative value for the experiment. The mean data for single and double operators were compared by two-sample t-test assuming unequal variances. Total sample size was 15.

3. RESULTS AND DISCUSSION

3.1 Physical and Physiological Characteristics of Female Subjects

The mean resting heart rate of the subjects was found to be 70.3 beats/min with a range of 65 - 75 beats/min and the corresponding mean OCR was 0.19 l/min. The maximum heart rate was in the range of 176 – 200 beats/min with a mean value of 188.2 beats/min. The mean $VO_{2\ max}$ was observed to be 1.70 l/min. In general, it was observed that the $VO_{2\ max}$ of female decreased with increase in age. Similar results of $VO_{2\ max}$ of Indian female subjects were also reported earlier (Nag, et al., 1988; Gite, 1996; Vidhu, 2001). The mean blood pressure of the subjects was 111 mm Hg / 79 mm Hg which is normal in Indian women. The mean body mass index (BMI) was 22.32 kg/m^2 with the range as 20.5 – 23.25 kg/m^2 that indicated that all the subjects were in normal health as per the classification given by Garrow (1987).

Table 3. Physical and physiological characteristics of the subjects (N=15)

Physical and physiological characteristics	Range	Mean	Std. Deviation
Age, Years	18 - 44	31.1	8.06
Weight, Kg	45 - 59	51.7	4.91
Height, cm	142.1 – 162.9	152.3	7.61
HR_{rest}, beats/min	65 - 76	70.3	3.17
HR_{max}, beats/ min	176 - 200	188.2	7.27
$VO_{2\ rest}$, l/min	0.16 – 0.24	0.19	0.02
$VO_{2\ max}$, l/min	1.56 – 1.81	1.7	0.08
Blood pressure (Sys/Dias), mmHg/mmHg	100/72-122/86	111 / 79	6.88 / 3.28
BSA, m^2	1.37 – 1.69	1.52	0.12
BMI, kg/m^2	20.5 – 23.25	22.32	0.82
Blood Lactate Accumulation, mM/l of blood	0.9-1.3	1.2	0.08

3.2 Ergonomic Evaluation of Pedal Thresher

Table 5 shows the ergonomics of the women in 20 minutes of operation of pedal paddy thresher. Physiological responses parameters show the distress symptoms. Any departure from the equilibrium of the physiological responses quantifies the distress level for any work. The change in physiological responses depends on how much the subject exerts to carry out a work.

3.2.1 Heart Rate

The working heart rate (HR_{work}) of the subjects when the pedal thresher was operated with single operator ranged from 125.8 to 140 beats/min with a mean value of 135.9 ± 1.3 beats/min. The corresponding values with two operators were 119 to 124.6 and 121.2 ± 1.0 beats/min respectively. This showed a significant ($P<0.01$) decrease of mean HR_{work} by 10.82 %. The mean work pulse (Δ HR) with single operator was observed to be 65.7 ± 0.9 beats/min but reduced to 51.5 ± 1.6 beats/min with two operators; a reduction of Δ HR by

21.5 %. Work pulse of 40 beats/min is the allowable limit for sustained working (Kroemer et al., 1997). This is also termed as limit of continuous performance (LCP). Mean HR_{work} of 140.8 beats/min in pedal threshing with single operator has been reported by Nag and Dutta (1980). Nag et al. (1980) reported a heart rate of 153.3 beats/min in threshing by pedal thresher. In another study (Annon, 2004), the mean HR_{work} and the Δ HR were reported to be 143 and 77 beats/min respectively. Agarwal et al. (2005) while studying the effect of range of pedal movement that subsequently reflected on the knee angle movement reported a HR_{work} ranging from 129.3 to 148.3 beats/min with a single person operating the thresher. In the present study, with single and double operators and studies conducted earlier, the work pulse was more than the LCP of 40 beats/min; hence, modification in the thresher is required.

The trend in the rise of HR_{work} has been shown in Fig. 3. The HR_{work} increased till six minutes of threshing in both cases and stabilized thereafter. The peak HRs reached were 138 and 125 beats/min with single and double operators respectively. The HR recovered to its pre-work stage after 8 minutes of rest in case of single operator whereas it was 6 minutes in case of double operators. This showed that a rest pause of 8 minutes could be given to the operator before restarting the job. However, more rest may be needed to subside the muscular fatigue developed during the threshing operation. In between the threshing, 30 minutes rest was given to the operators. Yadav and Pund (2007) reported a rest pause of 14 minutes while working with a manual weeder to restart the work where the peak HR of the subjects ranged from 142 – 150 beats/min.

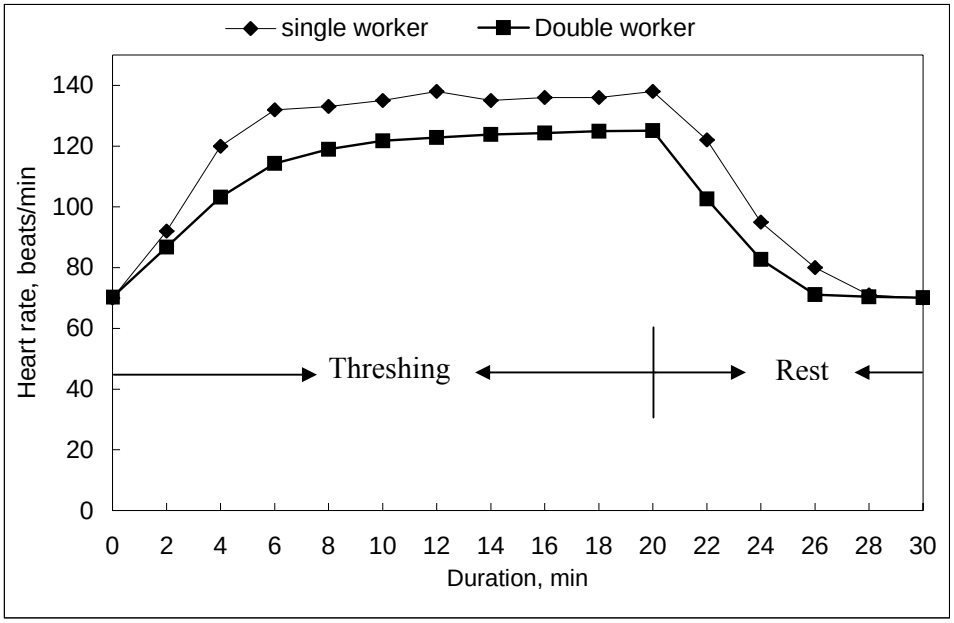

Figure 3. Mean heart rate and recovery pattern at different duration of threshing operation

The increase in HR per kg of grain threshed was compared to assess the extent of drudgery, as HR is a major parameter in quantification of drudgery (Astrand and Rodahl, 1977). It was observed that the ΔHR per kg of grain threshed was in the range of 122-181 beats/kg with

single operator with a mean of 146.4 ± 4.4 beats/kg. However, with double operators, there was considerable reduction in ΔHR per kg of grain threshed to the tune of 76.0 ± 4.1 beats/kg; a reduction of 48 % (P<0.01). With double operators the ΔHR decreased but the output of the thresher increased which resulted in a decrease of ΔHR/kg of grain threshed.

3.2.2 Oxygen Consumption Rate (OCR)

The OCR was found to be 0.91 ± 0.02 and 0.79 ± 0.02 l/min respectively for single and double operators. T-test showed a significant decrease (13.57 %) in OCR with double operators (P<0.01). The OCR required in case of single operator was less in the study than 1.31 l/ min reported by Nag and Dutta (1980), 1.407 l/min by Nag et al. (1980) and 0.93 l/min by (Annon, 2004). The workload that is OCR as percentage of $VO_{2\ max}$ was 53.3 ± 1.1 and 46.97 ± 1.26 % in case of single and double operators respectively. The reduction in workload with two operators was 11.79 % and was found significant (P<0.01). The acceptable workload for Indian workers is 35 % of the $VO_{2\ max}$ (Saha et al., 1978). However, the workload in this study was above the allowable workload both with single operator and double operators. Gite and Singh (1997) reported that an OCR of 0.63 l/min and a HR of 105 beats/min for women was considered acceptable for sustained work of 8 hours with intermittent rests. The HR_{work} and OCR with two operators was 121.2 beats/min and 0.79 l/min and need to be reduced to the acceptable limit with suitable modifications.

3.2.3 Energy Expenditure Rate

Energy expenditure rate (ERR) with single operator operating the pedal thresher was observed to be 18.9 ± 0.4 kJ/min whereas with two operators it decreased to 16.6 ± 0.3 kJ/min (12.2 %). ERR of 21-34 kJ/min in pedal paddy threshing has been reported by Nag and Nag (2004). Nag and Dutta (1980) has also reported an ERR of 27.56 kJ/min by single operator. Nag et al. (1980) conducted an extensive study on Indian agricultural operators to assess the occupational workload on the basis of cardio-respiratory responses and individual capacity to perform work. They classified the work intensity of agricultural operations in terms of 'light', 'moderate', 'heavy' and 'extremely heavy' which corresponds to energy cost values, OCR and percentage of VO_2 max (table 4). Accordingly, pedal threshing of paddy with single operator can be put in the 'heavy' category but with two operators, it is a 'moderate' work.

The total cardiac cost of work (TCCW) was found to be 1391 and 1115 in case of single and double operators respectively. With double operators, the TCCW reduced by 19.84 %. The corresponding physiological cost of work (PCW) was 70 and 56 in single and double operators respectively.

Table 4. Categorization of the agricultural work (Nag et al., 1980)

Variables	Light	Moderate	Heavy	Extremely Heavy
VO2 max (%)	<25%	Up to 50%	Up to 75%	Above 75%
O2 consumption, (l/min)	0-0.435	0.436-0.870	0.871-1.305	>1.306
Energy cost (kJ/min)	<9.10	9.11-18.15	18.16-27.22	>27.23

3.2.4 Blood Lactate Accumulation

Blood lactate analysis result showed blood lactate accumulation (BLA) of 3.08 ± 0.4 and 3.0 ± 0.4 mM/l of blood when the thresher was operated with single and two operators respectively. The BLA increased by 156 and 150 % in case of single and double operators respectively over the initial BLA 1.2 mM/l of blood at rest condition. There was no significant variation of BLA between single and double operators. BLA is measure to know the muscular fatigue. In both the modes of operation of the thresher, the blood lactate level was lower than the point of onset of blood lactate accumulation (OBLA) that begins when BLA is 4.0 mM/l of blood. Mc Adrle et al. (2000) reported that OBLA took place when the workload was 55-65 % of the $VO_{2\ max}$, but in the study the workloads were 53.3 ± 1.1 and 46.97 ± 1.3 % of the $VO_{2\ max}$ in case of single and double operators respectively.

3.2.5 Pedal Force and Strokes

The pedal force exerted by the single operator was 232.3 ± 7.0 N. It reduced to 199.7 ± 5.8 N when two operators were engaged and the reduction in pedal force was significant at 5 % level of significance. The reduction of pedal force was only 14 % because each operator tried to exert leg force as per her capability. This resulted in an increase in number of strokes to 96/min with two operators compared to 75 strokes/min with single operator; a significant ($P<0.01$) increase of 28 %. However, the force requirement was still higher than the mean leg strength of 164.2 N of the women operators in Orissa. The leg strengths of women vary from region to region in India and are dependent on the bodyweight of the operators. Tewari et al. (2007) found the mean leg strength of women in West Bengal state of India as 129 N. Agrawal et al. (2007) reported leg strength of 152.8 N (5^{th} percentile) for women in Central India. This study showed that the leg strength required to operate the thresher was more than the leg strengths of women operators in different parts of India and needs modifications.

3.2.6 Overall Discomfort Rating

Overall discomfort rating (ODR) was 6.8 ± 0.14 and 5.9 ± 0.20 with single and double operators respectively. ODR decreased significantly ($P<0.01$) by 13.24 % with two operators. ODR of 5.7 has been reported by Agricultural equipment and technology. (2004). The body parts with maximum discomfort as expressed by the operators were right upper leg, lower back, right lower leg, right foot, right upper arm and right in the descending order. The body parts discomfort was mainly due to the pedal operation, holding the crop bundle on the threshing drum and effort to maintain a static posture while pedaling and feeding the crop. Similar observations were also made by Dewangan (2007) while comparing the ergonomics of three designs of pedal threshers for paddy.

3.2.7 Output Capacity

The capacity of the thresher increased by 51.15 % ($P<0.01$) from 26.92 kg h^{-1} $person^{-1}$ with single operator to 40.69 kg h^{-1} $person^{-1}$ with double operators. Increase in capacity with two operators was because of quick threshing due to increased in number of strokes/min (96/ min) from 75/min in case of single operator that resulted in more peripheral speed of the threshing drum.

Table 5. Data on ergonomic evaluation of the thresher with single and double operators

Sl No	Parameter	With single operator		With double operators		% decrease	t_{cal}
		Range	Mean	Range	Mean		
1	HR_{work}, beats/min	125.8-140	135.9 ±1.3#	119-124.6	121.2 ± 1.0	10.82	8.66 **
2	Work pulse (Δ HR), beats/min	59.8 –70.8	65.7 ± 0.9	45.3-59.5	51.6 ± 1.6	21.50	8.01 **
3	Increase in HR/kg of grain threshed	122-181	146.4 ±4.4	47.53-105	76.0 ± 4.1	48.00	11.76**
4	OCR, l/min	0.78 –1.0	0.91 ± 0.02	0.72-0.92	0.79 ± 0.02	13.57	5.52 **
5	Work Load (WL), % of $VO_{2\ max}$	45.0-58.8	53.3 ± 1.1	40.2-57.9	46.97 ± 1.3	11.79	3.65 **
6	EER, kJ/min	16.3 –21.2	18.9 ± 0.4	15.1-19.3	16.6 ± 0.31	12.20	4.66 **
7	Total cardiac cost of work (TCCW)	-	1391.0	-	1115.0	19.84	-
8	Physiological cost of work (PCW)	-	70.0	-	56.0	20.00	-
9	Blood Lactate Accumulation (BLA), mM/l of blood	2.3 - 3.8	3.08 ± 0.4	2.3 –3.8	3.0 ± 0.4	2.60	0.57 ns
10	Pedal force required, N	197-279.5	232.3 ± 7.0	162-233.5	199.7 ± 5.8	14.0	3.54 *
11	Overall Discomfort Rating	6.0-7.5	6.8 ± 0.14	5.0-7.0	5.9 ± 0.20	13.24	4.11 **
12	No. of pedal strokes/min	68-86	75 ± 2	90-103	96 ± 1.01	28.00 ↑	9.13 **
13	Output Capacity, kg h^{-1} $person^{-1}$	22.1-32.3	26.9 ± 0.74	34.4-52.0	40.69 ± 1.4	51.15 ↑	9.02 **

#: Standard Error of Mean (N=15), ↑: Increase with two operators over single operator, ** Significant at 1 % and * significant at 5% level of significance.

3.3 Modifications Suggested

The feedback of the operators participated in the study revealed that the length of the threshing drum (60.5 cm) was not sufficient to accommodate two operators. Each operator needed a space of 35-40 cm of the threshing drum for spreading and rotating the crop bundle for effective threshing. The drum length can be increased by 10 cm for two operators or can be reduced to 40 cm to be used by a single operator. The feeding height platform was 75 cm. As per Tewari et al. (2007), the feeding height should be at 5^{th} percentile of illiocrystale height of the operator. The 5^{th} percentile illiocrystale height of the women operators of state of Orissa is 80 cm while that is 83 cm in women of West Bengal (table 2). Hence, the feeding platform should be increased by 5 cm to make it 80 cm from the ground level to prevent bending while operating the thresher. The leg strength required to operate the thresher was still higher than the mean leg strength of the women operators. If the force on the pedal is reduced, then the number of strokes per minute will reduce leading to a decrease in peripheral

velocity of the threshing drum. So, the pedal arm of the thresher could be increased by 2 cm so that less pedal force is required to obtain the desired number of strokes. The operators also observed that while threshing, the detached grains sometimes hit the face and suggested that a safety cover should be provided over the rotating drum.

4. CONCLUSION

The ergonomic evaluation of pedal paddy thresher revealed that using two operators the physiological responses and physiological cost of work reduced significantly. The HR_{work}, ΔHR, OCR, workload (% of $VO_{2\ max}$), ERR and physiological cost of work reduced from 135.9 to 121.2 beats/min, 0.91 to 0.79 beats/min, 53.3 to 46.97 %, 18.9 to 16.6 kJ/min and 70 to 56 respectively when two operators were used to operate the thresher instead of one. However, the ΔHR (work pulse) was still higher than the limit of continuous performance (LCP) of 40 beats/min. The increase in HR per kg of grain threshed reduced by 48 % contrary to the reduction of HR_{work} by 10.82 %. The pedal force reduced from 232.3 N with single operator to 199.7 N with double operators; a reduction of 14 %. This seemed less when two operators were engaged. But more pedal force with two operators could increase the number of strokes from 75 to 96/min which resulted in increased peripheral speed of the thresher and the capacity increased from 26.9 to 40.69 kg h^{-1} $person^{-1}$; an increase of 51.15 %. It is advisable to operate the thresher with two operators. The pedal force exerted by individual operator was still higher than the mean leg strength of the women operators of eastern India (Orissa and West Bengal). It is suggested that the pedal arm of the thresher should be increased to reduce the pedal force requirement to obtain desired number of strokes per minute. It was further suggested that the feeding height should be increased from 75 cm to 80 cm to prevent bending by the operator while feeding the crop on to the threshing drum.

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