J. Human Ergol., **19**: 31–40, 1990
Center for Academic Publications Japan. Printed in Japan.

BODY DIMENSIONS OF INDIAN HOUSEWIVES

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Anthropometric dimensions of Indian housewives have been measured from the viewpoint of architectural and product design ergonomics. Altogether, 79 different body dimensions were measured on 147 urban housewives of age range varying between 21 to 56 years. The average stature and weight of Indian housewives as observed in this study were 153.2 cm (SD±5.7) and 55.1 kg (SD±9.7), respectively. Average values along with 5th and 95th percentile values for all measurements have been determined. Values were compared with other Indian studies. A correlation between the body height, weight, and other measurements were obtained with the help of a PDP 11/23 microcomputer. Based on the existing data ratio scale relationships between the body height and other measurements of Indian women were determined.

An anthropometric data, pack is presently lacking; therefore, the findings herein can be used while determining household workplace layouts, evaluating area specifications, determining work-surface heights, clearances, reach, *etc*. A similar study on a larger population size for Indian women has been suggested for establishing national standards.

Human body measurements have been important since the beginning of human evolution. The idea that the physical size of a person is somehow related to his ability to function is so old that the concept is often neglected in everyday thought. However, since 1912, when the Gilbreths conducted their classic studies on the use of body kinematics and dimensions to improve work output, many systematic studies of human body dimensions have been carried out for various purposes related to commercial products, medical records, and military selection (REBUCK *et al.*, 1975).

On account of the high cost and practical difficulty of conducting a truly representative national survey, most anthropometric descriptions on a national

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Received for publication February 19, 1990.

scale have come from military rather than civilian resources. Several attempts have also been made to present the body characteristics of civilian population groups in terms of anthropometric measurements (BASTEW, 1982; PHEASANT, 1980; PIETERS *et al.*, 1977; PUSHPAMMA *et al.*, 1981; RAJA and SINGH, 1980). But most of those studies were aimed at providing an indirect assessment of skeletal muscle, frame size, body fat, and state of nutrition. There is also some documented data on the body type and dimensions of the Indian working population. NAG (1986) studied the anthropometric parameters of women working in small-scale industries while RAY *et al.* (1983) reported on the anthropometry of Indian female nurses. EVELETH and TANNER (1976) in their publication on the 'World-wide variation in human growth' have mentioned the body dimensions of Indian males and females. SAHA *et al.* (1968, 1969) studied the static body dimensions of a section of women working in factories. However, those body measurements were particularly applicable to the design of sitting arrangements and appropriate workplace, except the study of RAY *et al.*, in which 64 different body dimensions were measured on 132 female hospital nurses. The latter has importance from the viewpoint of designing hospital products and hospital work environment design.

The Bureau of Indian Standards (earlier ISI) has published the anthropometric measurements of children. But there are hardly any full-scale anthropometric studies conducted on the Indian women population. We do not have Indian standards on anthropometry of adult women and men. Indian architects and product designers blatantly rely on Western Standards (U. S. A. or U. K.) by using a conversion factor of 0.9, which is obtained by dividing the mean statures of the two sample populations. This is highly erroneous because of three basic facts: 1) body dimensions are highly affected by several factors such as climatic condition, ethnic diversity, nutritional status, occupation, *etc.*; 2) the factor would differ in the case of various body measurements; 3) the factor is different for different percentile values.

Under the auspices of the University Grants Commission (U. G. C.) India, a study was undertaken to ergonomically evaluate household tasks as they are traditionally performed by housewives in the metropolitan city of Bombay. At the initiation of the project it was thought pertinent to analyze the anthropometric characteristics of the homemaker population. Indian women are actively engaged as housewives between the ages of 21 and 50 years. They have unique sitting, squatting, as well as standing postures during household activities compared to Westerners, whose domestic task performance is dependent on the chair-bench complex. Hence it becomes necessary to study the anthropometric parameters of a large cross section of ages and in sufficient detail with the objective of providing as complete a picture as possible of the diversity in size and shape among women. The information could be resourcefully utilized as important reference data, in planning ergonomic workspace layouts, in evaluating area specifications, in determining work-surface heights, clearances, reach dimensions zones of comfortable reach, as well as in assessing work methods, techniques, and postural demands during work performance. This would enhance operability, safety, convenience, and comfort while performing domestic tasks besides augmenting work efficiency and would reduce 'rework' costs. In the domestic working environment there is also wider scope for using the data in the design of functional kitchen gadgets, appliances, and a gamut of tools.

SUBJECTS, MATERIALS AND METHODS

Subjects. Subjects included 147 urban housewives of age range between 21 and 56 years, without any physical deformity or complaints of chronic ailments, who resided in the greater area of Bombay. Fifty percent of the sample population were full-time homemakers while the remainder were employed in an educational institute. Thirty-five percent of the sample were Maharashtrians and 19% were Gujaratis. There were minor representatives of every other Indian community who had settled since varied periods in Bombay city.

It was virtually impossible, and hence no attempt was made, to select and measure an ideally stratified random sample. The most satisfactory practical alternative, suggested by HERTZBERG *et al.* (1950), seems to be a sample selected by measuring all the available housewives of different types at large number in different locations. But due to the time limit and financial restrictions, the sample size in this study was restricted to 150, out of which three were later discarded during compilation due to some technical error.

Materials and methods. A standard MARTIN-type anthropometric kit (Siber Hegner Machinery Limited, Switzerland) was used to determine the population of homemakers anthropometrically. Under the conditions of fieldwork, it was a common experience that the collection of subjects took more time than the actual measurements. Hence, besides the basic list (18 measurements) recommended by the International Biological Program (WEINER and LOURIE, 1981), 61 other measurements pertaining to workplace organization and product design were incorporated to carry out a complete anthropometric examination of the sample population. Out of 61 measurements, 4 are related to squatting posture, which is a special cross-legged sitting posture frequently adopted by Indians.

Definition of 61 measurements and measuring techniques were followed as per HERTZBERG *et al.* (1950) and CLAUSER *et al.* (1972). The definition and landmark for four anthropometric measurements in squatting posture are given in Fig. 1.

A team of three workers, properly trained, regularly checked the repeatability of the measurements with each observer, necessarily taking the same set of measurements on the entire sample. Body weight was ascertained using a frequently checked and calibrated bathroom scale whereas the grip strength was measured

Table 1. Statistical results Indian housewives anthropometric measurements.

	Body dimensions	Anthropometric measurements					Correlation coefficient between body weight, stature and different anthropometric measurements significant at 0.1% level		Fractional relationships (f) between different body dimensions (D) and stature (H) of Indian women significant at 0.1% level ($D=f\times H$)
		Mean	SD	CV	Percentile values				
					5th	95th			
1.	Weight	55.1	9.7	17.7	39.5	70.9	1.000	—	0.349
2.	Stature	153.2	5.7	3.7	143.5	162.6	0.449	1.000	—
	Heights								
3.	Nasal root	143.6	5.4	3.8	133.2	152.6	0.442	0.860	0.937
4.	Eye level	142.1	5.3	3.7	133.1	150.9	0.447	0.872	0.928
5.	Supra sternal	125.4	5.0	4.0	116.5	125.0	0.474	0.877	0.818
6.	Bust/nipple	111.6	4.7	4.2	104.2	119.4	0.397	0.808	0.728
7.	Acromion	127.9	5.1	4.0	119.6	136.7	0.496	0.884	0.835
8.	Anterior waist level	92.5	4.0	4.4	85.4	99.7	—	0.663	0.603
9.	Trochanteric	80.8	4.0	4.8	74.4	86.7	—	0.567	0.527
10.	Cervicale	131.0	5.3	4.1	121.5	131.0	0.526	0.873	0.855
11.	Buttock	80.5	3.7	4.6	74.2	86.5	0.435	0.760	0.525
12.	Gluteal furrow	71.3	3.8	5.4	64.8	77.6	0.352	0.663	0.464
13.	Elbow	96.1	3.9	4.0	89.4	102.8	0.474	0.786	0.627
14.	Wrist	75.1	3.3	4.4	70.0	80.7	—	—	0.490
15.	Knuckle	68.1	3.1	4.6	62.6	73.6	—	—	0.444
16.	Tibeal	43.9	4.7	10.7	38.3	50.4	—	—	—
17.	Ankle	11.0	1.0	8.8	9.4	13.1	—	—	—
18.	Lateral malleolus	6.6	0.7	10.0	5.7	7.8	—	—	—
	Grasps and reaches								
19.	Max. arm reach	79.2	4.2	5.3	72.5	86.8	0.424	0.603	0.515
20.	Functional arm reach	71.9	4.1	5.7	65.1	79.2	0.376	0.534	0.468
21.	Overhead grasp	188.9	8.3	4.4	174.1	201.6	0.417	0.790	1.232
22.	Total arm span	156.5	7.6	4.9	144.3	169.3	0.403	0.781	1.020

Table 1. (Continued).

	Body dimensions	Anthropometric measurements					Correlation coefficient between body weight, stature and different anthropometric measurements significant at 0.1% level		Fractional relationships (*f*) between different body dimensions (*D*) and stature (*H*) of Indian women significant at 0.1% level ($D=f\times H$)
		Mean	SD	CV	Percentile values				
					5th	95th			
	Sitting measurements								
23.	Sitting height	78.1	3.7	4.7	71.3	84.0	0.460	0.686	0.509
24.	Mid-shoulder height	53.1	3.3	6.3	47.3	58.3	0.424	0.589	0.345
25.	Upper lumbar height	20.0	3.0	14.9	15.7	26.0	—	—	—
26.	Lower lumbar height	10.7	1.9	18.0	7.7	14.2	—	—	—
27.	Elbow rest height	20.9	2.9	13.9	16.3	26.0	—	—	—
28.	Thigh clearance height	12.4	1.5	12.4	9.7	15.0	—	—	—
29.	Eye level height	67.4	3.7	5.5	60.5	73.9	0.473	0.689	0.439
30.	Popleteal height	37.2	3.2	8.7	32.0	42.1	—	—	—
31.	Buttock-knee length	52.3	3.1	5.9	47.4	57.2	—	—	0.340
32.	Buttock-popliteal height	43.3	2.9	6.8	38.4	47.9	—	—	—
33.	Thigh-thigh length	28.9	3.3	11.5	22.9	34.1	0.674	—	—
	Squatting measurement								
34.	Squatting height	77.1	3.6	4.7	70.7	82.8	0.418	0.667	0.503
35.	Knee height (max.)	21.5	2.9	13.3	16.3	25.6	—	—	—
36.	Knee-knee length	55.9	4.9	8.7	47.0	65.0	—	—	0.363
37.	Buttock-knee length	50.3	3.7	7.3	43.9	56.5	0.510	0.442	0.327
	Breadths (standing)								
38.	Biacromion	30.3	2.4	8.1	26.3	34.7	0.450	0.438	
39.	Bideltoid	38.5	3.2	8.3	32.9	43.7	0.784	—	
40.	Elbow-elbow	39.4	3.6	9.1	34.9	44.9	0.830	—	
41.	Chest exp.	26.1	2.7	10.4	22.1	30.8	0.635	—	
42.	Waist anterior	26.2	4.0	15.2	19.2	32.4	0.538	—	
43.	Hip	31.6	2.9	9.1	27.3	36.1	0.600	0.352	
44.	Head	14.1	0.8	5.6	12.8	15.4	—	—	

Table 1. (Continued).

Body dimensions	Anthropometric measurements					Correlation coefficient between body weight, stature and different anthropometric measurements significant at 0.1% level		Fractional relationships (f) between different body dimensions (D) and stature (H) of Indian women significant at 0.1% level ($D=f\times H$)
	Mean	SD	CV	Percentile values				
				5th	95th			
45. Foot	8.8	0.5	6.2	7.8	9.7	—	—	
46. Heel	5.9	0.5	8.8	5.1	6.7	—	—	
47. Biocular	8.7	0.6	6.9	7.9	10.1	—	—	
48. Interocular	3.2	0.6	9.6	2.6	3.7	—	—	
49. Nasal root	1.8	0.2	11.1	1.4	2.1	—	—	
50. Nasal	3.5	0.3	9.2	3.0	4.1	—	—	
51. Ear	3.2	0.3	8.1	2.7	3.6	—	—	
52. Hand breadth at thumb	8.6	0.5	5.4	7.8	9.4	—	—	
53. Hand at metacarple	7.4	0.4	4.8	6.8	8.0	—	—	
54. Chest depth (exp.)	22.1	3.1	13.9	17.0	27.7	0.648	—	
55. Humeral width (right)	8.0	0.8	9.9	6.7	9.1	0.600	—	
56. Radio ulnar width (right)	5.1	0.4	7.7	4.4	5.7	—	—	
57. Femoral width (right)	9.6	1.0	10.4	7.8	11.2	0.604	—	
Lengths								
58. Hand	16.7	0.9	5.1	15.4	18.1			
59. Palm	9.4	0.6	6.0	8.5	10.4			
60. Foot	23.0	1.3	5.5	21.0	25.1			
61. Lip	4.8	0.4	8.8	4.1	5.5			
62. Ear	5.3	0.4	8.3	4.6	6.1			
Circumferences								
63. Head	53.7	1.8	3.3	51.0	56.4	—	—	0.350
64. Neck	32.3	2.8	8.6	27.5	36.9	0.580	—	—
65. Bust	86.7	8.5	9.8	73.4	101.0	0.665	—	0.560
66. Waist	80.1	9.8	12.3	63.8	98.4	0.789	—	0.515
67. Hip	92.2	7.8	8.5	78.8	105.0	0.825	0.321	0.597

Table 1. (Continued).

Body dimensions	Anthropometric measurements					Correlation coefficient between body weight, stature and different anthropometric measurements significant at 0.1% level		Fractional relationships (f) between different body dimensions (D) and stature (H) of Indian women significant at 0.1% level ($D=f\times H$)
	Mean	SD	CV	Percentile values 5th	Percentile values 95th			
68. Calf	31.8	3.8	12.1	24.7	37.8	0.658	—	—
69. Ankle	20.3	2.1	10.3	17.2	24.0	0.531	—	—
70. Biceps (relaxed)	26.2	3.1	12.0	21.1	32.0	0.781	—	—
71. Biceps (flexed)	27.7	3.3	11.9	22.4	33.8	0.609	—	—
72. Forearm (relaxed)	22.5	2.6	11.4	18.2	26.3	0.609	0.336	
73. Wrist (relaxed)	14.8	1.4	9.7	13.0	16.3	—	—	—
74. Nose protrusion	1.7	0.2	13.6	1.3	2.1	—	—	—
75. Lip-lip distance	1.9	0.3	14.9	1.5	2.3	—	—	—
76. Interpupilary distance	6.1	0.3	5.3	5.4	6.6	—	—	—
77. Grip diameter (inside)	4.8	0.4	7.3	4.2	5.3	—	—	—
78. Handgrip strength	25.1	4.2	16.9	17.1	32.2	—	—	—
79. Hand thickness at metacarple	2.3	0.2	9.2	1.9	2.6	—	—	—
Skinfolds								
80. Triceps						0.655	—	
81. Midcalf						0.532	—	
82. Subscapular						0.596	—	
83. Suprailliac						0.542	—	
84. Biceps (Rt.)						0.601	—	

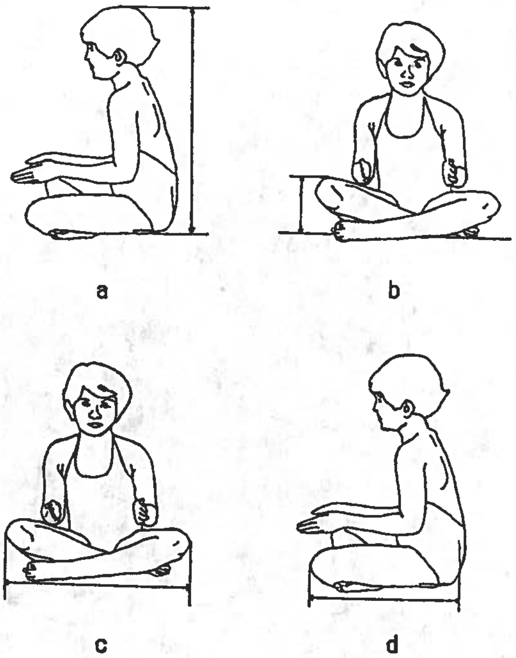

Fig. 1. Four measurements relating to squatting posture frequently adopted in Indians. a. Squatting height: Subject sits erect in a squatting posture, head in a Frankfort plane, upper arms hanging relaxed, forearms and hands extended forward horizontally. With the anthropometer arms firmly touching the scalp, measure the vertical distance from the sitting surface to the top of the head. b. Squatting knee height (Max.): Subject sits erect in a squatting posture as in squatting height. With the help of an anthropometer, measure the vertical distance from the floor to the top of the right or left knee, whichever is maximum. c. Squatting knee-to-knee breadth: Subject sits erect in a squatting posture as in squatting height. With the help of a beam of anthropometer, measure the horizontal distance between the two knees. d. Squatting buttock-knee length: Subject sits erect in a squatting posture as in squatting height and the buttock is touching a wall. With the help of anthropometer, measure the horizontal distance from the wall to the right knee.

using a calibrated grip dynamometer (TKK, Japan). The grip diameter was determined by using a calibrated cone fabricated from a PVC block.

RESULTS AND DISCUSSION

The mean stature and weight of the sample population were 153.2 cm. (SD± 5.7) and 55.1 kg (SD±9.7), respectively. The mean, coefficient of variation (CV), and percentile values of other dimensions are presented in Table 1.

While comparing the data obtained from the present study with works of Nag (1986), Ray *et al.* (1983), and Eveleth and Tanner (1976), it was observed that mean values of stature and other anthropometric heights in the standing, sitting, and squatting positions as well as for the dimensions of hands and feet did not show any striking differences. However, variations were much more in terms of the ranges of each dimension between different observations, which may be due to ethnic variations. As there are no national-level surveys on a wider population, these variations must be considered while designing an ergonomic workplace or tools. In comparison to other studies on Indian population, the present study showed a slightly higher variation ($p > 0.04\%$) over the mean body weight, bideltoid breadth, chest, waist, and calf circumferences.

An attempt was made to determine the relationship between Indian and Sri Lankan female population regarding their body dimensions. A comparison based on mean body dimensions as mentioned by ABEYSEKERA and SHAHNAVAZ (1987) in respect to our study was made. It was observed that there were many similarities of mean body dimensions between these two populations except the body weight, neck, bust, waist, hip, and bicep circumference, which are greater in Indians.

A simple correlation between body weight, stature, and other body dimensions (Table 1) was computed, demonstrating the relationship between selected anthropometric variables. Results are indicative of a definite relationship between weight and sitting thigh lengths, bideltoid elbow and chest breadths. A high correlation (correlation coefficient above 0.321 is significant at 0.1% level) also exists between different standing, sitting, and squatting lengths, total arm span and reaches including maximum arm reach and overhead grasp. Based on the correlation coefficient, fractional relationships between the body height and other body dimensions are presented in Table 1. Although the correlation coefficient between the body weight, stature, and body dimensions was high in many cases, due to the small number of the sample size attempts were not made to establish a simple or multiple regression equation to predict different body dimensions from body weight and stature.

The authors sincerely express their heartfelt thanks to the housewives and other volunteers, without whose kind cooperation the study could not have been conducted. Thanks to the SNDT College of Home Science and Industrial Design Center, Indian Institute of Technology, Bombay, for extending all facilities for conducting the study. Sincere thanks to Ms. N. Atryae and Ms. A. Bhatnagar for assisting as anthropometrists throughout the study. Heartfelt thanks to Mr. N. Sadhu, faculty, IDC, IIT, for statistically analyzing the data. The study was funded by the University Grants Commission, Govt. of India.

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WISNER

ERGONOMICS, 1991, VOL. 34, NO. 1, 103–108

Biomechanical evaluation of lift postures in adult Koli female labourers

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Three lift-postures, back straight and knees bent, back bent and knees straight and squatting were evaluated biomechanically based on data from 100 Koli female labourers, when lifting loads from the floor to hold them at knee height. The maximum weight was lifted with the back bent and the knees straight which is a posture commonly used by Indian labourers for lifting a load. Squatting (a posture used by Indians for performing household chores) produced the least physical strain in terms of moment and moment ratio (moment per kilogramme of load lifted). Consequently, squatting was found to be the best posture for lifting a load, specifically for the Indian labourers who are accustomed to squatting when working.

1. Introduction

The principle of levers may be used efficiently in defining the forces acting on a body when performing different tasks, considering the human body as a system of bony levers. Also, when the same work can be performed using different postures, calculation of forces can help to identify the 'best' way to perform a given task. The best way being the one that produces the least physical strain on the body, evaluated in terms of moment produced. With this perspective in mind, an attempt has been made to compare biomechanically three postures, (*a*) back straight and knees bent, (*b*) back bent and knees straight, and (*c*) squatting.

2. Methods

On the basis of a pilot survey, a suitable sample size for the study was estimated to be 100 within an accuracy of 5% and a confidence limit of 95·4%, following the statistical method of Boyd *et al.* (1985).

A random sample of 100 adult Koli females, aged 21 to 45 years, was collected from 17 labour encampments situated in different parts of Delhi. Koli is a scheduled caste group of Rajasthan, a desert state in the north-western part of India. Although the traditional occupation of the Koli was agriculture, severe droughts and famines in Rajasthan in the last several decades have compelled the members of the group to migrate to cities and work as construction labourers.

Anthropometric measurements on each subject were taken following the standard techniques of Tanner *et al.* (1969). The mean age of the Koli females was 32·2 years with an average stature of 151·7 cm (SD=5·72 cm) and an average body weight of 42·7 kg (SD=6·52 kg).

Biomechanical efficiency is the capacity of the body to maintain a stable position in a stressful condition. Maintenance of stability involves dynamic flexion and extention of body joints or mechanics of the body segments. To assess the biomechanical efficiency of the body during lifting, three parameters, the maximum load lifted, the moment and the moment ratio (moment per

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kilogramme of the maximum load lifted) were used. The maximum lifting capacity, as defined by Jorgensen and Poulsen (1974), of each subject in all three postures was determined. A load was said to be the 'maximum' when the subject was unable to lift even an additional 0·5 kg of weight. Maximum load was found by trial and error. Starting initially from a load of 12 kg, the initial and final changes of resolution in load were 2 kg and 0·5 kg respectively. Loads were cuboid shaped bricks, weighing 0·5 kg each, of dimensions 7 cm × 5 cm × 3 cm, and put in a basket without handles. Subjects were asked to lift the load from the floor to knee height and to hold it there for one minute. This also facilitated taking photographs. The subjects were encouraged to lift the maximum load, allowing them at least one minute rest between each attempt. Help of a medical practitioner was taken in ascertaining medical fitness of the subjects. Medically unfit subjects were not included in the sample.

The method of Mairiaux *et al.* (1984) was used with minor changes for calculating the moment. In this biomechanical model, the moment about the fourth and fifth lumbar vertebra joint was calculated from the data derived from the subjects anthropometry and photographically recorded trunk postures. The model included in the equation body mass, centre of gravity of various segments, as well as the angles between various segments in a posture. In their study, there was a standard head posture in relation to trunk and the upper limbs were in bilaterally symmetrical positions. In their study it was assumed that the lengths of body segments bear a constant relation to each other, regardless of actual size, and the centres of gravity occupy similar positions in each body segment. Two changes from the basic model were introduced in the present study. Firstly, segmental body lengths were determined indirectly from stature using conversion equations of Roebuck *et al.* (1975), rather than measuring body segmental lengths directly. Secondly, since Mairiaux's method was based upon an upright posture, appropriate modifications were made for calculating moments in the three postures. The moments were calculated about the heel point. The equations used for the calculation of moments ($M1$, $M2$, $M3$) are as follows:

(1) *Back straight and knees bent:*

$$M1 = W1\ L1/2 \text{ Cos } \theta_1 + W2(L1 \text{ Cos } \theta_1 - L2/2 \text{ Cos } \theta_2) + W3(L1 \text{ Cos } \theta_1 - L2 \text{ Cos } \theta_2 + L3/2 \text{ Cos } \theta_3) + W4\ (L1 \text{ Cos } \theta_1 - L2 \text{ Cos } \theta_2 + L3 \text{ Cos } \theta_3 + L4/2 \text{ Sin } \theta_4) + W5\ (L1 \text{ Cos } \theta_1 - L2 \text{ Cos } \theta_2 + L3 \text{ Cos } \theta_3 + L4 \text{ Sin } \theta_4 + L5/2 \text{ Sin } \theta_5) + W7\ (L1 \text{ Cos } \theta_1 - L2 \text{ Cos } \theta_2 + L3 \text{ Cos } \theta_3 + L4 \text{ Sin } \theta_4 + L5 \text{ Sin } \theta_5).$$

(2) *Back bent and knees straight:*

$$M2 = W6\ L6/2 \text{ Cos } \theta_6 + W3\ (L6 \text{ Cos } \theta_6 + L3/2 \text{ Cos } \theta_7) + W4\ (L6 \text{ Cos } \theta_6 + L3 \text{ Cos } \theta_7 - L4/2 \text{ Sin } \theta_8) + W5\ (L6 \text{ Cos } \theta_6 + L3 \text{ Cos } \theta_7 - L4 \text{ Sin } \theta_8 + L5\ /2 \text{ Cos } \theta_9) + W8\ (L6 \text{ Cos } \theta_6 + L3 \text{ Cos } \theta_7 - L4 \text{ Sin } \theta_8 + L5 \text{ Cos } \theta_9).$$

(3) *Squatting:*

$$M3 = W1\ L1/2 \text{ Cos } \theta_{10} + W2\ (L1 \text{ Cos } \theta_{10} + L2/2 \text{ Cos } \theta_{11}) + W3\ (L1 \text{ Cos } \theta_{10} + L2 \text{ Cos } \theta_{11} - L3/2 \text{ Sin } \theta_{12}) + W4(L1 \text{ Cos } \theta_{10} + L2 \text{ Cos } \theta_{11} - L3 \text{ Sin } \theta_{12} - L4/2 \text{ Sin } \theta_{13}) + W5(L1 \text{ Cos } \theta_{10} + L2 \text{ Cos } \theta_{11} - L3 \text{ Sin } \theta_{12} - L4 \text{ Sin } \theta_{13} - L5/2 \text{ Sin } \theta_{14}) + W9\ (L1 \text{ Cos } \theta_{10} + L2 \text{ Cos } \theta_{11} - L3 \text{ Sin } \theta_{12} - L4 \text{ Sin } \theta_{13} - L5 \text{ Sin } \theta_{14}).$$

where,

$L1$ = Lower leg length;
$L2$ = Upper leg length;
$L3$ = Trunk and head length;
$L4$ = Upper arm length;
$L5$ = Forearm and hand length;
$L6$ = Total leg length;
$W1$ = Weight of lower leg;
$W2$ = Weight of upper leg;
$W3$ = Weight of trunk and head;
$W4$ = Weight of upper arm;
$W5$ = Weight of lower arm;
$W6$ = Weight of total leg.

Segmental body lengths ($L1$ to $L6$) and segmental body weights ($W1$ to $W6$) were calculated using the formulae given by Roebuck *et al.* (1975) and Piscopo and Bailey (1981). $W7$, $W8$ and $W9$ were the maximum load (weight) lifted in BSKB, BBKS and squatting postures respectively.

After the experimental work, the desire functional measurement of body angles θ_1 to θ_{14}, presented in figure 1, were measured from magnified photographs. The data were analysed on a Commodore 64 Home Computer.

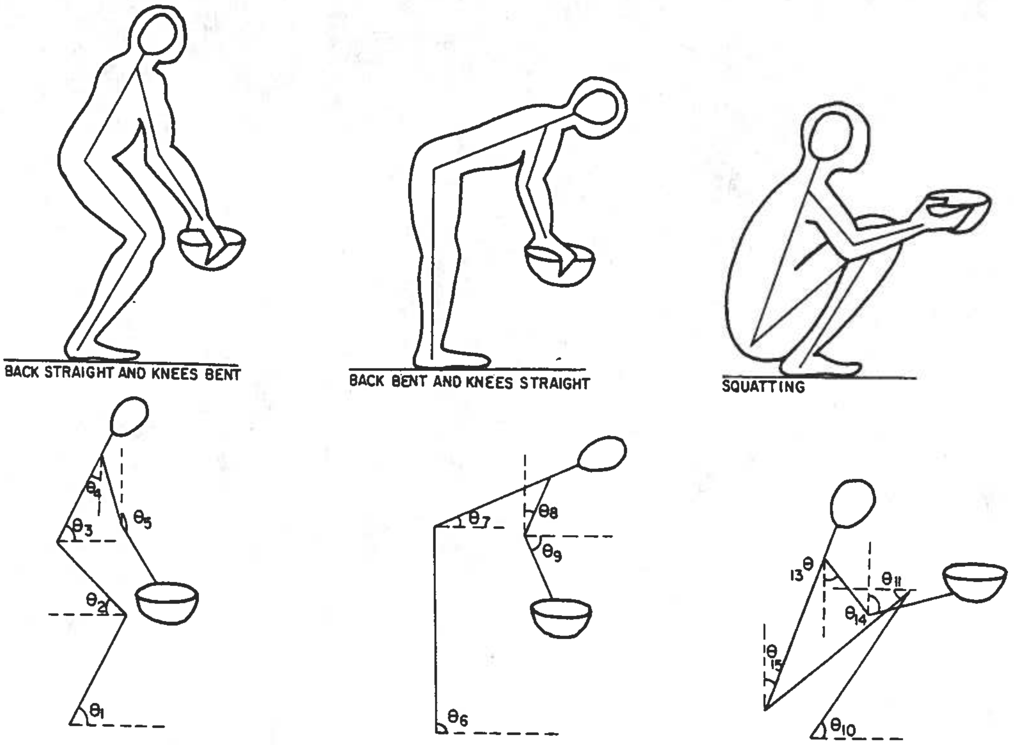

Figure 1. The model used for biochemical evaluation of lift postures.

3. Results

Koli females are able to lift the heaviest load in the back bent and knees straight posture, followed by the squatting posture and the least in the back straight and knees bent posture, the differences are statistically significant at 5% probability level (tables 1 and 2).

In terms of moment, the back bent and knees straight posture is the most demanding, followed by the back straight and knees bent and the squatting posture (table 1), the differences are, however, statistically not significant (table 2). Significantly high positive correlation values between the maximum load lifted and the moment indicates that the moments caused during lifting depends, at least partially, on the load magnitude (table 3). Therefore, to evaluate the biomechanical efficiency of the three postures when lifting, the effect of maximum lifted load was adjusted by computing the moment ratio (moment per kilogramme of the maximum load lifted) for each posture. Table 1 shows that, in Koli females, the back bent and knees straight posture has the maximum moment ratio, followed by back straight and knees bent and the minimum when squatting. As such, females exhibit the same trend in moment ratio as reported earlier for the moment. Inter-postural comparisons, however, reveal that postural differences in moment ratio are statistically significant, except those between the back straight and knees bent and the back bent and knees straight postures.

4. Discussion

It is known that the repetitive use of a particular posture involving specific muscles leads to their development. A gymnast exercising on the parallel bars,

Table 1. Variation in the maximum lifted load, moment and moment ratio in Koli females. (The values are mean and the standard deviations are in parentheses.)

Lift-postures	Maximum lifted load (kg)	Moment (Nm)	Moment ratio
Back straight and knees bent	17·2 (4·2)	250·5 (87·9)	14·9 (4·8)
Back bent and knees straight	18·3 (4·3)	295·5 (82.7)	15·4 (3·8)
Squatting	17·7 (4·6)	218·4 (82·0)	12·8 (5·3)

Table 2. Inter-postural difference in the maximum lifted load, moment and moment ratio.

	Values of pair '*t*' test		
Lift-postures	Maximum lifted load	Moment	Moment ratio
BSKB-BBKS	12·882*	0·444	1·019
BBKS-SQAT	7·013*	0·866	4·679*
BSKB-SQAT	4·194*	0·866	3·296*

BSKB: Back straight and knees bent
BBKS: Back bent and knees straight
SQAT: Squatting
*Indicates that the values are significant at 5% probability level.

Table 3. Relationship (values of coefficient of correlation) of maximum lifted load and moment in three lift-postures.

Lift-postures	Coefficient of correlation
Back straight and knees bent	0·461*
Back bent and knees straight	0·656*
Squatting	0·451*

*Significant at 5% probability level.

for example, is more likely to develop the musculature of the upper body than of the other body parts (Imrie and Dimson 1986). In India, the back bent and knees straight is the most frequently used posture for lifting a load. Squatting is commonly used in performing various household chores, such as cleaning, washing and cooking. The back straight and knees bent posture is the least known, and is therefore rarely practised by the Indian labourers. A study by Snook (1978) on manual handling of materials indicated that industrial workers cannot lift the maximum weight when required to maintain the back straight and knees bent posture. Since the frequency of use of a posture determines the development of specific muscles, it may explain why, in this study, the weight lifted was greatest with the back bent and the knees straight, and the least with the back straight and the knees bent and intermediate when squatting. In fact, the labourers are unaware of the repurcussions of lifting with a 'bad' posture. They generally do not choose a posture for lifting a load and continue to work in the same posture for as much as 8–10 hours a day, even if the posture is bad.

The variation in moment of force in three postures can be, at least partially, attributed to the difference in the maximum load lifted, as evident from the significant positive correlation between the maximum lifted load and the moment. It is expected that if the maximum loads are of similar values, variation between the loads and the effects of this variation would be marginal. None the less, eliminating the effect of maximum lifted load did not influence the trend of moment ratio in Koli females. As such, the moment of force per kilogramme of weight lifted was the greatest in the back bent and knees straight, intermediate in the back straight and knees bent, and the least in the squatting posture. There exists an inverse relationship between the moment ratio and the biomechanical efficiency. As the moment ratio was the least in the squatting posture, it has been concluded as the best posture for lifting. However, to work in a squat posture is not easy; Hanson and Jones (1970) observed in a study that Europeans were not able to maintain squat position while working.

At a construction site, loads have to be lifted and carried from one place to another. Since lifting is generally a precursor to the work task involving lift and carry a load, it should be performed sequentially. Thus each step of the activity should be performed by a different person. For example, while lifting and carrying a load, one person should lift the load in a squat position, another should hold it with a back straight and knees bent posture and yet another should carry it to the destination. These persons may, however, preferably interchange their positions so as not to overstrain any muscle or group of muscles. Such a procedure can increase efficiency as well as reduce stress.

From this study on Koli, it may be concluded that, though marginally more weight was lifted with the back bent and the knees straight, it was physically the most strenuous posture. Back bent and knees straight posture was also found to be the most strenuous in terms of per kilogramme of load lifted. On the other hand, lifting a load in a squat posture necessitated the least biomechanical efforts, and hence was adjudged to be the best posture for lifting a load, specially in India where people are accustomed to work when squatting.

Acknowledgements

We thank the Indian Council of Medical Research for the research grant. We are grateful to Mr Sunil Malik for his help in computer programming. We also wish to thank Mr Atul Kumar Pandey and Miss Anju Swami for their assistance.

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Received 25 September 1988.
Revised manuscript received 28 February 1990.

J. Human Ergol., **23**: 51–57, 1994
Center for Academic Publications Japan. Printed in Japan.

INTERRELATION OF ONE MILE RUNNING TIME AND HST SCORE AMONG RURAL SCHOOL BOYS

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Peak physiological capabilities are necessary for top level performance in sports, although skills and motivation play an important role. Laboratory assessments often give us valuable insights concerning the physiological factors underlying athletic performance. The Physical Fitness Index (PFI) determined by the Harvard Step Test (HST) is one of the most important indexes which predicts the physical abilities of athletes. HST, Cooper's 12-min run-walk test and one-mile run are good measures of cardiorespiratory fitness. In the present study, we have attempted to determine the relationship between HST and the one-mile run in an open field on 31 school boys of a rural village, 14–15 years of age, who were in early puberty. The mean HST score was 90±7.07, and one-mile running time was 443.45±29.82 s. There is a good correlation between HST and running time ($r=0.94$). Probable running time for one-mile may be determined from the HST score by using the regression equation: Running time in $s=783-4^{*}$ HST±0.13 (SE of estimate).

Quality of performance of a strenuous physical activity suffers two obvious inadequacies, both as a quantitative measure of physical fitness and as a standard against which other tests of physical fitness are compared for adequacy:

1) Quality of performance is not a pure measure of fitness, but instead represents the application of variable level of fitness with variable degrees of skill and motivation.
2) Fitness is task-specific, in a greater or lesser degree, differing from 'functional or dynamic fitness' as defined by ELBEL et al. (1958).

Among the various physical fitness tests, the Harvard Step Test (HST) has aroused interest in assessing the physical performance capacity of an individual

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Received for publication August 17, 1993.

because of the simplicity and versatility of the test particularly when applied to large sample studies.

There has been increasing recognition that cardiorespiratory fitness is a prime factor, if not the most important one in physical fitness. Several means of assessing this factor has been developed that are valid and reliable, the Harvard Step Test, Cooper's 12-min run/walk for distance or 1.5 mile run for time for 13- to 18-year-old boys and the 9-min run/walk or one mile run for time for 10- to 12-year-old boys. The HST score is a good measure of cardiovascular fitness and has been a tool for studying physical fitness since its introduction. HST and Cooper's 12-min run/walk tests are highly correlated with maximum oxygen intake (VO_2 max). The complex nature of the direct determination of VO_2 max have contributed to development of safe and reliable indirect measurements based on the linear relationship that exists between the running speed and the energy cost (BRANSFORD and HOWLEY, 1977; COOPER, 1968; MARGARIA et al., 1975).

In the present study, we attempted to determine the relationship between the HST score and the one-mile run time in the open field of 31 school boys in a rural village. The one-mile run test was chosen in place of the 1.5-mile run test because, in a pilot study, most of the subjects were not able to run the full course or became too tired and did not wish to cooperate further.

METHODS AND MATERIALS

In the present study, 31 boys were selected randomly from the Bahirkhand Girish Institution in the Hooghly district in West Bengal. Their ages ranged from 14 to 15 years. All the subjects were in early puberty. All boys were villagers and belong to the economically poorer section. Their age, height, and weight was recorded and body surface area (BSA) calculated (BANERJEE and SEN, 1957). All the boys selected volunteered themselves for tests. Though none of them took part in regular athletics, a majority of them took part in agricultural activities regularly. Before going through the tests, they were well acquainted with the experimental protocol through several trials. After the completion of trials successfully, HST score and 1-mile run time were recorded as follows.

HST scores were measured with the help of standard step test described by GALLAGHER and BROUHA (1943) for subjects having BSA below 1.85 m^2 with a modification in duration. PFI scores were determined using a standard formula, and the gradations were made from the cumulative percentile curve.

One-mile run times were recorded by asking the boys to run around a grass 400 m track 4 times without stopping and the total running times were noted with the help of a stop watch.

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Table 1. Physical characteristics of school boys.

Age (yr)	Height (cm)	Weight (kg)	BSA (m^2)
14.67±0.47	156.79±6.85	41.29±6.48	1.41±0.11

Data are mean ±SD. $N=31$.

Table 2. HST score and one-mile running time.

HST score	One-mile running time (s)
90.00±7.07	443.45±29.82

Data are mean±SD. $N=31$.

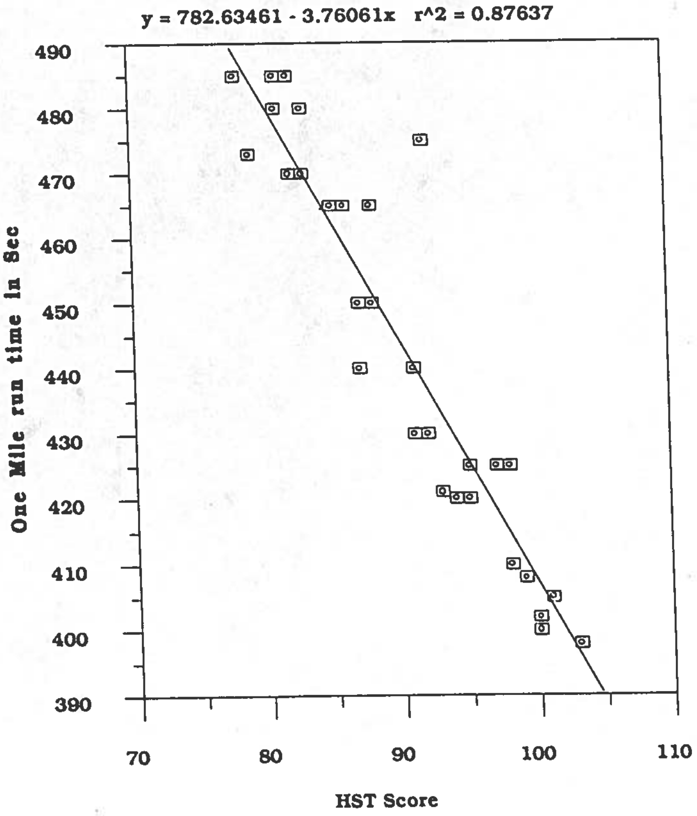

Fig. 1. Individual one-mile run time versus HST score.

Table 3. Gradation of HST scores according to percentile.

Percentile	Scores	Grade	Category
Above P90	Above 100	A+	Excellent
P75–P90	96–100	A	Very good
P50–P75	91–95	B	Good
P25–P50	84–90	C	Average
Below P25	Below 84	D	Poor

Table 4. Gradation of school boys from Table 3 (HST).

Scores population	Grade	No. of sub.	%
Above 100	A+	02	6.45
96–100	A	06	19.35
91–95	B	08	25.81
84–90	C	07	22.58
Below 84	D	08	25.81

RESULTS

Table 1 shows the average age, height, weight and body surface area of the 31 school boys. Their HST score and one-mile running time in s are shown in Table 2.

Individual one-mile run times and HST scores were plotted as shown in Fig. 1. The linear best fit line and its equation are also shown. The two parameters were highly correlated as shown by the r^2 value of 0.87637.

From the individual HST scores, 25th, 50th, 75th, and 90th percentiles were calculated. The corresponding scores were 84.5, 90.8, 96.1, and 100.0, which were rounded off to the nearest integer for categorization of the HST scores (Table 3). Table 4 shows the actual number of students in each category.

DISCUSSION

The maximal physical performance is determined by:

(a) the capacity of the energy delivering process of the body, i.e., the physiologicsal power and

(b) the mechanical efficiency of the individual.

The second point includes not only the skill or motivation factor but also the mechanical advantage of the body expressed in terms of a more suitable physical prototype, physical composition and flexibility. This point has been outright ignored in formulating the test procedures as controversial opinions have poured in regarding the correlation of these factors (as stated under point b) with the physical fitness scores as measured. However, practical experience suggests that the "physiological power" measured in terms of physical fitness remaining constant, the point (b) factors are the sole determinants of work performance. Among these factors, special emphasis should be laid on the physical prototype whose assessment involves no complication whatsoever.

Since the development of the first physical fitness test (step test) by BROUHA et al. (1943), numerous test procedures have appeared in accordance with the physiological demands of the sample population to be tested. The basic principle behind all such development was the same i.e., to test the cardiorespiratory status of the body by subjecting the body's circulatory and cardiovascular systems to a condition of maximal stress. Such all-out tests include those proposed by ELBEL and GREEN (1946), MILLER and ELBEL (1946), ELBEL et al. (1958), TUXWORTH and SHAHNAWAZ (1977), JOHNSON et al. (1942), GALLAGHER and BROUHA (1943), TUTTLE (1950), KEEN and SOLAN (1958), and COOPER (1968). Among the Indian workers DATTA et al. (1974), BANERJEE and CHATTERJEE (1983), BANDYOPADHYAY and CHATTOPADHYAY (1981), BANERJEE et al. (1970), and DAS et al. (1988a) have suggested some alteration in step height, frequency and duration of exercise. Regarding alterations, a step test with a lower work load, if used, would definitely fail to stress the cardiovascular system maximally and hence the fitness scores thus obtained would not reflect an almost true value.

Recently, the field estimation of VO_2 max is also widely practiced (COOPER, 1968, MARGARIA et al., 1965, and others). Among these, the COOPER 12-min run/walk test has proved to be immensely significant by DOOLITTLE and BIGBEE (1968) and many others. They proposed that the correlation was especially higher ($r=0.9$) in the case of men, hence this test was used as a parallel procedure to assess the physical fitness of the subjects. In the present study, the average HST score was 90 which is higher than the average 76 observed by BANERJEE and CHATTERJEE in 1983 of non-athletic urban school boys. GALLAGHER and BROUHA in 1943 reported that the average HST score was 90, DAS et al. in 1988 studied HST score of sub-junior soccer boys and got a mean score of 84 which belong to grade "C" according to their own gradation. In our present observation, a score of 90 also belong to grade "C" according to our computed statistical gradation, because our exercise duration was 5 min instead of the 4 min used by them. So their gradation will not give a true gradation in this case.

Regarding the one-mile run in our introductory part, it was reported that the 12-min run/walk test was well correlated with VO_2 max, as has been observed by many workers. DAS et al. (1988b) observed a correlation between the HST score and COOPER's 12-min walk as an alternative choice of endurance test. Though COOPER suggests 12 min run/walk or 1.5 mile run, these are roughly equivalent. The Texas Physical Fitness Program designed a 9-min run or one-mile run/walk test for school boys aged 10 to 12 yr, but very few works have been done fixing distance instead of time in our Indian subjects. Our observations reveal that the HST score and the one-mile running time were inversely related. The correlation coefficient between the two is -0.936 ($r^2=0.87637$). Texas Physical Fitness Program suggested one mile run for age group 10 to 12 yr but considering low physical status of our subjects it was used for 14 to 15 yr boys. So it can be concluded that both one-mile run and HST score would be meaningful for the study of endurance. A regression equation was formulated for prediction of one-mile running time (s) from HST score: One-mile running time (s) $=782.63461-3.76061$ (HST score) $\pm$ 0.13 as standard error of the estimate.

As stated before, all the subjects in this study were in early puberty. In this study, no consideration was given to relationship of age to PFI rating, because there are differences in opinion about the correlation between age and PFI. BANERJEE and CHATTERJEE (1983) reported a positive correlation between age and PFI, while BANDYOPADHYAY and CHATTOPADHYAY (1981) observed no significant correlation between age and PFI.

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J. Human Ergol., **22**: 163–172, 1993
Center for Academic Publications Japan. Printed in Japan.

ASSESSMENT OF COMFORT OF VARIOUS HEARING PROTECTION DEVICES (HPD)

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To evaluate the comfort of hearing protection devices, two models of ear plugs and five models of ear muffs were tested. The psychophysical method of 'single stimuli' was applied on a group of 30 subjects with or without wearing the devices for a short duration of 15 min under noise condition of 100 dBA in the acoustic chamber as also on a group of 10 weavers with the protection devices worn for longer durations of 1 h, 4 h and 8 h under noise exposure of 102–104 dBA in the weaving shed. Each subject performed 8 trials with each type of device on different days. Application force and tightness of spring were also evaluated. The results yielded a comfort grading for hearing protection devices. The comfort grading, however, depended on several factors in addition to application force and tightness of spring, which has been discussed.

Some workers are exposed to a high level of noise in their work places in industries for a prolonged period of time without ear protection, resulting in gradual hearing loss and finally deafening of the ear. Such hearing loss at high frequencies is known as noise induced hearing loss which is irreversible in nature (NIOSH, 1973). Thus, noise control is of paramount importance either to reduce the risk of hearing loss or to provide better working conditions. The control measures can be affected at least in two ways: (a) control of noise at source and transmission path, (b) control at the individual level with hearing protection devices. While the former is expensive and requires a long time to achieve, the latter can provide an instant solution. However, the workers in general express displeasure with wearing the protection devices because of the discomfort they experience in wearing them, some of which include: irritation on the outer ear and the ear duct, tightness of the ear muff spring, pressure on the skin surface, improper fitting, etc. All such considerations have laid the basis of the present investigation to evaluate the comfort of wearing hearing protection devices and also to examine some of the principal physical characteristics of these devices regarding the overall

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Received for publication July 30, 1993.

comfort sensation.

MATERIALS AND METHODS

Subjects. A group of 30 male college student volunteers, 20–27 years of age, with sound physical health and normal hearing participated in the experiment for a short-duration wear of the hearing protection devices. They did not have either previous exposure to noise and had not worn devices routinely.

A total of 10 male weavers, aged 20–27 years, occupationally exposed to noise but whose other characteristics were similar to those of the college students, volunteered for a long-duration wear of the devices in their real work situations.

Equipment. Hearing protection devices: Two models of ear plugs (models 'A' and 'B') and five models of ear muffs (models 'A', 'B', 'C', 'D', and 'E') which were tested are depicted in Fig. 1. These were purchased from various manufacturers in India without disclosing their intended use. The physical characteristics of the devices are given in Table 1.

Ear plugs: Both models, made of soft vulcanised rubber, are conical in shape and can fit in the adult ear. Each pair of ear plugs is separated by a long thread to prevent loss. To wear the plugs, the subject pulls up the pinna with the contralateral arm and inserts them with the other arm into the external auditory meatus until they close the opening of the ear.

Ear muffs: Each model of ear muff consists of two cups which are joined together with an adjustable headband. The cups are made of hard plastic. To wear them, the subject positions the headband over his head and rests the cups over the pinna and adjusts them in such a way that a good, leak-free contact is made with the surface of the head. The structures of the ear muffs are as follows:

Model 'A': The cups are rectangular in shape. A thin layer of foam is spread at the base inside the cup. The headband is made of hard plastic.

Model 'B': The cups are oval shaped. The layer of foam is a little thicker than that of model 'A' and is spread inside the cup. The headband is also made of hard plastic.

Model 'C': The cups are rectangular in shape. Two layers of foam, one on top of the other, are placed inside the cup. The headband is made of metal wires (steel), which are covered with a thin layer of foam seal.

Model 'D': The cups are also rectangular in shape, which are joined with a rigid rubber headband. A thick layer of foam is stuck at the centre of the cup, leaving much of the interior unsealed. The volume available inside the cup for accommodating the pinna is considerably less.

Model 'E': Its cups are oval-shaped, more akin to the structure of the pinna. The interior of its cups contain a thick layer of foam spread over at the base followed by another foam seal with a 1-mm thick nylon wire mesh on top of it. The latter foam seal is separated from the former by 37 mm of air. The volume available

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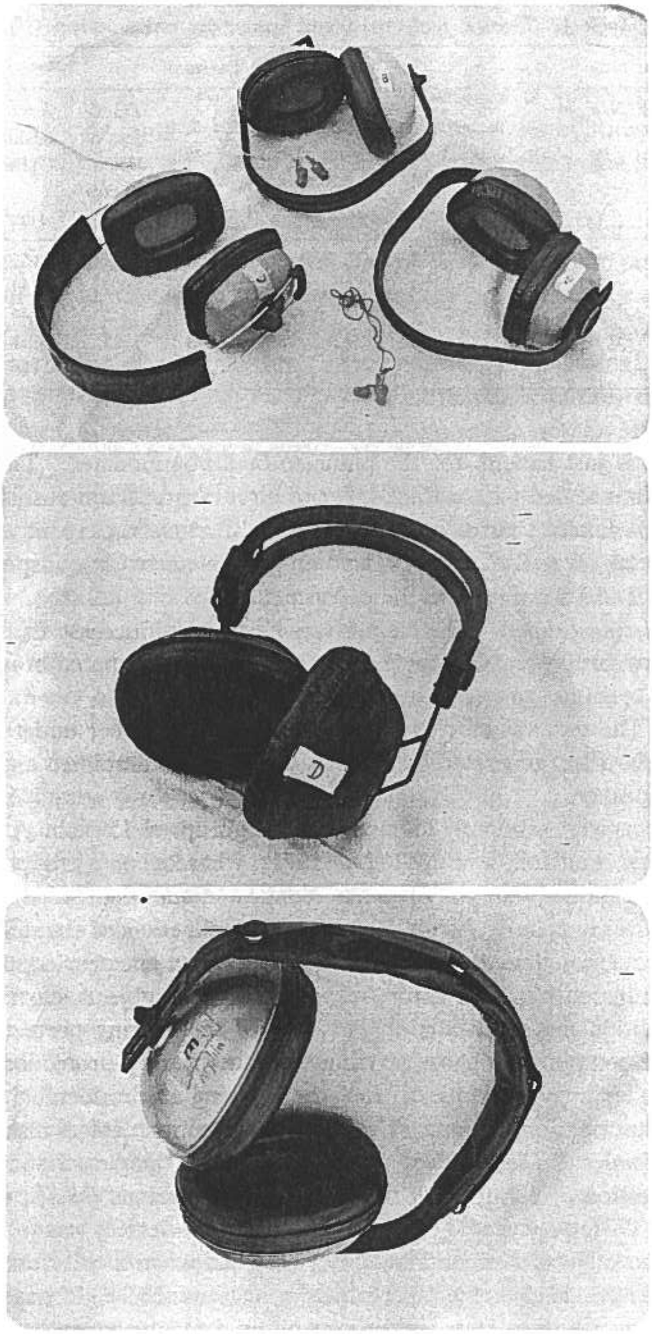

Fig. 1. Various models of Hearing Protection Devices.

Table 1. Physical characteristics of hearing protection devices.

Model of ear protectors	Ear plug		Ear muff							
	Length (cm)	Weight (g)	Weight (g)					Thickness of foam in cup (cm)	Area of cushion seat (cm^2)	Volume of cup with foam inside (cm^3)
			Cup	Foam cushion	Foam in cup	Headband	Total weight (g)			
A	2.0	156	60	10	3	54	200	0.7	52	73
B	1.0	148	41	10	4	50	160	1.2	51	69
C	—	—	41	9	4	57	165	1.5	46	42
D	—	—	26	15	4	80	170	2.5	58	18
E	—	—	40	10	5	70	180	1.0	44	29

inside the cup is just enough for the pinna to be accommodated. The headband made of plastic is sealed with a thick layer of circumaural foam cushion.

Testing conditions. An acoustic chamber (BHATTACHARYA et al., 1985), a sound level meter (B & K, Denmark) and an audiometer with loudspeakers (M/s. Arphi (India) Ltd.) were used in the experiment.

Vernier sliding caliper. The caliper was modified to increase its length to 16 cm and its cross-arms were lengthened by the addition of tapered brass extension riveted to the original arms (HUGHES and LOMAEV, 1972).

Design. The test was carried out in the acoustic chamber under white noise condition of 100 dBA, generated by the audiometer, then amplified and finally led into a set of speakers.

The subjects were randomly divided into two groups of 15 each. A statistically balanced design was followed (WINER, 1971) whereby one group of subjects experienced the noise with an open ear condition and then with the hearing protection devices in position, while the other group experienced the same first with the hearing protection devices in position followed by an open ear condition. This procedure eliminated bias in comfort responses in that subjects starting with the open ear condition may find later the wearing of the hearing protection devices uncomfortable compared to those starting with the hearing protection devices in position and they may continue to feel the wearing uncomfortable even when wearing the most comfortable one. The hearing protection devices also were worn in a random order. The psychophysical method of "single stimuli" involving absolute impression of comfortable-uncomfortable sensations (WOODWORTH and SCHLOSBERG, 1971) produced by the hearing protection devices was followed. The sensation of the subjects were obtained after they had worn the devices for a short duration of 15 min. Each subject performed a maximum of eight trials with each model, spread over 4 days, thus yielding a total of 1,680 responses.

An equal number of responses were also obtained from a group of 10 weavers who also performed likewise in their workplaces in the weaving shed interposed with noise of 102–104 dBA, following wearing of the devices for longer durations of 1 h, 4 h, and 8 h.

Other characteristics such as bizygomatic breadth of subjects (a maximum distance between the bony structures forward of the ears), tightness of headband spring, application force, application pressure, etc. were also taken into consideration.

Procedure. In the acoustic chamber, the subjects were tested individually, once per day, at the same time of day (10 : 00 h). They were seated on an adjustable stool in front of the speaker in such a way that the horizontal axis of the speaker coincided with the vertical axis of the head. They were then briefed about the nature and purpose of the experiment. Their queries were answered, if any. They were also given the option to discontinue their participation if they so wished. No subjects declined to participate. The principal investigator then left the acoustic chamber.

The subjects experienced the noise condition for 15 min either with open ear or with the hearing protection devices in position. Proper fit of the protection devices was ensured. The subjects were not allowed to know which model of the devices was placed in position into their ear ducts or over their heads. Neither were they allowed to talk or chew during the experiment. They were then required to judge their sensation as 'comfortable' or 'uncomfortable' including while moving their heads. On the day before the test day, the subjects were familiarised with the tests in try-out sessions.

Similarly, the weavers were tested for comfort in wear while they were doing their normal routine work in the weaving shed.

The bizygomatic breadth was measured with a vernier sliding caliper with its arms pressed lightly against the bone at its most prominent positions following the method of Hughes and Lomaev (1972).

A brief interview was conducted to identify the specific deficiencies of the devices that could produce discomfort.

RESULTS

For each model of the hearing protection devices, the proportion of comfort responses was calculated to be the ratio of the number of 'comfort' responses to the total number of responses, obtained separately by the student volunteers as well as the weavers. These proportions were then multiplied by 100 to obtain percent of comfort responses. The standard deviations were also calculated.

For each of the two models of ear plugs, the percentage of comfort responses was very high, 98.5% for model 'A' and 97.9% for model 'B', indicating that almost all the subjects felt comfort in wear.

For ear muffs, the percent of comfort responses with the standard deviations depicted in Fig. 2 indicate that the comfort responses varied considerably from one

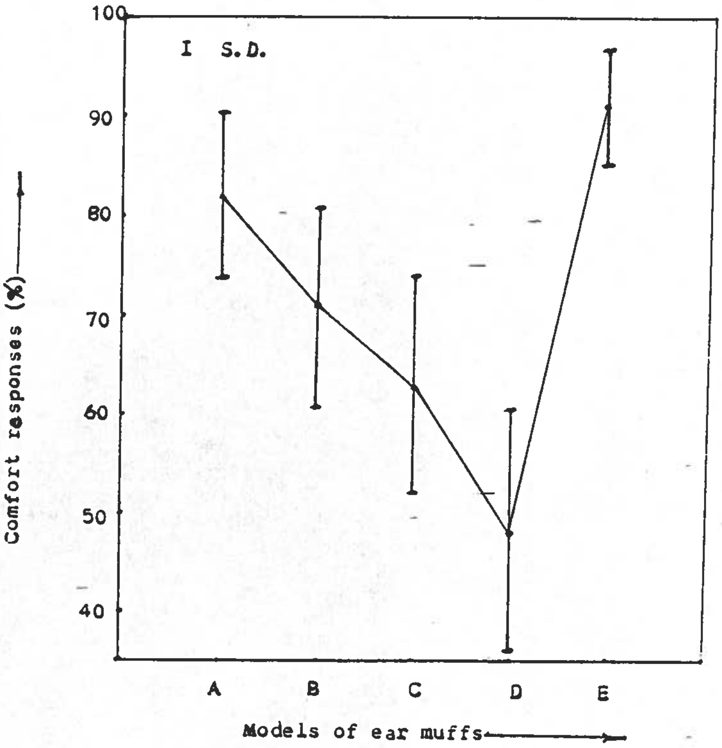

Fig. 2. Comfort ratings for each model of ear muffs.

model to the other. The highest percentage of comfort response was obtained for model 'E' followed in order by models 'A', 'B' and 'C'. Model 'D' was cited as the least comfortable. It may also be seen that the variability in comfort responses for model 'E' is small and for model 'D' high compared to the other models.

Figure 3 shows that the comfort responses of the weavers were similar to those of the student volunteers, but the percentage of comfort responses decreased with time as the duration of wearing the muffs increased up to 4 h, which further decreased as the wearing continued up to 8 h.

As close fit of the ear muff and its ability to attenuate sound depends on the application force, the application force was estimated (in Newtons) for each model of ear muff with respect to the bizygomatic breadth (138–146 mm) of subjects following the guidelines of ANSI (1974) and standard deviations were calculated, as shown in Fig. 4a. Further, 'tightness of the spring' of the ear muff was calculated as the ratio of the application force of each ear muff to the width between its cups, as shown in Fig. 4b. It may be seen from these figures that the application force of model 'E' was low and the tightness of the spring was also less compared to the other models. The application force of models 'A' and 'B' were comparatively high

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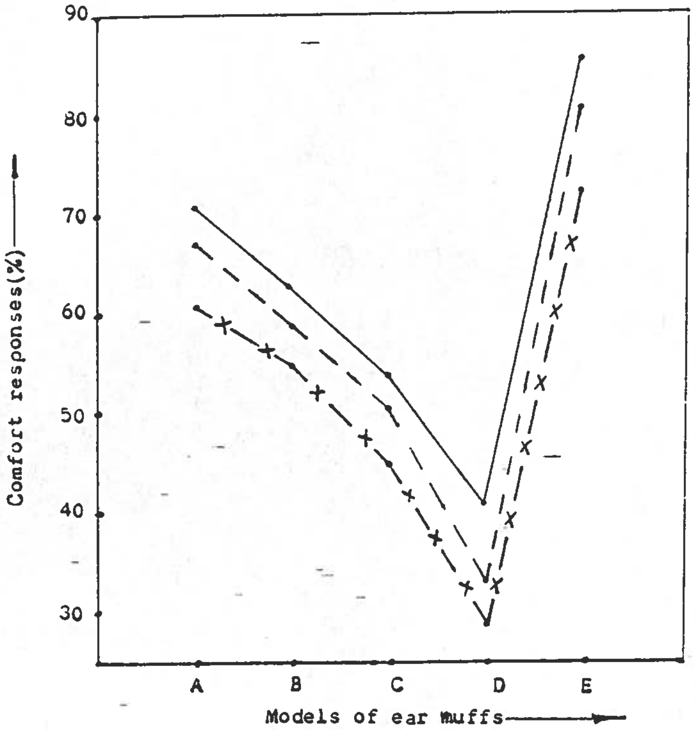

Fig. 3. Comfort ratings for each model of ear muffs after 1 h (——), 4 h (----) and 8 h (×—×) use.

as also were the tightness of the springs of its headbands. However, the application force and the tightness of the springs for models 'C' and 'D' were low compared to models 'A' and 'B'.

DISCUSSION

The comfort sensation of hearing protection devices are governed by several physical factors such as its mass, attenuation characteristics, structural features, application force, application pressure, tightness of the spring of the headband, etc.

The sound attenuation characteristics of the two models of ear plugs ('A' and 'B') and five models of ear muffs ('A', 'B', 'C', 'D' and 'E') have been reported earlier (BHATTACHARYA et al., 1993).

The mass of the hearing protection devices are well below the recommended value of 200 g (ZWISLOCKI, 1955) and hence its influence on comfort sensation would be insignificant.

The high percentage of comfort sensation for each model of the ear plugs are

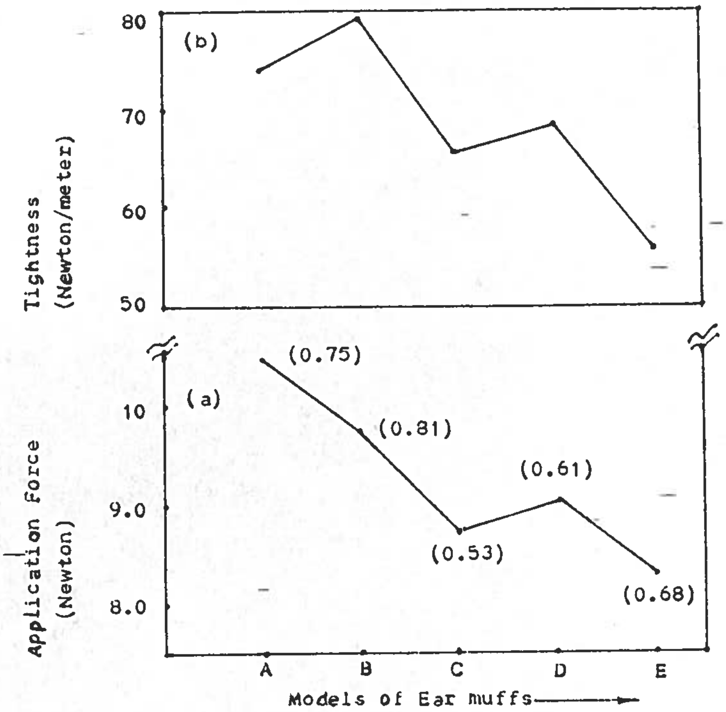

Fig. 4. Showing (a) application force and (b) tightness of the spring for each model of ear muff. Figures in parentheses indicate standard deviations (±).

attributable to the facts that the plugs are less in weight, the material used for their manufacture are supple enough to be easily compressed and the structural characteristics are similar to those of the ear duct contour, thus providing a good fit into the ear duct. Also, the fact that the ear plugs regained their original shapes on removal from the ear canal and thus would ensure their re-use with comfort. However, the interview session revealed that the ear plugs are not able to provide sufficient attenuation in a high sound field; these findings are in agreement with those reported by BHATTACHARYA et al. (1993). The weavers also gave similar responses when they wore the plugs in their work places with the noise level reaching as high as 104 dBA. However, they revealed that the ear plugs could be worn for a short duration in work situation where sound levels are either at or slightly higher than the safe exposure limit of 90 dBA.

For the ear muffs, the relatively high percentage of comfort responses for model 'E' is due to its low application force and smaller application force of its spring compared to those of the other ear muffs, as the comfort in wear appreciably increases with decreasing values in the former two variables (LUPKE, 1964). The structural features of ear muff 'E' also contributed to its comfort value; firstly, its oval-shaped cups comform better with the outer structure of the pinna; secondly, the foam in two layers separated by an air column (37 mm) inside the cups facilitated high sound attenuation, and the wire mesh spread on top of the foam layer further enhanced sound dissipation (BHATTACHARYA et al., 1993), thereby favouring comfort sensations; thirdly, the volume available inside the cup is enough to accommodate the external ear with ease and comfort; fourthly, the cups with plastic foam-filled seal holds the sides of the head without causing any pain on the surface of the skin; and finally, the soft circumaural cushion sealed to the headband further helps reduction of headband tension (ACTON et al., 1976).

Models 'A' and 'B' were graded as less comfortable compared to model 'E' because the application force of the former two models are comparatively high, as are the tightness of the headbands. The headband thus holds the sides of the head tightly as the tightness increases with the increase in application force (LUPKE, 1964). However, the design considerations of the muffs are also responsible for the diminished comfort: the headsets of both models are made of hard plastic without any foam cushion seal on it, thereby producing high headband tension. Moreover, a single thin layer of foam spread inside its cups caused a lowering of acoustic efficiency.

Model 'C' is rated as less comfortable and model 'D' as least comfortable compared to the other models, despite its low application force and less tightness of the headband (spring) relative to those of models 'A' and 'B'. This is the result of the design characteristics of these two ear muffs. The headband of model 'C' is made of metal wires (steel) with a very thin foam cushion on it, resulting in improper fit on the outer ear. In model 'D', the outer ear is compressed against the foam seal placed inside the cup. The attenuation characteristics of the muff is also considerably less than the other models. The headband is made of hard rubber. The design of its cups is incompatible to the structure of the ear; thus, it fails to provide adequate seal on the outer ear and consequently decreases comfort in wear. This suggests that for comfort in wear application force and tightness of spring (headband) are not the only determining factors, but the complete design features of the hearing protection devices that contribute to the overall comfort sensation.

Although the application pressure of hearing protection devices is another determinate for comfort in addition to application force, its influence in this experiment has appeared to be marginal as the application force of the various models of ear muffs are below the recommended value of 12 N (BRINKMANN and BROCKSCH, 1977). The standard deviations also do not exceed the stipulated range of ±1N. The standard maintains that application force could produce tangible application pressure should the former be higher than the standard value. Thus, the application pressure did not merit measurement in this experiment.

However, it should be borne in mind that the feeling of comfort is a psychological sensation and any small variation of width between the cups can produce appreciable variation in application force and consequently in the tightness of the

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INFLUENCE OF AIR FLOW ON SKIN TEMPERATURE

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The skin temperature is fundamental to heat exchange between the human body and the environment. The convective and evaporative heat exchanges depend on the temperature gradient and the extent of air flow over the skin surface. An attempt was made to study the topographical differences in skin temperature (T_{sk}) under varied levels of air flow and to examine the possible body temperature regulatory mechanism. Five volunteers were examined in a climatic chamber at 30 and 36°C DB at 55–60% RH (ambient vapour pressure of 2.58 and 3.53 kPa, and air flow of 0.6, 1.4, 1.9, 2.1 m/s). The deep body temperature (T_c) and local T_{sk} were recorded at 5-min intervals during 10 min pre-exposure, 30 min exposure to heat and 15 min recovery period after air flow was withdrawn. The time taken to attain at the lowest T_{sk} in different air speeds varied from 30 to 45 min. The highest drop in T_{sk} (2.4°C) was recorded for forehead at 30°C DB and significant skin cooling was achieved at an air flow of 0.6 m/s for most body regions. The overall drop in local T_{sk} was more greater at a higher ambient temperature (36°C), and the changes were significantly different ($p < 0.05$) to those recorded at the pre-exposure level. There was a consistent drop in T_{sk} with time, while no definite pattern of drop was noted with the magnitude of air flow. The T_c increased significantly with the continued air flow and following withdrawal of air flow the T_c tended to drop, suggesting heat gain by the body with a consequent increase in T_c.

The skin temperature is fundamental to heat exchange between the body and its environment. The skin temperature affects the energy transfer by convection and radiation, and also influences other physiological functions such as heat loss from sweat evaporation by determining the saturation of vapour pressure at the skin surface. Since the convective and evaporative heat exchanges depend on the extent of air flow, the topography of the surface skin temperatue is obviously

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Received for publication June 21, 1993.

influenced by air circulation over the skin (HEISING and WERNER, 1985). OLESEN et al. (1972) in a longitudinal study of a single subject indicated physiological comfort conditions at sixteen conditions of activity, clothing, air velocity and ambient temperature, and arrived at a constant mean body temperature (i.e., weighted as 0.2 times mean skin temperature and 0.8 times rectal temperature). That is, the comfortable mean body temperature at rest and light exercise could be taken as 36.3°C. However, when satisfactory air circulation is not available, this may significantly cause disturbance in the regulation of body temperature. In this report, the topographical differences in skin temperature are investigated under varied levels of air flow in controlled environmental conditions, and the possible body temperature regulatory mechanism in humans are examined.

MATERIALS AND METHODS

Five young healthy male volunteers (age: 22 ± 2.2 years, body height: 162.1 ± 2.5 cm, body weight: 49.6 ± 5.3 kg, body surface area: $1.51 \pm 0.07\,\mathrm{m}^2$) participated in the study. The experiments were conducted in a Walk-in environmental chamber (Hotpack International, U.S.A.) at different combinations of environmental parameters: (i) ambient temperature: 30 and 36°C, at 55 to 60% RH (the ambient water vapour pressure was equivalent to 2.58 and 3.53 kPa) and (ii) air flow: 0.6, 1.4, 1.9 and 2.1 m/s. In total, there were eight experimental conditions to which the subjects were exposed on different days. For each exposure condition, initially the subjects were exposed at a given temperature with a free zone of convection. After a steady state period ranging between 15 to 20 min, the subjects were exposed to a selected air flow for a duration of 30 min and then the blower was switched off.

The skin temperatures at different local sites of the body were recorded at 5-min intervals throughout the exposure by a multi-channel telethermometer (Aplab, India). The temperature-sensing probes were placed on the forehead, chest, back, upper arm, lower arm, palm, upper leg, lower leg and foot.

Since the local skin temperature varied with the sites, an average skin temperature has conventionally been obtained with relative weighting of local temperatures based on the surface area of the body segments. Therefore, the selection of sites, number of measurement points, and the weighting system in estimating mean skin temperature ($\bar{T}_{sk}$) have been the subject of discussion for many years (TEICHNER, 1958; RAMANATHAN, 1964; NADEL et al., 1973; LUND and GISOLFI, 1974; NAG et al., 1980). In the present study, the $\bar{T}_{sk}$ was obtained using the equation given below:

$$\begin{aligned}\bar{T}_{sk} = {} & 0.248\ \text{forehead} + 0.251\ \text{chest} + 0.251\ \text{back} + 0.054\ \text{upper arm} \\ & + 0.023\ \text{lower arm} + 0.010\ \text{palm} + 0.116\ \text{upper leg} + 0.028\ \text{lower leg} \\ & + 0.016\ \text{foot}\end{aligned}$$

The weightings for the abovementioned skin sites were derived by combining the

Table 1. Skin temperatures (°C) attained at different air flow.

Area	Dry bulb temp (°C)	Rest	Velocity (m/s)				Time range (min)
			0.6	1.4	1.9	2.1	
Forehead	30	34.1 (0.6)	31.7 (1.3)	32.7 (0.6)	32.5 (0.9)	32.7 (1.6)	30–35
	36	35.8 (0.3)	34.7 (0.3)	34.9 (0.5)	34.9 (0.2)	35.0 (0.2)	30–40
Chest	30	32.6 (0.4)	31.5 (0.6)	31.1 (0.6)	31.6 (0.1)	32.3 (0.2)	30–40
	36	35.6 (0.4)	34.1 (0.8)	34.5 (0.5)	34.4 (0.2)	34.5 (0.4)	25–45
Back	30	32.3 (0.4)	31.8 (0.4)	31.3 (0.5)	31.7 (0.4)	31.3 (0.7)	30–40
	36	35.1 (0.4)	33.4 (1.3)	34.1 (1.0)	33.4 (0.6)	33.6 (0.1)	30–45
Upper arm	30	32.4 (0.4)	30.8 (0.5)	32.2 (0.1)	31.8 (0.6)	31.8 (0.5)	20–35
	36	35.6 (0.3)	34.9 (1.1)	35.0 (0.8)	34.6 (0.3)	34.1 (0.4)	30–35
Lower arm	30	32.8 (0.4)	32.1 (0.7)	31.4 (0.5)	31.8 (0.3)	32.1 (0.5)	30–35
	36	35.5 (0.3)	34.5 (1.0)	34.8 (1.1)	34.6 (0.3)	34.2 (0.3)	25–35
Palm	30	33.0 (0.4)	32.2 (0.7)	32.3 (0.5)	32.6 (0.5)	32.3 (0.2)	20–45
	36	35.6 (0.3)	35.1 (0.6)	35.2 (0.6)	34.3 (0.3)	34.3 (0.4)	25–35
Upper leg	30	33.2 (0.9)	33.1 (1.2)	32.2 (0.9)	33.1 (1.5)	33.0 (0.1)	40–45
	36	35.4 (0.6)	34.7 (1.8)	35.1 (1.1)	35.0 (1.0)	34.4 (1.3)	35–45
Lower leg	30	32.0 (0.5)	31.3 (0.9)	31.2 (0.5)	32.1 (0.5)	31.4 (0.1)	30–45
	36	35.0 (0.6)	34.1 (1.2)	34.2 (1.3)	33.8 (1.5)	33.9 (0.4)	40–45
Foot	30	31.9 (0.9)	31.8 (1.0)	31.6 (1.1)	30.1 (1.3)	30.8 (1.2)	20–40
	36	35.6 (0.4)	35.5 (0.9)	35.2 (0.9)	35.0 (0.2)	34.5 (0.5)	25–45

Figures in parantheses indicate standard deviation.

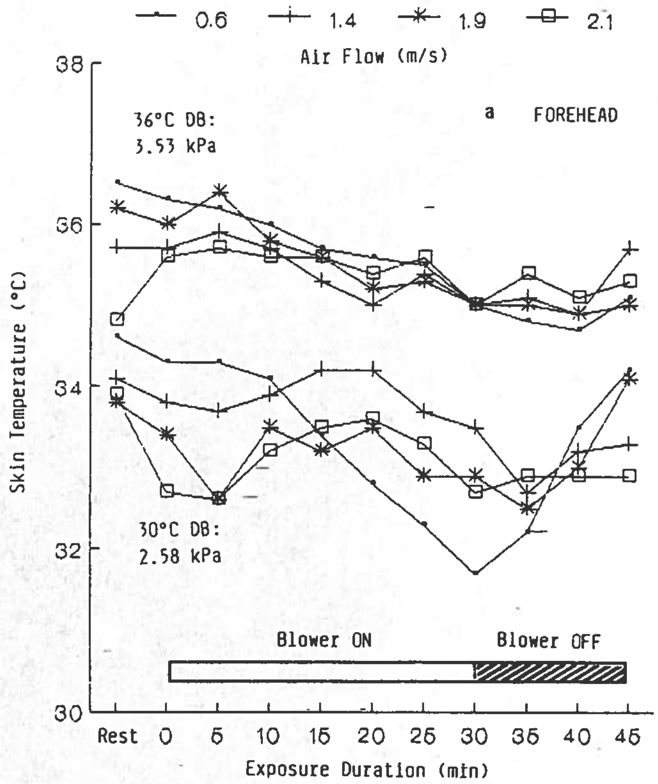

Fig. 1a. Time pattern of forehead skin temperature at different ambient temperatures and air flows.

thermal sensitivity factors (Szabo, 1962; Stevens and Marks, 1971; Nadel et al., 1973) and the surface area weightages (Nag et al., 1980). Body surface area weightages were calculated from the fractionated weight of body segments (Head—8.4%, Trunk—55.4%, Upper and lower arms—6.6%, Palms—1.4%, Upper and lower legs—18.6%, Feet—3.6% of the body weight and the rest is the central blood), and the Meeh constant (Meeh, 1879), i.e., the surface area is equal to the two-third power function of the weight of the body segment times the body shape factor.

The deep body temperature of the subjects was recorded by a measurement device (Deep Body Thermometer Ltd., Cambridge, U.K.), which was developed on the principle of creating a zone of zero heat flow across the body shell (Solman and Dalton, 1973; Fox et al., 1973). A probe pad ($6\times6\times0.6\,m^3$) was fitted over the right sternum. The pad was made of two closely matched thermistors, a piece of nylon gauze and a thin film heater element closely enclosed in silicone rubber. The signal from the thermistor in contact with the skin was fed to the measurement d air

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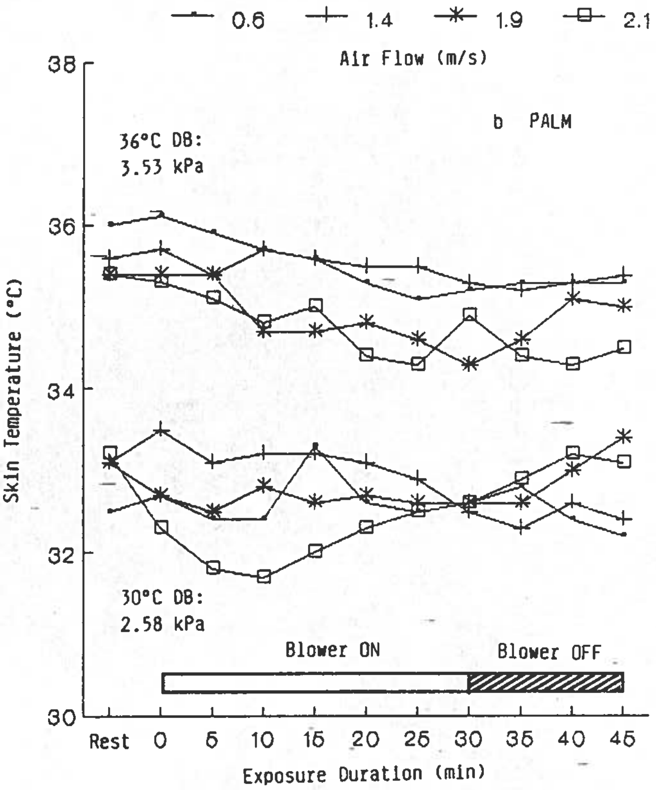

Fig. 1b. Time pattern of palm skin temperature at different ambient temperatures and air flows.

device and recorded every minute.

RESULTS

The air flow causes varying magnitude of cooling response on skin surface with consequent lowering in temperature. Table 1 shows the skin temperatures at different ranges of air flow in two levels of ambient temperatures. The time taken to attain the lowest skin temperature at different air speeds varied from 20 to 45 min; in some cases, better cooling of skin was noted even after about 15 min of withdrawal of air flow. The highest drop in temperature (2.4°C) was recorded for the forehead (DB—30°C; air flow—0.6 m/s). Other noticeable drops in skin temperatures were as follows: 1.5°C on chest (DB—30°C; air flow—1.4 m/s, and DB—36°C; air flow—0.6 m/s), 1.1°C on the forehead (DB—36°C; air flow—0.6 m/s), 1.7°C on the back (DB—36°C; air flow—1.9 m/s), and 1.5°C on the upper arm (DB—36°C; air flow—2.1 m/s).

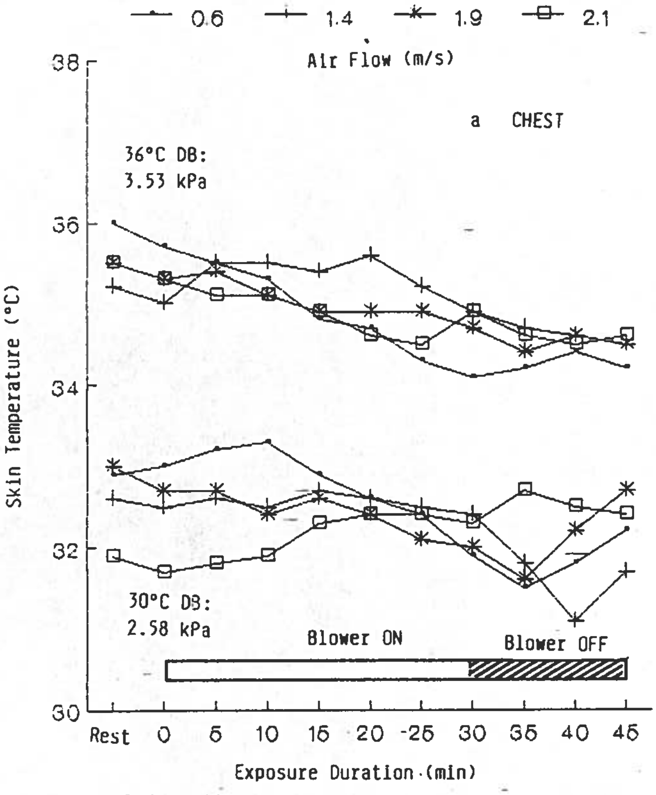

Fig. 2a. Time pattern of chest skin temperature at different ambient temperatures and skin flows.

As a comparison of all the skin sites, the overall drop in skin temperature with the air flow was greater at a higher ambient temperature (36°C DB, 3.53 kPa) compared with those observed at 30°C DB, 2.58 kPa; however, in both ambient temperature exposures, the changes in skin temperatures were significantly different ($p < 0.05$) to those recorded at the pre-exposure resting level.

The time pattern of skin temperature of the forehead and palm, and the chest and back are shown in Figs. 1 and 2, indicating a consistent drop in skin temperature with time. No definite pattern in temperature drop, however, was noted with the magnitude of air flow. The resultant $\bar{T}_{sk}$ in different air flows are shown in Fig. 3 in two groups: 30°C DB, 2.58 kPa, and 36°C DB, 3.53 kPa. This clearly indicates that the $\bar{T}_{sk}$ was much lower at 30°C DB (2.58 kPa), compared with those observed at 36°C DB (3.53 kPa).

The effects of air flow on the deep body temperature build-up are shown in Fig. 4, indicating that the deep body temperature gradually increased with the exposure time. Furthermore, this was consistently noted at both ambient exposure condi-

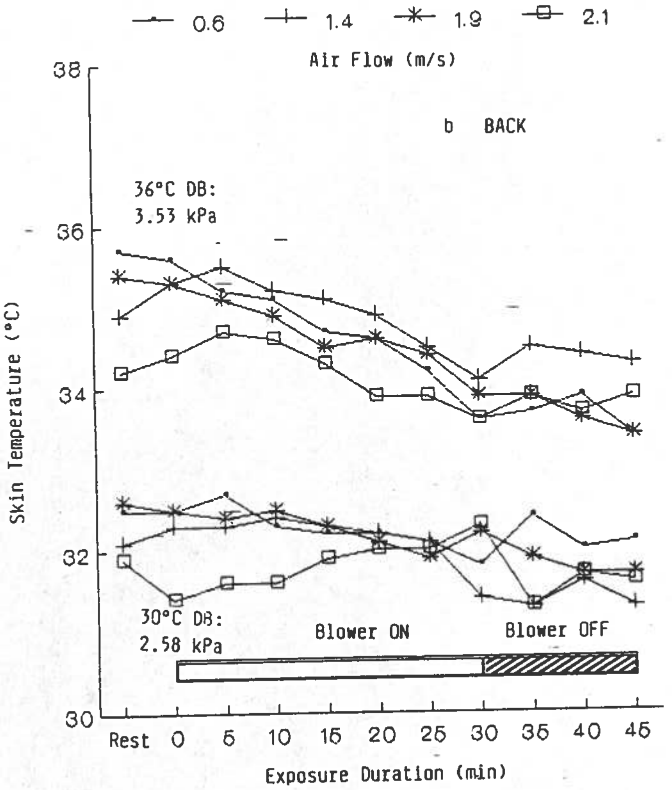

Fig. 2b. Time pattern of back skin temperature at different ambient temperatures and air flows.

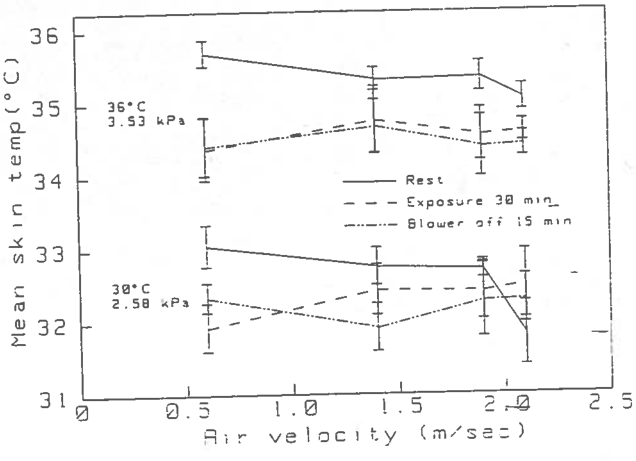

Fig. 3. Mean skin temperature (T_{sk}) at different air flows.

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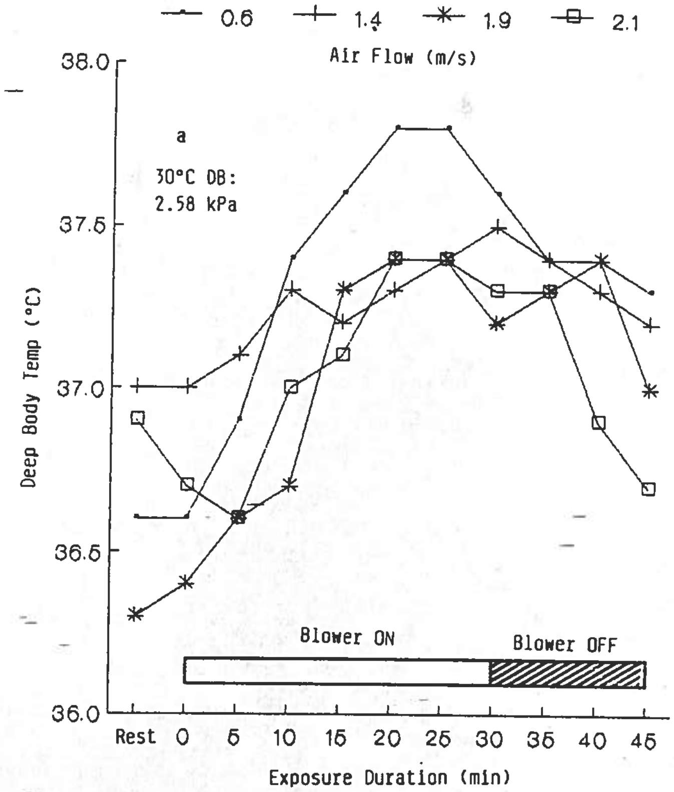

Fig. 4a. Changes in deep body temperature with the duration of exposure at different air flows (DB 30°C: 2.58 kPa).

tions of 30°C DB and 36°C DB. As with the skin temperature variations, the deep body temperature response did not show any significant pattern with the magnitude of air flow. With the withdrawal of air flow, the deep body temperature tended to drop in all cases. This was in contrast to the situation in local skin temperatures (Figs. 1 and 2), where the temperatures continued to fall during the air flow and continued to drop for up to 15 min after withdrawal of air flow.

DISCUSSION

The nature and magnitude of air movements over the skin surface are likely to vary with the body orientation, type of activity performed and also the direction of air flow. This has a consequent variation in the rate of convective and evaporative heat transfer by different local skin areas (Nag, 1984). Taking these into account, the skin temperature responses at various locations of the body were examined at different air velocities to which the subjects were exposed. The results indicate that

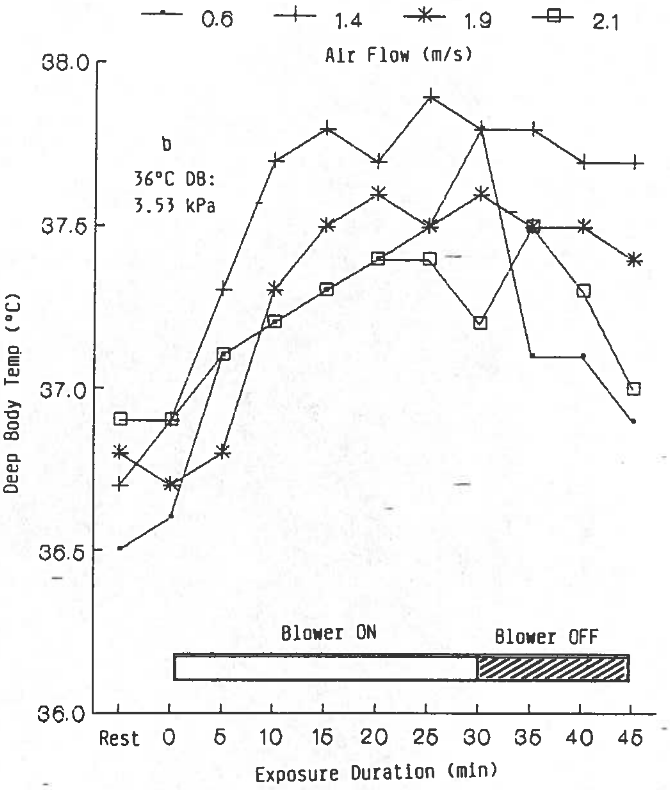

Fig. 4b. Changes in deep body temperature with the duration of exposure at different air flows (DB 36°C : 3.53 kPa).

the skin temperature fluctuations over the whole duration of exposure vary from site to site; the forehead temperature had the highest drop compared to those recorded at other locations of the body. In general, the skin surface cooling (lowering of skin temperature) was observed with exposure to air flow, though there was no clear relationship between the extent of temperature variation and the increase in air flow. This observation supports the findings of OLESEN et al. (1972) who suggested that clothing and air velocity had no significant influence on the $\bar{T}_{sk}$ and the evaporative loss, at neither the low nor the high activity levels.

It was noted that the deep body temperature increased significantly with the continued air flow and, following withdrawal of air flow, the deep body temperature tended to drop. This suggests that for the ambient temperatures and air speeds selected in the study, there was a heat gain by the body with a consequent increase in deep body temperature. The body temperature responses indicate that the central regulatory mechanism has an intricate function in increasing deep body temperature and consequent lowering in skin temperature, as an adjustment towards controlling heat dissipation through skin. It is likely that the influence of air flow on thermoregulation is of primary importance, particularly at higher ambient temperatures which induce an increase in body temperature. The secondary influences are the compensatory adjustment of temperature regulation by lowering the skin temperature and thus widening the gradient for heat dissipation from the body core.

These observations support the findings of BULLARD et al. (1967), NADEL et al. (1971), and OGAWA (1970) who reported that the presence of a constant central nervous system drive influences the local T_{sk} and sweating rate. The central nervous system drive on local T_{sk} and on sweating can be modified at the periphery with the area influences (STOLWIJK et al., 1971; NADEL et al., 1973), and therefore, the differential pattern of thermoregulatory response may vary with the regions of the body, as observed in the present study. There is a likelihood that the different thermoreceptors in the skin respond differently in autonomic thermoregulation with the duration of air flow, the ambient temperature and surrounding vapour pressure, and it is less likely that they are regulated by the magnitude of air flow (MAIRIAUX et al., 1987). It may be concluded that significant skin cooling may be achieved even at an air flow of 0.6 m/s for most of the body regions.

The kind permission of the Director of the Institute is gratefully acknowledged. The authors express their sincere thanks to Mr S. P. Ashtekar and M. S. Vaghela for their technical assistance.

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OPTIMUM HANDLE HEIGHT FOR AN ANIMAL-DRAWN BLADE HARROW

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A blade harrow is a tillage implement commonly used by the farmers of Central and Western India. The handle is one of the main components of a blade harrow and its height has an influence on operator's comfort as well as work performance. Therefore, this study was carried out to determine the optimum handle height for an animal-drawn blade harrow. Two experiments were conducted with four male subjects to study postural discomfort and physiological reactions separately at six handle heights. Downward force applied by the operator on handle, and depth and speed of operation were also recorded. The lowest postural discomfort was noticed at handle height equal to 1.0 metacarpale III height. Here, the overall discomfort rating was 2.4 on an eight point psychophysical rating scale (0=no discomfort, 7=extreme discomfort) and the body part discomfort score was 16.3 (the maximum being 53.8 at working height equal to 1.6 metacarpale III height). The mean heart rate and oxygen consumption at this handle height were 103.9 beats/min and 0.536 *l*/min, respectively. Considering the data of postural discomfort and also of heart rate and oxygen consumption, the optimum handle height for the animal-drawn blade harrow worked out to be equal to 1.0 metacarpale III height, *i.e.* 637 to 732 mm (5th and 95th percentile values respectively, of metacarpale III height of Indian agricultural workers).

A blade harrow (Bakhar) is a tillage implement commonly used by the Indian farmers in clayey soil region for seed bed preparation. It consists of a frame (wooden cross beam), two tines, a blade, a beam and a handle. The implement is hitched to a yoke through the beam. The operator holds the reins of bullocks in one hand and controls the operation through the handle with other hand. Depending upon the field situation, the operator applies downward force on the handle to get

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Received for publication March 9, 1992.

the desired depth of operation. The height of handle* has an effect on the operator's comfort as well as work performance. Therefore, proper handle height is necessary for efficient operation. As per the recommendation of Bureau of Indian Standards (BIS, 1979), the height of handle of animal-drawn blade harrow should be adjustable between 800 and 1,100 mm. However, no objective data is available to support this recommendation. Therefore, this study was undertaken to generate such data and to determine the optimum handle height for an animal-drawn blade harrow.

Blade harrow is a traditional implement. ICAR (1960) reported details about nine different types of blade harrow being used in the country. No specific mention has been made of handle height, but figures show the handle height between 600 to 900 mm. In traditional blade harrows, the handle is made of wood and generally the operator makes his own adjustment according to his requirement. However, in improved blade harrows, the handle as well as frame are made of steel; therefore, the scope of adjustment is provided at the time of fabrication itself.

METHODS

Two experiments were conducted separately: one for studying physiological reactions and another to assess postural discomfort (four male subjects). All the subjects were well acquainted with handling of bullocks and blade harrow operation. Their mean age, stature, metacarpale III height** and weight were 38.3±5.2 years, 161.8±4.6 cm, 66.6±1.9 cm and 49.5±4.0 kg, respectively. A traditional blade harrow having 500 mm blade width and weighing 40 kg was used for the experiment. A handle having provision for variation of grip height was fabricated and used in the experiment. Six handle heights (Table 1) varying from 0.8 MH** to 1.60 MH of the subject were studied. For heart rate measurement, UNI-INSTA (India) ECG telemetry system having 30 m range was used whereas oxygen uptake was measured using Morgan Oxylog (U.K.) (Fig. 1). Downward force applied by the operator in the line of handle was measured by using a Novatech load cell (50 kgf capacity) with digital indicator (Fig. 2). The overall body discomfort was measured on an eight point psychophysical rating scale (0=no discomfort, 7=extreme discomfort) using the adapted CORLETT and BISHOP (1976) scale (YU and KEYSERLING, 1989). The localized discomfort was assessed in 23 body regions using the modified CORLETT and BISHOP (1976) technique (LEG and MAHANTY, 1985). Quality of harrowing operation was measured in terms of depth and speed of operation. The physiological trials were of 10-min duration whereas the postural discomfort trials were of 30-min duration. Rests of 10- and 15-min duration,

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* Handle height: The vertical distance between ground and the center of handle grip when the harrow is set in its working position.

** Metacarpale III height: MH: It is the height of the knuckle (from ground level) where the middle finger joins the palm. It is generally equal to grip height in standing posture.

Table 1. Physiological responses of the subjects and parameters of harrowing operation at different handle heights (Experiment 1).

Handle height		Heart rate (HR)	Oxygen uptake ($\dot{V}O_2$)	Force applied on handle	Depth of operation	Speed of operation
Notation	Level	beats/min	l/min (STPD)	N	mm	km/hr
H_1	0.85 MH	109.1	0.510	98	90	1.79
H_2	1.00 MH	103.9	0.536	86	92	1.75
H_3	1.15 MH	108.9	0.595	77	91	1.48
H_4	1.30 MH	107.6	0.533	57	81	1.64
H_5	1.45 MH	105.6	0.481	64	78	1.43
H_6	1.60 MH	105.5	0.605	50	67	1.21
$F_{(5,15)}$		0.919	1.83	13.37	9.40	1.92
Significant at $p<$		0.5	0.25	0.001	0.001	0.25

Fig. 1. Measurement of heart rate and oxygen consumption of the operator during operation.

respectively, were given in these trials. Sequence of treatments was decided at random in both of these trials. The data were analyzed with a single factor repeated measures analysis of variance (WINER, 1971). The multiple t-test technique (RAGHAVARAO, 1983) was used to probe significance amongst treatment means.

RESULTS

Table 1 gives mean values of physiological responses of four subjects while working with six handle heights and also the details of ploughing operation in experiment 1. The heart rate varied from 103.9 to 109.1 beats/min and the oxygen consumption from 0.481 to 0.605 l/min. However, in both cases, the differences

Fig. 2. Measurement of downward force (in the direction of handle) applied by the operator on handle during operation.

Table 2. Postural discomfort experienced by the subjects and parameters of harrowing operation at different handle heights (Experiment 2).

Handle height		Overall discomfort rating (ODR)	Body part discomfort scores	Force applied on handle N	Depth of operation mm	Speed of operation km/hr
Notation	Level					
H_1	0.85 MH	2.8	20.5	103	87	2.60
H_2	1.00 MH	2.4	16.3	101	93	2.47
H_3	1.15 MH	4.1	33.5	86	91	2.57
H_4	1.30 MH	4.6	45.8	80	90	2.18
H_5	1.45 MH	5.5	48.5	76	84	2.31
H_6	1.60 MH	6.0	53.8	71	81	2.11
$F_{(5,15)}$		11.70	5.67	6.50	1.63	2.27
Significant at $p<$		0.001	0.005	0.005	0.25	0.10

were not significant at $p < 0.05$.

Table 2 gives data on postural discomfort along with details of ploughing operation. The overall discomfort rating (ODR) was lowest for H_2 treatment, its value being 2.4 on the 8-point scale. The body part discomfort score was also lowest (*i.e.* 16.3) in H_2 treatment.

DISCUSSION

Heart rate

Working posture has influence on heart rate. If the hands are raised from bench level to shoulder level and above, the heart rate would be higher (ASTRAND *et al.*, 1968). However, the circulatory stress imposed due to increase in handle height could not get reflected in the heart rate data because the magnitude of force applied by the subjects on the handle decreased with increase in handle height. The downward push force in the line of handle varied from 98 N to 50 N (in experiment 1) and 103 N to 71 N (in experiment 2), in treatment H_1 to H_6. The subjects could apply the largest force in H_1 treatment. However, the treatments H_1 and H_2 were at par (at $p < 0.05$). At higher handle height, it was difficult to apply the downward force and therefore the depth of operation was less. In H_5 and H_6 treatments, maneuverability of the implement was also poor.

Oxygen uptake

Oxygen uptake is the measure of physical workload on the subject during the operation. Here, the physical workload was in three components, *viz.* walking, applying a downward push by left hand, and controlling the bullocks by holding reins and stick in right hand. The variation observed in $\dot{V}O_2$ uptake in different treatments was not significant at $p < 0.05$.

Postural discomfort

For minimum muscular fatigue during work, the hands should be positioned below the waist level (HERBERTS *et al.*, 1980; WIKER *et al.*, 1989). As mentioned earlier, harrowing operation involves downward application of force while walking behind the harrow. It was observed that at H_1 height the operator had to stoop, thus causing some discomfort in waist region. At higher handle heights, *i.e.* H_4, H_5 and H_6, the discomfort was experienced in arms and shoulder region. The overall discomfort rating and the body part discomfort scores (Table 2) show that H_2 was the best height as it had the least postural discomfort scores.

Optimum handle height

The criteria for deciding optimum handle height would be minimum postural discomfort, lower physiological cost and better harrowing operation. It can be seen that at H_2 handle height, the postural discomfort was minimum and the operation was better. The heart rate and oxygen uptake at this handle height were 103.9 beats/min and 0.536 *l*/min, respectively. Therefore, this handle height can be taken as the optimum one for the blade harrow (Fig. 3). The H_2 height is equal to 1.0 metacarpale III height. As per the anthropometric data available (GITE and YADAV, 1989), the 5th, 50th and 95th percentile values of metacarpale III height of the Indian agricultural workers are 637 mm, 685 mm and 732 mm, respectively. Thus the optimum handle height for a blade harrow works out to be between 637 to 732 mm. Preferably, the height should be adjustable within this range. For a fixed type handle, a height of 685 mm is recommended. It would be equal to 1.07 MH of the 5th percentile worker and 0.94 MH of the 95th percentile worker.

Fig. 3. Posture of the operator while working at optimum handle height.

Comparison with mould board plough

In the experiment on animal-drawn mould board plough (Gite, 1991), the optimum handle height was found to be equal to 1.15 MH and for a fixed-type handle: a height of 770 mm was recommended. The handle height for blade harrow is lower than this value. In mould board plough, the operator had to provide support for stability of plough in addition to application of downward force whereas in blade harrow operation, the operator had to apply downward force only. Therefore, in blade harrow, the subjects preferred lower handle height.

CONCLUSION

For an animal-drawn blade harrow, the handle height should be adjustable between 637 to 732 mm. For a fixed-type handle, the height should be 685 mm.

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ERGONOMICS, 1994, VOL. 37, NO. 9, 1491–1494

Prediction of maximal aerobic power in man: a nomographic approach

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Keywords: Maximal aerobic power; Regression equation; Cardiorespiratory strains; Nomogram.

Direct estimation of maximal aerobic power is an intricate procedure and requires the facility of a well-equipped laboratory. Attempts have been made, therefore, to develop linear and nonlinear regression equations for its indirect assessment, but many biomedical scientists have difficulty in using these statistically based equations. Bearing this in mind, this paper constructs two nomograms for predicting maximal aerobic power. The first nomogram, based on cardiorespiratory strains, is more precise but requires the facility of an equipped laboratory owing to the involvement of some physiological variables; the second nomogram, based on the two variables body weight and time for a 3·2 km run, does not require any laboratory facility for prediction of maximal aerobic power. Both nomograms have limited validity. The first is most reliable in the range 1·83–3·28 $\mathrm{l.min^{-1}}$; the second is best in the range 1·76–3·06 $\mathrm{l.min^{-1}}$ of maximal aerobic power.

1. Introduction

Nomographic approaches play an important role in clinical physiology and avoid the necessity to use lengthy linear and nonlinear regression equations, which frequently involve complex statistical computational work. Direct estimation of maximal aerobic power is cumbersome and requires the facility of a well-equipped laboratory. Moreover, the exertion required to attain maximal aerobic power needs motivation and co-operation from a healthy subject and may be hazardous to some unfit individuals, particularly in higher age groups. Consequently, attempts have been made for indirect estimation of maximal aerobic power from heart-rate measured at submaximal work loads using linear models (Åstrand and Ryhming 1954, Fox 1973, Maritz *et al.* 1961, Margaria *et al.* 1965, Wyndham 1967). Other workers (Issekutz *et al.* 1962) have used the respiratory exchange ratio at submaximal work loads for this purpose but both these approaches have limitations and their relative merits and demerits to predict accurately have been discussed previously (Rowell *et al.* 1964, Glassford *et al.* 1965, Davies 1968). Verma *et al.* (1977) gave an indirect estimation of maximal aerobic power from combined cardiorespiratory strains imposed on the subject during submaximal effort to increase the accuracy of the prediction. More recently Verma *et al.* (1984) also proposed multiple regression equations for predicting maximal aerobic power from body weight, time for a 3·2 km run and exercise dyspnoeic index. All these linear and nonlinear regression equations require good knowledge of mathematical and statistical concepts and many physiologists may face some difficulty in using these regression equations. To overcome this difficulty, an attempt is made in the present paper to construct two nomograms for predicting maximal aerobic power. The first nomogram is useful to predict aerobic stress from cardiorespiratory strains imposed on the subject during submaximal exercise using the prediction formula developed by Verma *et al.* (1977). The second nomogram is useful for estimating maximal aerobic power from

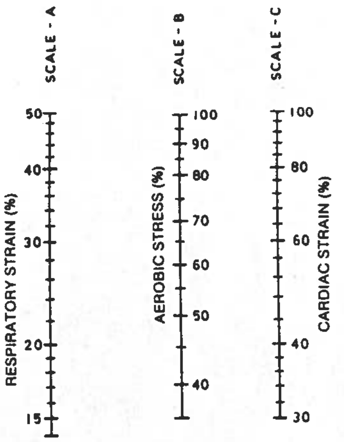

Figure 1. Nomogram for estimating aerobic stress from cardio-respiratory strains.

body weight and time for a 3·2 km run using the multiple regression equation developed by Verma *et al.* (1984).

2. Nomographic approach

The nomographic approach consists of two nomograms for estimation of maximal aerobic power. Figure 1 shows a nomogram for predicting aerobic stress from cardiac strain and respiratory strain. In this figure, Scale A gives the percentage values of respiratory strain and Scale C shows the percentage values of cardiac strain. The value of aerobic stress can be read from Scale B by direct alignment across the scales. After obtaining the value of aerobic stress, the value of maximal aerobic power may be determined very easily by substituting the oxygen consumption during exercise. Figure 2 shows a nomogram for predicting maximal aerobic power from body weight and time for a 3·2 km run. In this figure, Scale A shows the values of time for a 3·2 km run in minutes and Scale C shows the values of body weight in kilograms: the maximal aerobic power can be predicted from Scale B by alignment across the three scales.

3. Discussion

The nomographic approach provided by the nomograms in the present paper is of practical importance to research workers engaged in different branches of physiology and allied sciences. These nomograms may be considered as simple and quick methods for the estimation of maximal aerobic power without involving excessive calculations. The first nomogram is based on physiological variables that requires laboratory facilities and beyond the range of 1·83–3·28 $\mathrm{l.min^{-1}}$ of maximal aerobic power may yield significant errors in prediction. The second nomogram is based on only two simple variables. Time for a 3·2 km run and body weight are very simple to measure and require no laboratory facility. For this reason, the second nomogram should be most useful in field situations. However, the application of this nomogram beyond the range of 1·76–3·06 $\mathrm{l.min^{-1}}$ of maximal aerobic power may yield significant prediction errors. These simple nomograms are a continuation of our earlier studies (Verma *et al.* 1979) for wider applications of multiple linear regression equations to estimate energy spiratory strains.

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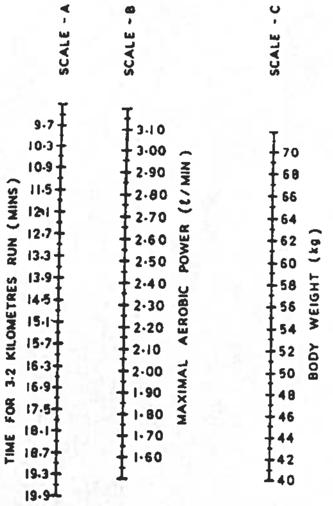

Figure 2. Nomogram for estimating maximal aerobic power from body weight and time for 3·2 km run.

expenditure from minute ventilation and heart rate at different work rates. Similarly, Chorbajian (1971) simplified the heart beat frequency model of Cardus and Zeigler (1968) by suggesting a nomographic approach to estimate heart rate recovery time after exercise based on three values of heart beat frequency during the first two minutes of recovery, and, Bandopadhyay *et al.* (1993) constructed a nomogram from the multiple linear regression equation developed for predicting peak expiratory flow rate from age and body height in Indian girls. Thus, nomographic approaches have played an important role in all branches of biomedical sciences and biostatistics.

4. Conclusion

Maximal aerobic power has been accepted as a measure of cardiorespiratory strain of a subject and may be considered as a direct measure of physical fitness. The nomograms suggested in this paper for indirect estimation of aerobic power are simple and quick procedures for practical research work in the field situation without involving complicated statistical calculations. However, the applications of these nomograms beyond the stated ranges of maximal aerobic power may yield significant errors in prediction.

Acknowledgement

The author is grateful to Dr W. Selvamurthy, Director, Defence Institute of Physiology and Allied Scences for his keen interest and encouragement.

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Center for Academic Publications Japan. Printed in Japan.

PHYSICAL EFFICIENCY OF BENGALI FARMERS IN RESPONSE TO CHANGE IN ENVIRONMENTAL FACTORS

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The present study was conducted on young farmers, selected randomly from a village of West Bengal. Their pre-exercise heart rate (HR), blood pressure (BP), mean arterial pressure (MAP), and other physical parameters were recorded. They were asked to perform standard step test at four different times of a day when environmental factors were recorded. Recorded environmental factors were maximum ambient temperature ($T_{\max}$), and minimum ambient temperature ($T_{\min}$) for the whole day, ambient temperature (T_a), relative humidity (RH), air velocity (AV), and globe temperature (T_g). The barometric pressure (P) was noted to be constant throughout the experiment. Post-exercise HR and MAP were also recorded. Our observations showed that environmental factors changed as the day progressed from the morning to noon and from noon to night; the physiological parameters of the farmers also changed. HR was lowest in the morning and night but highest in the evening while MAP was highest at midday and gradually returned to the pre-exercise level by the evening. The determined Physical Fitness Index (PFI) of the farmers was noted to be lowest at midday but highest at night. Our studies indicate that environmental factors have a role on the physical efficiency of farmers. T_a, RH and T_g appear to be primarily responsible for the alterations in the physiological functions and PFI.

Environmental factors have an immense effect on living organisms. Most important factors influencing human performance are the changing ambient temperature (T_a), relative humidity (RH), air velocity (AV), radiant heat (T_{rad}), and barometric pressure (P). These factors are always changing, even during the course of a day. Human performance, which depends on the energy-yielding

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Received for publication August 17, 1993.

processes of the body concomitantly show variation along with the change in environmental factors. In spite of presence of an effective homeostatic mechanism to stabilize internal environment, several environmental factors impose certain limitations on the work performance by impairing/altering physiological functions of several organs, even in extreme cases, loss of lives are also reported. DILL et al. (1931), and ASMUSSEN (1940) reported that there was no increase in cardiac output (CO) in hot environment while heart rate (HR) rose markedly and stroke volume (SV) decreased considerably. It was also reported that gradual decrease in mean arterial blood pressure (MAP) and SV brought about cardiovascular inability to continue work (ASMUSSEN, 1940; DILL et al., 1931; BEISER et al., 1970; ROWELL, 1974). ROWELL (1974) also revealed that an increase in HR was not sufficient for the increase in CO under exercise and thermal stress. SUZUKI (1980) showed that a decrease in SV might cause a decline in O_2 uptake with decreased CO. He also reported that this decrease in SV probably resulted from the alteration in peripheral circulation and/or distribution of blood in hot environment. He also suggested that the ability to perform exercise in a hot environment decreases due to cardiovascular failure. SENGUPTA et al. (1977) observed that Indian subjects showed a progressive decline in steady state O_2 consumption with an increase in the environmental heat load.

Although several workers studied the effect of different environmental factors on the human body, very few (if any) reports were on the combined effect of several environmental factors together on the outdoor work performance of workers throughout the day. Therefore, the present study was undertaken to investigate how the changes in environmental factors affected the work performance of outdoor workers of Bengali farmers in different periods of the day.

METHODS AND MATERIALS

The present investigation was conducted in May, 1991, for a duration of 4 weeks, in the Churpuni village near Katwa P. S. of the Burdwan District in West Bengal, India. Ten young healthy farmers from this village were randomly selected for our investigation. The mean age, height and weight of the subjects were 25.0± 5.37 yr, 161.5±5.61 cm and 49.5±5.79 kg, respectively (Table 1). Their body surface area (BSA) was calculated by using standard nomogram (BANERJEE and SEN, 1957). BSA and BW ratio (SEN et al., 1977) was also determined. These values are shown in Table 1. None of the subjects had a history of any serious

Table 1. Physical characteristics of farmers (mean±S.D., $n=10$).

Age (yr)	Height (cm)	Weight (kg)	BSA (m^2)	BSA/Bd. wt. ×100 (m^2/kg) %
25.0±5.37	161.5±5.61	49.5±5.79	1.55±0.11	3.14±0.16

illness.

The Physical Fitness Index (PFI) was determined as per the procedure of GALLAGHER and BROUHA (1943), and modified by DAS et al. (1988). The procedure for determining the PFI was as follows.

PFI was determined from Harvard Step Test (HST) according to the modified method of GALLAGHER and BROUHA (1943) who suggested that, for evaluating subjects with a body surface area below 1.85 m^2, an 18-inch stool should be appropriate. The test was done on an 18-inch stool with 30 steps up and down per minute for a maximum duration of 4 min. The recovery heart rates were counted between 1 to 1.5 min, 2 to 2.5 min, and 3 to 3.5 min at the end of the step test. The PFI was scored as follows

$$\mathrm{PFI} = \frac{\text{Duration of exercise in sec} \times 100}{2 \times \text{Sum of three half-min heart rates}}$$

The subjects were well acquainted with the experimental protocol by preliminary trials till they could perform the test without any problem.

Normal daily activities of the subjects were not altered during the course of this investigation. Four specific times of the day were chosen for the step test according to their availability and expected maximum change in environmental factors. The four specific times were

i) 7:00 h before start of their routine work in field,
ii) 12:00 h break for their lunch,
iii) 17:00 h when they left field for the day and finally
iv) 21:00 h before they went to bed.

The meal timing of the farmer community and especially the test subjects were as follows:

i) 6:00 h. Morning tea with light snack of puffed rice.
ii) 9:00 to 10:00 h. Breakfast of rice and vegetable or jaggery.
iii) 13:30 to 14:30 h. Lunch of rice and vegetable with occasional fish or egg.
iv) 19:00 h. Tea with light snack of puffed rice.
v) 21:30 to 22:30 h. Dinner of rice with vegetables.

RESULTS

At each time period prior to the exercise test, environmental factors, T_a, wet bulb temperature T_{wb}, AV and globe temperature T_g were measured. From those measurements, the Wet Bulb Globe Temperature Index (WBGT) was calculated (Table 2). T_{max} and T_{min} were noted once each day, the mean values ± standard deviation were 36.38 ± 3.30 and 29.00 ± 1.30°C, respectively.

The physiological parameters recorded were resting heart rate and blood pressure prior to step test at said four times by standard techniques. MAP

Table 2. Environmental parameters at different times of day (mean±S.D., $n=6$).

	7:00 h	12:00 h	17:00 h	21:00 h
T_a (°C)	31.7±1.62	36.8±3.30	33.7±3.42	30.0±1.75
T_{wb} (°C)	26.5±2.05	31.4±2.57	31.2±2.22	25.0±1.52
T_g (°C)	34.2±1.87	38.2±2.29	35.3±2.94	30.0±0.82
RH (%)	69.0±4.03	86.0±5.72	85.0±7.48	62.0±3.14
AV (m/s)	1.98±0.50	1.12±1.28	1.72±0.90	2.24±0.65
WBGT (°C)	28.8±2.30	35.5±1.90	32.4±2.39	26.5±1.09

Table 3. Physiological response of the farmers at different times of day (mean±S.D., $n=10$).

	7:00 h		12:00 h		17:00 h		21:00 h	
	Before exercise	After exercise	Before exercise	After exercise	Before exercise	After exercise	Before exercise	After exercise
Heart rate (beats/min)	69.00±6.54	93.60±5.99	78.40±8.56	110.50±7.28*	79.50±9.75	107.70±5.50*	68.80±6.19	96.00±7.62
Systolic blood pressure (mmHg)	117.50±5.94	149.10±7.08	128.10±6.43	155.10±6.40	116.40±7.58	142.20±6.92	114.20±6.21	155.00±6.02
Diastolic blood pressure (mmHg)	78.10±4.04	79.50±3.54	87.90±4.28	75.90±2.60	78.00±2.62	76.50±2.95	77.00±3.49	79.90±2.73
Mean arterial pressure (mmHg)	91.00±3.85	102.30±4.24	101.20±3.73	101.80±2.58	90.90±3.69	98.10±3.36	88.20±4.77	104.10±3.67
Physical fitness index		99.90±7.86		80.80±5.32*		83.80±3.25*		101.20±6.08

* Statistical significance $p<0.001$.

(Diastolic Pressure + 1/3 Pulse Pressure) was calculated. Also recorded were change in heart rate and MAP immediately after cessation of exercise every time (Table 3).

The PFI was determined as recommended by GALLAGHER and BROUHA (1943), and DAS et al. (1988) for Indian subjects at the said four specified times. The PFI score is reported in Table 3 along with other physiological parameters. Student's *t*-test was performed on post-exercise physiological parameters and PFI with morning 7:00 h post-exercise values. The significant differences in mean are flagged in the table.

DISCUSSION

Our present study showed that physiological parameter and PFI changed with the alteration of environmental factors. Performing capacity decreased with increase in T_a, RH, T_g, but significantly increased when these factors were low. Air velocity, favoring cooling, showed increased effect with those of T_a, T_{wb}, T_g on the PFI. Several previous studies also reported the decrease in several physiological functions with an increase in heat load and/or increase in humidity (ASMUSSEN, 1940; ÅSTRAND et al., 1964; ADAMS et al., 1975; BEISER et al., 1970; BROUHA et al., 1943; COHEN and MUCHL, 1977; DILL et al., 1931; MARX et al., 1967; and MITCHELL et al., 1972).

It was demonstrated by SUZUKI (1980), ROWELL (1974), and others that the most affected physiological function under heat stress was the cardiovascular system. A decrease in stroke volume and increase in HR was reported by DILL et al. (1931) and ASMUSSEN (1940) during heat stress. BEISER et al. (1970) and ROWELL (1974) suggested that cardiovascular inability due to decrease in MAP and SV during heat stress reduced the working efficiency of the subjects. Our observation also showed a decrease in the PFI score of the farmer in the midday when the T_a was highest, along with maximum RH and T_g and minimum AV. Perhaps reduced cardiovascular efficiency was the cause of the reduced efficiency. Besides, several other workers observed that during thermal load there was a redistribution of blood flow (SUZUKI, 1980). In thermal stress, an increase in blood flow through skin reduces venous return and thereby CO (MITCHELL et al., 1972); the changed flow pattern reduced O_2 uptake and thereby decreased the ability to perform work (SUZUKI, 1980). SENGUPTA et al. (1977) also observed that steady state O_2 consumption progressively decreased as the environmental heat load increased. A decrease in PFI in the present observation was also commensurate with other related factors. Due to the decrease in O_2 availability, performance capacity was lowest, but when thermal stress decreased, as at night and in the morning, efficiency was maximum. The probable mechanism by which increased intensity of environmental factors reduces PFI may be due to the limitations of the cardiovascular system. Further study will reveal the exact cause of such alterations during variation of environmental factors.

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ERGONOMICS, 1980, VOL. 23, NO. 2, 91–102

Occupational workload of Indian agricultural workers

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The occupational workload of 13 agricultural workers was determined during a summer season, on the basis of cardio-respiratory responses and individual capacity to perform work. Thirty different agricultural operations were observed during the actual working season. $\dot{V}O_2$max of the workers was 34·8 cm^3 min^{-1} kg^{-1}, ranging from 28·6 to 41·5 cm^3 min^{-1} kg^{-1}. Pulmonary ventilation during the operations varied from 14 to 41 l min^{-1}; only water lifting, bund trimming in dry-land and pedal threshing operations demanded more than 30 l min^{-1}, and these were found to be the heaviest jobs in agricultural work. About 29% of total man-hours are involved in light work, 64% in moderate work and only 6% in heavy work. Daily energy expenditure of the workers varied from 10·3 to 11·7 MJ, of which 53 to 56% energy was expended during the working day (*i.e.* the time-weighted work demand was about 30 to 40% of $\dot{V}O_2$ max) and about one-fifth of total heat production of the body was external thermal load.

1. Introduction

Physiologists and ergonomists have determined the energy needs of many industrial workers and miners in India during occupational work and leisure-time activity (Banerjee *et al.* 1959, Chakraborty and Guha Ray 1963, 1966, Sen *et al.* 1964 a and b, 1966, Sen and Nag 1974, 1975). Similar studies on agricultural workers (Nag *et al.* 1978 b, Ramana Murthy and Belavady 1966, Rao and Saha 1965) have been sporadic and scanty. The authors have recently reported some important agricultural work operations in the western part of India (NIOH report 1977).

The present paper reports the energy used by agricultural males in different types of work and leisure-time activity, with a hope that activity levels could be quantified and standardised for man-power management. The occupational workload of the agricultural workers must be set, not only in relation to energy expenditure as it has often been done by earlier investigators, but also in terms of individual capacity to perform work under various environmental conditions.

2. Materials and methods

The investigation was carried out in two phases in the Eastern and Western part of India during the summer months of April and May. Thirteen healthy young male workers, apparently free from any disease were selected. They were solely dependent on farming economy. Physical characteristics, *e.g.* age, body height, body weight and skinfold thicknesses of the workers were measured. The lean body mass and body fat were calculated.

A month-long observation on the nature of agricultural work was undertaken and a large number of elements of work were noted using standard work-study techniques. The man-hours involved in each of the elements of work were recorded during a one week period. In total, thirty agricultural operations were studied. Many other operations were done only by female workers. Some non-occupational farm activities were performed by the workers and these are not taken into account in man-hours calculation. Food intakes of the workers were recorded using a standard technique (Weiner and Lourie 1969).

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2.1. *Physiological measurements*

During actual work, physiological responses were measured using the traditional techniques. To measure pulmonary ventilation, the expiratory side of the low resistance respiratory valve was connected to a calibrated *Kofranyi-Michaelis respirometer* and an aliquot (0·6) sample of each expired breath was collected through the side-tube of the respirometer. The oxygen content of the expired air was measured using a *Beckman paramagnetic oxygen analyser*. The radial pulse rates of the subjects were recorded from stop-watch time for 10 pulse beats. Energy expenditure was calculated from the oxygen consumption and the weighted average of the coefficient of energy equivalent of one litre of oxygen, which was obtained from mixed nutrients, i.e. total protein, fat and carbohydrate consumed by the workers. The average energy equivalent of one litre oxygen was found to be 20·86 ± 0·025 kJ. The whole-day energy expenditure was calculated from the detailed time-records of daily activities of the workers. Thermal data was recorded at the work place, using a whirling psychrometer, katathermometer and globe thermometer.

The step-increase exercises were performed by the workers under similar climatic conditions on a *Fahrrad's bicycle ergometer* in order to determine the maximum oxygen uptakes. Most of the workers were accustomed by bicycle riding; thus training on the bicycle ergometer was not required. However, prior to the tests the workers were acquainted with the experimental protocol. A similar procedure to that of Åstrand and Rodhal (1970) was followed to select the workloads, and the workers pedalled at the rate of 60 rev min^{-1} for 4 to 5 min, starting from 50 W. Oxygen uptake was determined using the methods described above, and the exercise heart rates at intervals of one minute were obtained from a continuous ECG record. The criteria for attaining maximum oxygen uptake were volitional exhaustion, a heart rate of more than 190 beats min^{-1}, and/or no material change in oxygen uptake with the increase of workloads.

3. Results and discussion

The physical characteristics of the agricultural workers are given in table 1. The ages of the subjects ranged from 19 to 36 y, with a mean of 26·8 y. The average body weight of the subjects was 44·6 kg, and the body fat was only 8% of the body weight. All of them were regularly engaged in agricultural work.

It was reported earlier (Nag *et al.* 1978 b, NIOH 1976) that the energy requirement levels of Indian agricultural workers are above subsistence threshold. The diets are heavily weighted towards less preferred starchy staples. The average daily energy intake of the present workers was 11·9 ± 1·1 MJ, of which 82% of the total energy was obtained from carbohydrate. Only 8·5 and 9·2% of the total energy respectively were derived from fat and protein. Most of the protein was derived from vegetable sources and animal protein was negligible.

The average maximal oxygen uptake of the workers was 34·85 ± 2·42 cm^3 min^{-1} kg^{-1}, ranging from 28·6 to 41·5 cm^3 min^{-1} kg^{-1}. Of the thirteen subjects, 3 subjects had maximal oxygen uptake of less than 1·5 l min^{-1}. The average values of the present workers were slightly less than those of Indian industrial workers (Sen 1967, Ramaswamy *et al.* 1964) and similar to our earlier group of agricultural workers (Nag *et al.* 1978 a). The maximal oxygen uptake for an average subject of 23 y of age was 42·8 cm^3 min^{-1} kg^{-1}, and for a subject of 34·8 y of age the value was only 35·7 cm^3 min^{-1} kg^{-1}. The maximal oxygen uptake values were used to express the relative cost of different agricultural work, as a percentage of $\dot{V}O_2$max.

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Table 1. Physical characteristics and nutritional status of Indian agricultural workers.

Variables	Mean	± Standard error
1. Age (y)	26·8	1·8
2. Body height (cm)	157·6	1·7
3. Body weight (kg)	44·6	1·4
4. Body surface area (m²)	1·49	0·03
5. Lean body weight (kg)	41·0	1·3
6. Daily energy intake (MJ)	11·9	1·1
7. Energy from carbohydrate (%)	82·0	2·6
8. Energy from protein (%)	9·2	0·5
9. Energy from fat (%)	8·5	2·8
10. Energy equivalent of one litre oxygen (kJ)	20·88	0·03
11. Maximal oxygen uptake ($cm^3\ min^{-1}\ kg^{-1}$) STPD	34·85	2·43

3.1. *Physiological responses in work*

Different agricultural operations included in the study are presented in table 2, and some of the typical operations are shown in figures 1–9. On the basis of severity of physiological responses, (i.e. pulmonary ventilation, energy expenditure, heart rate and the relative cost of the work as percentage of the maximal oxygen uptake), the operations are graded in sequence, as shown in table 2. Pulmonary ventilation, oxygen consumption and energy expenditure are expressed per 50 kg reference body weight of Indians (Sen, Nag and Ray 1977). The pulmonary demand due to the operations varied from 14 to 41 l min^{-1} (BTPS). As many as seventeen operations out of thirty, demanded pulmonary ventilation within 20 l min^{-1} (BTPS). Only three operations (*i.e.* water lifting, bund trimming in dry-land and pedal threshing) demanded more than 30 l min^{-1} pulmonary ventilation. Though the difference between the two adjacent pulmonary ventilation, as given in table 2, are not marked in most cases, the large coefficient of variations in each case suggests wide inter-individual variation. There were also large variations in the oxygen uptakes in different operations for the same pulmonary demand. Usually, the oxygen uptakes varied from 0·37 to 1·407 l min^{-1} (STPD). As many as nineteen agricultural operations lie within the oxygen uptake of 0·65 l min^{-1}. Operations such as laddering (by two men) to level the ploughed ground (7·82 kJ min^{-1}), fertilising (9·7 kJ min^{-1}) and cutting crops (10·25 kJ min^{-1}) *etc.* are the lightest jobs, and ploughing (20·96 kJ min^{-1}), water lifting (22·05 kJ min^{-1}) bund trimming (wet land and dry land: 23·11 and 29·54 kJ min^{-1} respectively), threshing of paddy pennacles using a pedal thresher (27·56 kJ min^{-1}) *etc.* are the heaviest jobs in agricultural work. The present values are similar to some earlier Indian studies (Rao and Saha 1965, Ramana Murthy and Belavady 1966). Out of eight agricultural operations, Ramana Murthy and Belavady (1966) observed that puddling and bund trimming were the heaviest agricultural work.

When the observations of all the field operations were pooled, the oxygen uptake had a good statistical relationship ($r = 0·8183$), *i.e.* significant at the 1% level, with the pulmonary demand. The corresponding regression equation is:

$$\underset{\substack{(l\ min^{-1})\\(STPD)}}{\text{Oxygen uptake}} = 0{\cdot}034 \times \underset{\substack{(l\ min^{-1})\\(BTPS)}}{\text{Pulmonary Ventilation}} \pm 0{\cdot}001\ (SEM)$$

Table 2. *Physiological responses of agricultural males in different agricultural operations.

Agricultural operations	Pulmonary ventilation $(\mathrm{l\,min^{-1}})$ BTPS	Oxygen uptake $(\mathrm{l\,min^{-1}})$ STPD	Energy expenditure $(\mathrm{kJ\,min^{-1}})$	Average work pulse rate (beats $\mathrm{min^{-1}}$)	O_2 pulse $(\mathrm{cm^3\,beats^{-1}\,kg^{-1}})$	Relative cost $(\%\dot{V}O_2\,\mathrm{max})$
Sitting leisurely work: (counting grains, levelling etc., watch-keeping to scare birds)	11·9 ±0·5 (10·8)	0·214 ±0·022 (37·9)	4·49 ±0·50 (39·9)	75·5 ±2·8 (13·5)	0·059 ±0·007 (42·7)	12·8 ±1·5 (38·9)
Laddering (by two men)	14·5 ±0·5 (13·1)	0·370 ±0·040 (37·8)	7·82 ±0·72 (33·1)	114·0 ±3·3 (10·4)	0·075 ±0·003 (13·3)	21·6 ±3·2 (53·3)
Fertilising by broad-casting	16·4 ±1·6 (32·2)	0·433 ±0·056 (46·2)	9·07 ±1·20 (46·6)	126·3 ±2·6 (5·8)	0·107 ±0·001 (4·2)	24·9 ±4·0 (57·2)
Walking with tools etc.	14·6 ±1·2 (29·5)	0·449 ±0·050 (36·9)	9·41 ±1·00 (36·8)	108·6 ±4·0 (13·1)	0·098 ±0·013 (49·1)	25·8 ±3·0 (40·7)
Cutting crops using a sickle	14·2 ±1·1 (28·1)	0·488 ±0·058 (40·3)	10·25 ±1·14 (40·3)	—	—	28·0 ±2·0 (27·2)
Plucking vegetables	15·8 ±0·7 (15·9)	0·495 ±0·027 (18·5)	10·35 ±0·58 (18·5)	—	—	28·4 ±2·8 (35·0)
Water supply	15·6 ±1·5 (35·0)	0·515 ±0·058 (37·0)	10·76 ±1·10 (37·1)	—	—	29·6 ±3·7 (42·8)
Uprooting (sitting with one or two legs flexed at knee)	15·5 ±1·2 (26·7)	0·539 ±0·053 (35·6)	11·30 ±1·1 (36·1)	109·6 ±2·4 (8·2)	0·100 ±0·010 (31·8)	30·7 ±3·4 (39·7)
Sowing	15·7 ±1·1 (25·9)	0·583 ±0·100 (50·6)	11·83 ±1·62 (49·6)	—	—	33·1 ±5·0 (57·4)
Weeding (sitting with flexed knee)	17·7 ±1·2 (23·5)	0·573 ±0·040 (25·3)	11·87 ±0·85 (25·7)	113·3 ±2·6 (8·4)	0·109 ±0·007 (24·5)	32·9 ±3·9 (40·7)
Levelling of surface by some auxiliary wooden rake attached with a handle bar	17·6 ±1·6 (32·3)	0·569 ±0·039 (21·1)	11·90 ±0·70 (21·1)	—	—	32·7 ±2·7 (29·9)
Winnowing (sitting on the ground with flexed knee)	14·2 ±2·3 (57·4)	0·578 ±0·118 (71·3)	12·08 ±2·52 (71·3)	—	—	33·2 ±5·2 (55·5)
Weeding using bending posture	16·6 ±1·8 (38·4)	0·578 ±0·067 (41·5)	12·18 ±1·51 (4·2)	114·0 ±1·5 (4·7)	0·103 ±0·010 (36·1)	33·3 ±3·2 (34·0)
Cutting cane sugar	21·7 ±1·7 (28·9)	0·586 ±0·024 (16·1)	12·24 ±0·54 (16·1)	—	—	33·6 ±0·6 (7·3)
Transplanting (bending)	17·4 ±0·8 (17·5)	0·618 ±0·024 (15·8)	13·00 ±0·57 (15·9)	109·2 ±2·0 (6·2)	0·113 ±0·004 (13·1)	35·5 ±1·7 (15·2)
Laddering (by one man)	17·5 ±0·6 (13·5)	0·632 ±0·045 (25·4)	13·26 ±0·93 (25·4)	133·7 ±1·0 (3·2)	0·095 ±0·007 (25·8)	36·3 ±3·0 (29·3)
Pedal threshing helper	20·1 ±1·2 (21·6)	0·643 ±0·053 (29·5)	13·53 ±1·11 (29·5)	120·3 ±5·5 (16·5)	0·113 ±0·014 (43·3)	36·9 ±4·7 (44·8)
Uprooting (bending)	19·2 ±1·5 (28·3)	0·653 ±0·100 (52·8)	13·70 ±2·0 (52·8)	117·8 ±2·5 (7·3)	0·119 ±0·014 (42·2)	37·5 ±5·7 (54·4)
Spraying of pesticides etc.	18·3 ±1·2 (23·5)	0·656 ±0·066 (37·2)	13·72 ±1·42 (37·4)	125·5 ±3·0 (8·5)	0·124 ±0·023 (60·5)	37·7 ±4·2 (41·0)

al operations.

O_2 pulse m^3 beats^{-1} kg^{-1})	Relative cost (%$\dot{V}O_2$ max)
0·059 ±0·007 (42·7)	12·8 ±1·5 (38·9)
0·075 ±0·003 (13·3)	21·6 ±3·2 (53·3)
0·107 ±0·001 (4·2)	24·9 ±4·0 (57·2)
0·098 ±0·013 (49·1)	25·8 ±3·0 (40·7)
—	28·0 ±2·0 (27·2)
—	28·4 ±2·8 (35·0)
—	29·6 ±3·7 (42·8)
0·100 ±0·010 (31·8)	30·7 ±3·4 (39·7)
—	33·1 ±5·0 (57·4)
0·109 ±0·007 (24·5)	32·9 ±3·9 (40·7)
—	32·7 ±2·7 (29·9)
—	33·2 ±5·2 (55·5)
0·103 ±0·010 (36·1)	33·3 ±3·2 (34·0)
—	33·6 ±0·6 (7·3)
0·113 ±0·004 (13·1)	35·5 ±1·7 (15·2)
0·095 ±0·007 (25·8)	36·3 ±3·0 (29·3)
0·113 ±0·014 (43·3)	36·9 ±4·7 (44·8)
0·119 ±0·014 (42·2)	37·5 ±5·7 (54·4)
0·124 ±0·023 (60·5)	37·7 ±4·2 (41·0)

Carrying loads (20 to 25 kg)	21·2 ±1·8 (30·0)	0·676 ±0·042 (22·6)	16·27 ±2·05 (43·7)	126·5 ±3·4 (8·5)	0·103 ±0·013 (46·9)	38·8 ±7·1 (65·9)
Weeding with projection finger type weeder in wet land.	24·4 ±2·8 (26·9)	0·793 ±0·069 (31·3)	16·70 ±1·50 (31·4)	116·3 ±2·0 (5·1)	0·137 ±0·012 (31·9)	45·5 ±3·4 (26·0)
Winnowing (standing)	22·9 ±1·2 (18·9)	0·808 ±0·043 (19·2)	17·06 ±1·00 (19·4)	124·3 ±2·0 (5·2)	0·132 ±0·010 (22·6)	46·4 ±3·0 (22·3)
Weeding with weeder in dry land	25·4 ±2·0 (28·5)	0·848 ±0·102 (43·1)	17·68 ±2·10 (43·3)	113·7 ±1·8 (5·6)	0·232 ±0·063 (56·0)	54·2 ±7·5 (49·6)
Manual threshing of paddy pennacle by beating	28·1 ±0·7 (8·8)	0·916 ±0·036 (13·7)	19·26 ±0·75 (13·6)	135·8 ±2·5 (6·5)	[illegible] [illegible] (16·1)	52·7 ±6·1 (43·5)
Ploughing	24·8 ±2·3 (32·7)	0·997 ±0·106 (39·9)	20·96 ±2·34 (40·0)	131·2 ±2·6 (6·7)	0·182 ±0·013 (26·0)	57·3 ±7·8 (48·9)
Water lifting using a device 'Donga'	31·2 ±1·6 (18·1)	1·050 ±0·069 (23·5)	22·04 ±1·48 (23·8)	153·8 ±1·8 (4·2)	0·138 ±0·010 (22·9)	60·3 ±4·5 (27·3)
Digging soil using spade (dry land)	27·4 ±1·7 (22·4)	0·948 ±0·070 (25·6)	22·58 ±1·15 (17·9)	131·2 ±3·1 (8·4)	0·163 ±0·007 (16·6)	54·4 ±4·7 (30·4)
Bund trimming (wet land)	28·2 ±1·7 (21·5)	1·100 ±0·074 (24·3)	23·11 ±1·18 (18·5)	131·0 ±3·1 (8·5)	0·178 ±0·007 (14·2)	63·5 ±9·8 (54·5)
Pedal threshing	41·2 ±0·7 (6·6)	1·310 ±0·095 (26·3)	27·56 ±2·20 (26·4)	140·8 ±2·7 (6·8)	0·188 ±0·014 (29·0)	75·2 ±10·1 (49·4)
Bund trimming (dry land)	34·6 ±2·1 (21·7)	1·407 ±0·092 (23·5)	29·54 ±1·98 (23·4)	133·3 ±5·3 (14·4)	0·213 ±0·007 (11·4)	80·8 ±3·5 (15·6)

* Values are means ± standard errors (coefficient of variation).

Many operations like weeding, uprooting and transplanting operations are performed by hand while sitting with one or two legs flexed at the knee and in bending postures. Removal of unwanted weeds from the cultivated land is one of the important agricultural operations and as many as 10% of the total man-hours are involved in weeding. Sometimes, it is performed with the help of some projection finger-type weeder, which is commonly observed in the eastern part of the country.

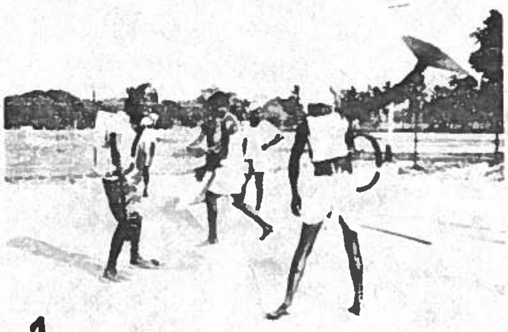
It was found that, though bending requires slightly more oxygen usage, weeding, either in the sitting (11·27 kJ min^{-1}) or bending postures (12·18 kJ min^{-1}) does not cause a marked difference. Whereas, uprooting rice plants demands a greater physiological cost of the bending posture (13·70 kJ min^{-1}) than in the sitting posture (11·30 kJ min^{-1}). Workers usually perform the work hapazardly in any of the postures. From an ergonomic point of view it is suggested that when work can be done in a sitting posture it should not be done in a bending posture.

Unlike respiratory responses, it has been found that there was not much consistency in average work pulse rate response with the severity of work operations as graded on the basis of respiratory parameters. The average work pulse rate ranged from 108 to 153 beats min^{-1} in different agricultural work. However, for a large number of operations cardiac responses were less than 130 beats min^{-1}, which was considered as a moderate level of heaviness of work (Christensen 1953, Sen and Nag 1975). Only water lifting and pedal threshing operations required 153·3 and 140·3 beats min^{-1} respectively.

Much of the agricultural work involved varying degrees of static components in dynamic work. Static components were involved in grasping and holding tools and in postural control of trunk and head in work in awkward postures. Work with a mixture of static-dynamic components yielded a disproportionately high heart rate response (Knox 1951, Lind and McNicol 1967, Lind *et al.* 1976) in contrast to other physiological responses, such as pulmonary ventilation and oxygen uptake, which are more related to the rhythmic component of work. Certain inconsistency in cardiovascular repercussions (which are further reflected in the oxygen-pulse, the combined expression of cardiovascular and respiratory responses) in the present study suggest differential involvement of static muscular components in the operations.

3.2. *Categorisation of occupational workload*

Work intensity of the present operations are classified in terms of 'light', 'moderate', 'heavy' and 'extremely heavy', which correspond to up to 25%, above 25 to 50%, above 50 to 75% and beyond 75% of the maximal oxygen uptake respectively, obtained from rhythmic bicycle ergometry. The operations are shown in table 3. Indicative values of the energy cost of present gradations are somewhat different from earlier reported values (Malhotra *et al.* 1966, Ramanathan *et al.* 1967, Sen and Nag 1975) on Indian subjects. This is possibly because of the difference in maximum oxygen uptake of the respective population. It is noted that out of 30 agricultural operations, only five operations are considered as heavy but as many as seventeen are moderately heavy.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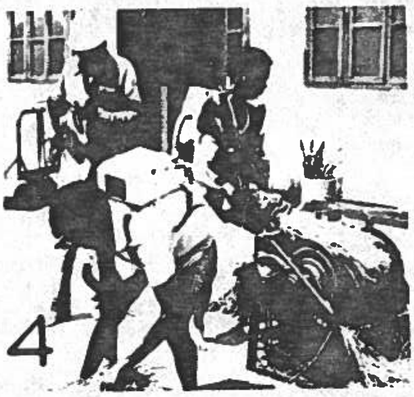
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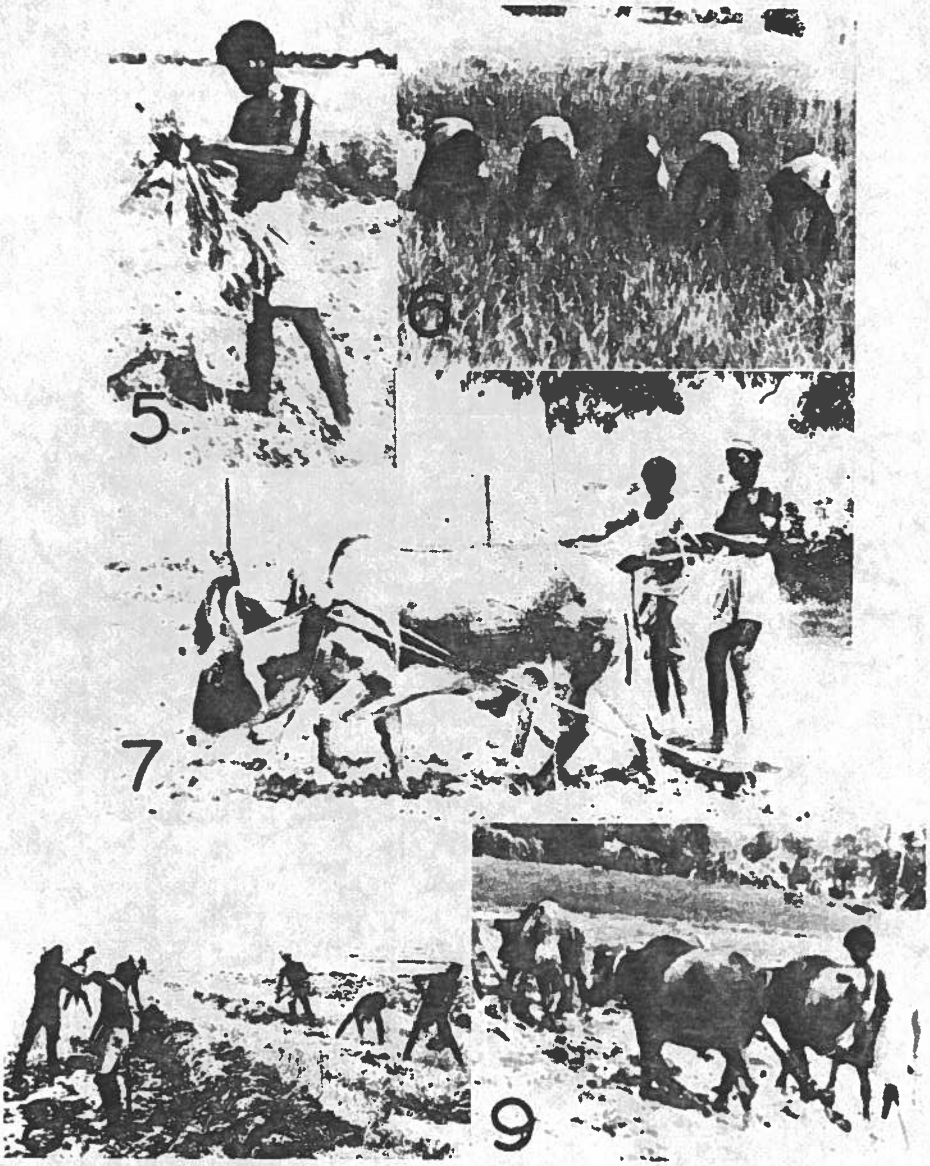

Figures 1–9. Some typical agricultural operations. (1) Winnowing; (2) Threshing of paddy pennacles by beating; (3) Lifting water using a device 'Donga'; (4) Threshing by pedal thresher; (5) Making bundles of paddy; (6) Weeding in wetland; (7) Laddering by two men; (8) Trimming bunds; (9) Ploughing.

The present authors agree with Petrofsky and Lind (1978) that a given percentage of maximal oxygen uptake for the particular job being done should be obtained and that it cannot be assessed in terms of percentage $\dot{V}O_2$max obtained from other kinds of work. Since this type of experimentation is of a complex nature and will definitely vary from job to job, it will not always be possible to assess the stress of the job based on time-consuming experimentation. For assessment of metabolic needs the technique which is more important (i.e. the amount of oxygen uptake for the job) as compared to the

Table 3. Categorisation of the agricultural work.

Variables	Light	Moderate	Heavy	Extremely heavy
$\dot{V}O_2$ max (%)	Below 25%	Up to 50%	Up to 75%	Above 75%
O_2 consumption ($l\,min^{-1}$)	<0·435	0·436–0·870	0·871–1·305	> 1·306
Energy cost ($kJ\,min^{-1}$)	<9·10	9·11–18·15	18·16–27·22	>27·23
Man-hours involved in each category (%)	29·0	64·0	6·0	1·0
Operations in each category	Sitting work and rest during field activities, watch keeping to scare birds, counting grains, shelving, and labelling, etc. fertilising, laddering by two men.	Laddering (single), walking with tools etc., plucking vegetables, water supply, uprooting (sitting and bending, cutting crops, winnowing (sitting and standing), cutting sugar cane, transplanting (bending), pedal threshing helper, spraying, carrying loads, weeding with projection finger type weeder.	Ploughing, water lifting, digging soil, bund trimming (wet land), manual threshing by beating.	Pedal threshing and bund trimming (dry land)

maximum oxygen uptake obtained from standard bicycle ergometry, may be used until a less cumbersome technique is evolved which will account for both static and dynamic components.

The man-hours involved in each of the operations were expressed as a percentage of the total man-hours involved in work during an actual working season. The average man-hours of each category (light, moderate, heavy and extremely heavy) are also shown in table 3. It is interesting that only 29% of the total man-hours are involved in light work, 64% in moderate work and only 6% in heavy work. For only about one per cent of the total man-hours, the workers had to undertake extremely heavy work. Thus the physical activities in agriculture usually lies within a moderate level of activity, excepting for periodical short spurts of heavy activities.

It has been shown (Åstrand 1960, Åstrand *et al.* 1973, Bonjer 1968, Michaels *et al.* 1961, Nag *et al.* 1979), that for long duration work the activity levels should not exceed 35 to 50% of $\dot{V}O_2$max in excess of which a substantial amount of anaerobiosis occurs in the working muscles. On the basis of lifting work, Petrofsky and Lind (1978) also suggested that above 50% of $\dot{V}O_2$max heart rate and arterial lactate concentration increased rapidly, and lifting could not be continued for periods of more than 2 h.

In the present subjects the oxygen uptakes obtained in laboratory exercises and during field operations at different levels of pulse rates (figure 10) showed no statistically significant difference. The oxygen uptakes at the pulse rates of 120, 130, 140, 150 and 160 beats min^{-1} correspond to 43, 48, 55, 61 and 74% of maximal oxygen uptake *i.e.*, from 120 to 150 pulse beats min^{-1}, the relative load of work was increased by about 5 to 7% of maximal oxygen uptake for every increment of 10 pulse beats per minute. Thus, to choose the optimal activity level at about 40 to 50% of maximal oxygen uptake, one may take an approximate pulse rate of 120 to 130 beats min^{-1} as

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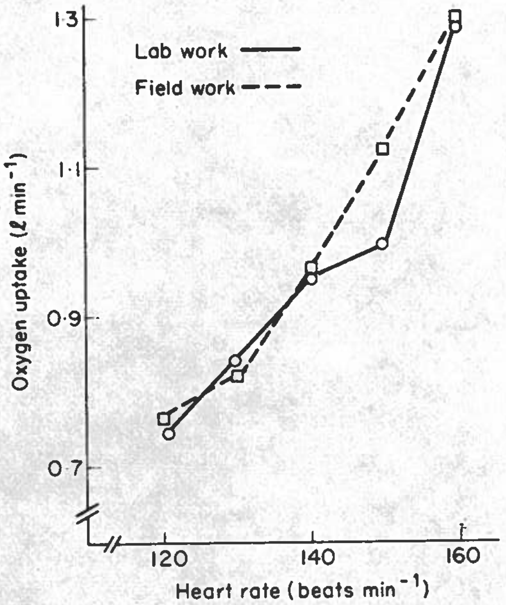

Figure 10. Oxygen uptake of the workers at different levels of heart rate during standard laboratory bicycle ergometric exercise and field operations.

the criteria for such a decision. By fixing the oxygen uptake it is also possible to arrive at 120 to 130 beats min^{-1}, representing a moderate level of activity. The total daily energy expenditure of the present group of workers varied from 10·3 to 11·7 MJ, of which 53 to 56% of the total energy (*i.e.*, about 5·6 to 6·6 MJ) was expended during a working day. While a time-weighted average of the whole-day activities amounts to 7·2 to 8·1 kJ min^{-1} (*i.e.*, the relative load was only around 20 to 22% of maximal oxygen uptake). Whereas, if the working day energy expenditure only is taken into account, the time-weighted average demand was around 10·9 to 14·6 kJ min^{-1} (*i.e.*, about 30 to 40% of maximal oxygen uptake). Considering occasional peak loads, it is suggested that the level of activity of Indian agricultural workers should be so adjusted that the demand of the body is maintained within a moderate level of activity (*i.e.*, within 50% of $\dot{V}O_2$ max). According to Wyndham and Sluis-Cremer (1969) the present group of agricultural workers may be capable of performing a moderate level of activity for a long duration, since their $\dot{V}O_2$max was more than 30 cm^3 min^{-1} kg^{-1}.

The heat stress indices were computed using suitable equations and/or nomograms, as given in table 4. The values suggest that there was a substantial amount of heat load on the workers during the summer months. The effective and corrected effective temperature, and wet-bulb-globe temperature varied around 31°C. The Heat stress Index (*i.e.*, $E_{req}/E_{max} \times 100$) (Belding and Hatch 1956) was found to be 345 for a moderate level of activity. It has been calculated that about one-fifth of the total heat production of the body was the external thermal load. Thus, at a moderate level of activity the exposure time was calculated as only 20 min h^{-1}. To reduce cardiovascular repercussions and thermoregulatory stresses, under the existing climatic conditions, there is justification, to adjust the work load downwards with due consideration to the heat load.

Table 4. Heat stress and strain indices in Indian agricultural work.

Variable	Mean	SE
ET (°C)	30·6	0·33
CET (°C)	31·1	0·30
WBGT (°C)	31·3	0·33
P_4SR (litres)–moderate work	2·89	0·07
HSI ($E_{req}/E_{max} \times 100$)		
Light work	143	61·2
Moderate work	345	93·6

As a matter of relevance, it may be stated that there is enough scope to reduce further the workload of Indian agricultural workers by improving certain traditional work methods. Sophisticated agricultural machines will not be very useful for various reasons, even if they are provided to the workers. Studies are in progress to improvise simpler tools and methods for Indian workers.

The authors sincerely express their gratitude to Dr. S. K. Chatterjee, Director of the Institute for his keen interest and valuable suggestions in the study. Kind co-operation of Mr. P. Dutt and Dr. G. T. Kurup, Agricultural Engineering Div., Mr. S. Tutti, Farm Superintendent, CRRI, Cuttack, Orissa, and Dr. R. M. Patel, Campus Director, Dr. D. P. Patel and Dr. T. G. Maheshwary of the Department of Agronomy, B.A. College of Agriculture, Anand, Gujarat are gratefully acknowledged. Thanks are due to Mr. M. S. Vaghela and Mr. G. C. Shaikh, NIOH and Mr. D. Das, CRRI for their technical help.

Sur la base des réponses cardio-vasculaires et la capacité individuelle de travail, on a déterminé la charge de travail chez 13 ouvriers agricoles pendant l'été. Durant cette saison, 30 tâches agricoles différentes ont été étudiées. La $\dot{V}O_2$max des ouvriers était de 34,8 cm^3 mn^{-1} kg^{-1}, allant de 28,6 à 41,5 cm^3 mn^{-1} kg^{-1}. La ventilation pulmonaire variait, durant ces tâches, entre 14 et 41.1 mn^{-1}. Seuls la taille des haies de terre aride, le puisage d'eau et le battage au moyen d'une machine à pédales, qui exigeaient plus de 30 l mn^{-1} pouvaient être considérés comme les opérations agricoles les plus astreignantes. Environ 29% des heures-hommes étaient consacrés au travail léger, 64% au travail modéré et 6% au travail lourd. La dépense énergétique journalière des ouvriers variait entre 10,3 et 11,7 MJ dont 53 à 50% étaient dépensés pendant la journée de travail (l'exigence de travail pondérée par le temps était d'environ 30 à 40% de la $\dot{V}O_2$max) et environ un cinquième de la production totale de chaleur corporelle était dû à la charge thermique externe.

Aus cardio-respiratorischen Reaktionen und der individuellen Arbeitskapazität wurde die berufliche Belastung von 13 Landarbeitern während der Sommersaison bestimmt. Während dieser Arbeitsperiode wurden 30 verschiedene landwirtschaftliche Tätigkeiten beobachtet.

$\dot{V}O_2$max der Arbeiter lag bei 34,8 cm^3 min^{-1} kg^{-1}, bei einer Spannweite von 28,6 bis 41,5 cm3 min^{-1} kg^{-1}.

Die Lungenventilation bei diesen Tätigkeiten variierte von 14 bis 41 l min^{-1}, nur beim Wasserschöpfen, beim Bearbeiten von trockenem Boden und beim Pedal-Dreschen war eine Ventilation höher als 30 l min^{-1} erforderlich, diese Tätigkeiten wurden als die schwarten bei der Landarbiet gefunden. Etwa 29% der gesamten Arbeitszeit wurde bei leichter Arbeit, 64% bei mittelschwerer und nur 6% bei schwerer Arbeit zugebracht. Der tägliche Energiemunsatz der Arbeiter variierte von 10,3 bis 11,7 MJ, wovon 53 bis 56% während des Arbeitstags aufgewendet wurde (d.h. die zeitgewichtete Arbeit verlangt etwa 30–40% von $\dot{V}O_2$ max); etwa ein Fünftel der gesamten Wärmeproduktion des Körpers ist auf die äußere Wärmebelastung zurückufüren.

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Manuscript received 24 April 1979.
Revised manuscript received 31 July 1979.

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Applied Ergonomics 1980, 11.2, 81–84

Circulo-respiratory efficiency in some agricultural work

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The cardio-respiratory performance of five subjects was studied in relation to two types of agricultural work, on germinating seedlings and threshing. Manual operations were compared with some simple implements. Transplanting of seedlings demanded 17·4 ℓ/min (BTPS) pulmonary ventilation and 0·618 ℓ/min (STPD) oxygen uptake. With the IRRI and the CRRI seeder, pulmonary ventilation and oxygen uptake were 41·9 and 39·6 ℓ/min, and 1·910 and 1·638 ℓ/min respectively. Pulse rates were 163 and 154 beats/min with the two seeders. The IRRI seeder required 4·1 man-hours per acre of land compared with 2·8 man-hours for the CRRI seeder. Manual threshing by beating demanded 28·1 ℓ/min pulmonary ventilation and 0·920 ℓ/min oxygen uptake and 135·8 pulse beats/min, the corresponding values in the case of pedal threshing were 41·2 and 1·310 ℓ/min and 140·8 beats/min respectively. Pedal threshing is about 50% more efficient than manual threshing. However, static muscular activity is more reflected in pedal threshing than in threshing by beating.

Agriculture is frequently thought of as an industry with a rather primitive image. Various forms of technological know-how are implemented in developing the work-methods and tools of agriculture. Even in labour intensive countries like India, the use of agricultural machinery is encouraged to reduce and channel labour requirements at peak working seasons. Since the work method is a potent factor in the basic resource endowments of an agrarian economy, ergonomists are concerned to see the efficacy of machinery in relation to the performance of the workers. To our knowledge, such studies on Indian agricultural workers are not available. A few studies (Nag *et al*, 1978; Ramana Murthy and Belavady, 1966; Rao and Saha, 1965) have been reported in determining the energy requirements of different agricultural operations. Since the majority of the farmers could not afford heavy or sophisticated machinery, this leads to improvising the existing method of work so as to minimise the overall physical demands of their tasks within allowable limits and to increase the aggregate output of the team. With this idea, effectiveness of weeding operations with different simple weeders (Nag and Dutt, in press) is to be reported with reference to physiological responses. The present study deals with the cardio-respiratory performance of skilled workers on two important agricultural jobs, ie, planting of germinated seedlings, and threshing to separate out grains from paddy pennacles.

Description of the operations

Germinated seedling planting

Usually germinating rice seeds are broadcast densely on a puddled field. When the plants are grown to about 15 to 20 cm height they are uprooted and transplanted with standard spacing to a bigger puddled area. Average spacing given in Indian field conditions is 15 x 15 cm, which is important for (i) easy access to remove unwanted weeds, (ii) sufficient sunlight and aeration for growing plants, and (ii) reducing humidity between the plants and discouraging breeding of insects. As much as 8% of total man-hours of agricultural work are required for broadcasting, uprooting and subsequent transplantation. To reduce the workload of this part of the cultivation, machinery is being developed.

A germinating seeder fabricated by International Rice Research Institute (Philephine) is shown in Fig. 1a. It consists of eight concentric aluminium pipes running upwards to a hopper, ie, the germinating seed reservoir. The distance between the pipes at the ground level is about 20 cm. As the structure is pulled on a chain wheel a flap of the reservoir is opened to the pipes through which seeds come out and fall on the ground.

One of the authors (P. Dutt) fabricated a germinating seeder in the Central Rice Research Institute (Cuttack, India) which is shown in Fig. 1b. A cylinder made of tinned iron (length: 0·95 m; diameter: 20 cm) contained six columns and six rows of holes, spacing 15 x 15 cm. Two iron band wheels are fixed to the cylinder, allowing it to rotate freely. Columns of holes are obstructed by six circular nylon belts connected with a horizontal bar to the wooden frame, leaving open one hole in each column of the upper side. As the seeder is pulled the cylinder rotates, and the seeds trickle down through the holes. Gradually those holes are covered by the belts, allowing another row of holes to open at every 15 cm distance, thereby making seeding possible at equidistant spacing. The device may be used by pulling or pushing, as desired by the operator.

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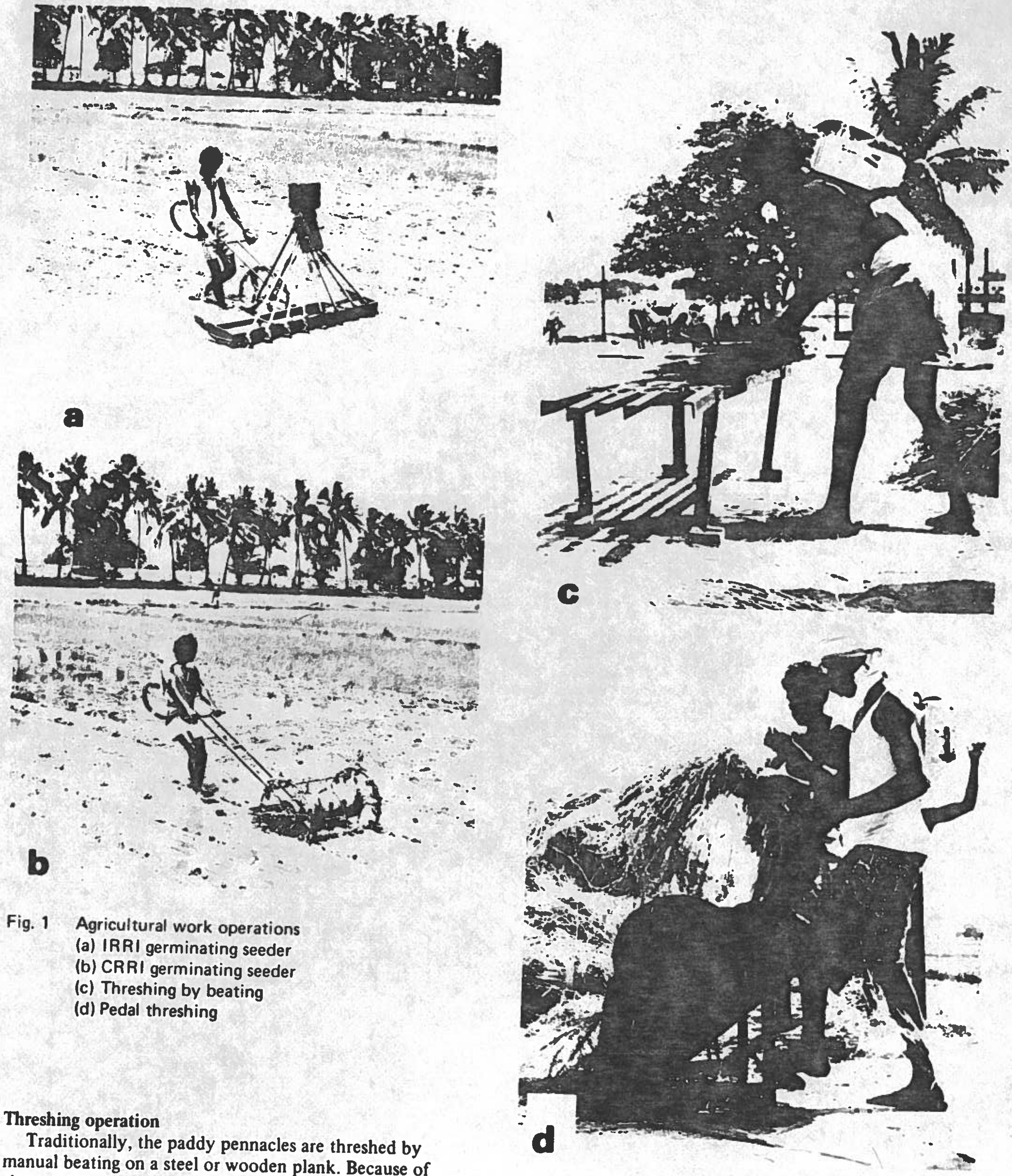

Fig. 1 Agricultural work operations
(a) IRRI germinating seeder
(b) CRRI germinating seeder
(c) Threshing by beating
(d) Pedal threshing

Threshing operation

Traditionally, the paddy pennacles are threshed by manual beating on a steel or wooden plank. Because of alternate bending and straightening of the back (Fig. 1c), both male and female workers consider the operation to be fatiguing. Today, different types of pedal thresher are available commercially. One such pedal thresher is shown in Fig. 1d. The worker has to incline forward to pedal while threshing the bundles of paddy pennacles.

Measurements

Five male agricultural workers were selected from the eastern part of the country. Maximal oxygen uptakes of the workers were determined from the progressive step-increase of the work load on a Fahrrad's bicycle ergometer.

At the steady state of work with the germinating seeders and pedal thresher, measurements of pulmonary ventilation, oxygen consumption and pulse rate were recorded. Oxygen consumption was determined from the pulmonary ventilation recorded through a calibrated KM respirometer and analysing the expired air in a Beckman paramagnetic oxygen analyser. The radial pulse rates were determined from the stop watch time for 10 pulse beats. Energy cost was calculated from the oxygen consumption and the weighted average of the coefficient of energy equivalent (20·86 kJ) of one litre of oxygen, which was derived from the mixed diet of protein, fat and carbohydrate consumed by the subject. The relative cost of work was derived from the oxygen uptake as percentage of V_{O2} max. The blood pressures were noted immediately after cessation of the work. The usual ways of manual operation of the agricultural jobs were taken for comparison with the machine versions of the seeders and pedal thresher. The actual area covered by the seeders was noted against time. Outputs with the two ways of threshing were measured in terms of separated straw and paddy grains.

Results and discussion

Workers selected in the study were skilled in agricultural work and had similar body status. Physical characteristics, ie, age, body weight, body height, body surface area and lean body weight of the workers, were 23·4 ± 1·9 years, 49·9 ± 0·8 kg, 164·6 ± 1·9 cm, 1·62 ± 0·02 m^2, and 47·1 ± 0·6 kg respectively. Average maximal oxygen uptake corrected for 50 kg reference body weight was 2·065 ± 0·360 ℓ/min, at STPD.

Seeding

The physiological reactions of the workers in the process of seeding are given in Table 1. The pulmonary demand while doing the transplanting operation by hand, using a bending posture, was only 17·42 ℓ/min (BTPS) which was about 17% less than that required for free walking in the puddled field. Consequently, the oxygen uptake was also higher during free walking in the puddled field when compared with that needed for the manual transplanting operation. Free walking on a plane clear surface demanded pulmonary ventilation and oxygen uptake about 24% and 18% respectively less than that of walking in a puddled field. The high energy demand in free walking in the puddled field was simultaneously associated with cardiovascular repercussions, as reflected in a higher pulse rate (ie, 126 beats/min) compared with sitting at rest, free walking on a plane surface and the manual transplanting operation.

The seeding operation needs to be done in a puddled field and the workers therefore have to immerse their feet in mud (mid calf to knee deep) during their activities. They cannot perform the job while sitting with one or two legs flexed at the knee, as is done on dry land. To transplant seedlings manually, about 35 man-hours are required per acre (14 man-hour/Ha) of land. Because of the need to maintain a bending posture workers often complain about back pain, etc. It has been earlier indicated (Nag *et al*, in press) that the physiological costs during weeding and uprooting operations are relatively less while working in a sitting posture compared with bending. Accumulation of fluid in the lower limbs during standing and bending may exert further stress to the cardiovascular system. Due to prolonged immersion in mud and stagnant water, skin irritation and infection are common in hands and feet among workers of both sexes and intestinal parasites have easy entry routes.

Seeding by the IRRI seeder required only 4·1 man-hours per acre (1·66 man-hour/Ha) of land, ie, about 8 times more efficient when compared with the manual transplanting operation. However, to maintain balance the operating labourer exerts effort against the whole weight of the machine. The labourers are always required to prevent the machine from falling side-ways. Due to the awkward work posture, the worker gets exhausted within a short period. The pulmonary demand was about 2·5 times higher than for the manual transplanting jobs. Oxygen uptake was equivalent to 86·2% of V_{O2} max. The pulse rate was as high as 163 beats/min, and corresponding systolic and diastolic blood pressures were 155 and 76 mm Hg respectively.

The CRRI seeder is much simpler in design and relatively easy in operation. Compared with the IRRI seeder this seeder demands relatively less physiological cost. The difference in the cardiovascular responses was statistically significant at the 5% level. Based on the suggested classification of Indian agricultural workers (Nag *et al*, in press), the work with both the IRRI and CRRI seeders was categorised as extremely heavy activity. Using the classification proposed by Christensen (1953) for steel mill workers, these work loads could be termed as heavy activity.

Table 1: Physiological responses of agricultural males during seeding operation*

Activity	Pulmonary ventilation (ℓ/min) (BTPS)	Oxygen uptake (ℓ/min) (STPD)	Energy cost (kJ/min)	Average work pulse rate (beats/min)	Relative cost of work (% of V_{O2} max)	Blood pressure (mm Hg)	
						Systolic	Diastolic
Sitting resting	12·3 ±0·6	0·202 ±0·041	4·25 ±0·86	75·2 ±5·5	9·8 ±2·0	115·2 ±6·5	79·0 ±3·8
Free walking on plane surface	15·9 ±0·9	0·534 ±0·051	11·21 ±1·06	115·2 ±4·7	25·9 ±2·5	–	–
Free walking on puddled field	21·0 ±1·8	0·653 ±0·025	13·73 ±0·53	126·3 ±3·6	31·6 ±1·2	–	–
Transplanting bending on puddled field	17·4 ±1·4	0·618 ±0·044	13·01 ±0·93	109·2 ±3·0	29·9 ±2·13	–	–
Germinating seeder (CRRI type)	39·6 ±3·0	1·638 ±0·111	34·42 ±2·34	154·0 ±4·6	76·8 ±16·0	148·5 ±5·3	79·0 ±3·7
(IRRI type)	41·9 ±1·6	1·910 ±0·173	40·20 ±3·64	163·0 ±7·4	36·2 ±13·6	155·3 ±1·8	76·0 ±5·3

*Values are means ± standard errors

Table 2: Physiological responses of agricultural males during threshing operations*

Activity	Pulmonary ventilation (ℓ/min) (BTPS)	Oxygen uptake (ℓ/min) (STPD)	Energy cost (kJ/min)	Average work pulse rate (beats/min)	Relative cost of work (% of V_{O_2} max)	Blood pressure (mm Hg)	
						Systolic	Diastolic
Sitting resting	12·3 ±0·6	0·202 ±0·041	4·25 ±0·9	75·2 ±5·5	9·2 ±2·0	115·2 ±6·5	79·0 ±3·8
Manual threshing by beating	28·1 ±1·1	0·920 ±0·058	19·26 ±1·18	135·8 ±4·0	50·6 ±9·9	132·6 ±5·8	67·7 ±5·3
Pedal threshing	41·2 ±1·2	1·310 ±0·155	27·56 ±3·25	140·8 ±4·3	73·0 ±16·1	138·5 ±8·5	58·0 ±4·8
Pedal threshing helper	20·1 ±2·2	0·644 ±0·095	13·53 ±1·99	120·3 ±9·9	38·0 ±8·5	110·5 ±2·2	67·5 ±2·1

*Values are means ± standard errors

The CRRI seeder required only 2·8 man-hours/acre (1·13 man-hour/Ha) of land. Relatively less physiological cost was associated with higher work output in the case of the CRRI seeder. Though much work could be performed by the seeders, the physiological demands were extremely heavy. Since the operations are performed on the puddled field, the worker had an inherent difficulty in movement. Attempts are being made to simplify the design further so that the physiological cost of work with the seeder can be reduced. A procedure can also be worked out for the possible use of animal power in seeding operations with either of the seeders. However it is to be noted that there is a considerable scarcity in the availability of good quality bullocks for agricultural work.

Threshing

Physiological reactions recorded during the threshing operations are given in Table 2. By alternate movements of the body a worker exerts a considerable amount of bodily force in threshing operations. This operation may be considered as moderately heavy. By manual threshing or beating, one can separate out 1·66 ± 0·15 kg grains and 1·94 ± 0·13 kg straw per min from medium-sized paddy plants. However, the pedal thresher had an output of 2·37 ± 0·37 kg grains and 3·06 ± 0·40 kg straw per min. As subjects were inclined forward while pedalling and holding the bundles of paddy plants on the roller, there was an increased activity of the extensor groups of muscles of the upper limbs, as is evident from the illustration. All these operations required a considerable amount of static muscular activity as well as the dynamic work. Pulmonary ventilation in pedal threshing was as high as 41·2 ℓ/min and oxygen uptake, 1·310 ℓ/min, ie, representing a heavy activity. While the statistical difference in pulmonary ventilation between the two tasks was highly significant at the 0·1% level, oxygen uptake was significant only at the 5% level. Comparing pulse rate and blood pressure responses, it may be stated that static muscular activity is reflected more in pedal threshing than in manual threshing. It is realised that pedalling a thresher can be so arranged that the rhythmic pattern of work of both legs is facilitated in both a sitting and standing posture; thereby a part of the postural maintenance reflected in the higher oxygen uptake may be reduced. Total output may also be increased, provided work arrangements are made on the basis of the anthropometric dimensions of workers.

There may be a presumption that these devices which impose a high human workload should not be implemented because of the high energy expenditure. However, it could be argued that the relatively lower productivity of agricultural workers is largely because of a traditional farming system that has been followed using local experience. Proper use of modern developments could enhance not only the agricultural production, but also minimise man-hour involvement per unit area of land. In the case of high energy expenditure with a device, appropriate short rest pauses may be inserted between spells of work so as to maintain the physical demands of the task within reasonable limits and without becoming unusually fatigued. Any surplus labour power could quite conveniently be channelled to make use of the vast areas of unused agricultural land in the country.

Acknowledgements

The authors sincerely express their gratitude to Dr S.K. Chatterjee, Director, NIOH, Ahmedabad, and Director, CRRI, Cuttack, for their kind permission to carry out the study. Thanks are due to Mr N.C. Sebastian, Mr M.G. Malvankar and Mr M.S. Vaghela of NIOH for their technical help.

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ERGONOMICS, 1990, VOL. 33, NO. 12, 1487–1494

Optimum handle height for a push–pull type manually-operated dryland weeder

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A laboratory study was carried out at the Central Institute of Agricultural Engineering (CIAE), Bhopal to find out the optimum handle height for a push–pull type manually-operated dryland weeder from ergonomic considerations. Four handle heights, i.e., 0·6, 0·7, 0·8 and 0·9 of shoulder height (SH) were compared with eight subjects in a laboratory set-up which involved an application of 98 N horizontal push for operating the weeder. The observations made during the experiment were heart rate, ventilation rate, energy expenditure and rating of perceived exertion (RPE). The lowest heart rate and RPE were observed while working at 0·7 SH and lowest oxygen consumption at 0·8 SH. However, no significant differences were observed in physiological cost and perceived exertion between working with 0·7 and 0·8 SH handle height. Working at 0·9 SH produced the highest heart rate and oxygen consumption and subjects perceived the work as very hard. A handle height of 0·6 SH proved too low for the subjects resulting in increased muscle fatigue and higher heart rate as compared to 0·7 and 0·8 SH. Based on the results of this experiment, and the available anthropometric data of Indian workers, a handle height of 100 cm is recommended for the push–pull type manually-operated dryland weeder under study.

1. Introduction

Weeding is one of the most labour intensive operations utilising about 20% of the total human energy used in crop production. In traditional agriculture, only short handled tools, e.g., hand hoe, weeding hook, spade etc. were used for the weeding operation. The output of a worker with such equipment is very low, i.e., about 40 to 80 m^2/hour. Recently a number of research organizations in India have developed manually-operated push–pull type weeders, e.g., the dryland weeder, and the wheel hoe. With these weeders a person can cover about 100 to 200 m^2 of area per hour. However, many of these tools involve a higher physiological cost. Handle height (while working) is one of the aspects whereby physiological cost can be reduced. Therefore, a laboratory study was carried out at CIAE, Bhopal to find out the optimum handle height for a push–pull type dryland weeder from ergonomic considerations.

Handle position in pushing and pulling has been studied by many research workers in Western countries (Ayoub and McDaniel 1974, Kroemer 1974, Davis and Stubbs 1977a, 1977b, 1978, Snook 1978, Chaffin 1983). In the main, these studies aimed to determine the maximum push–pull forces that can be exerted safely under various conditions. However, no data is available about the effects of repetitive push or pull on physiological parameters.

Some ergonomic studies on weeders have been carried out in India (Yadav *et al.* 1976, Nag and Datt 1979, Tewari 1985, Gill and Choudhary 1987). These studies mainly dealt with a comparison of different types of weeders, work–rest schedules of the workers, and development of improved weeding tools and equipment.

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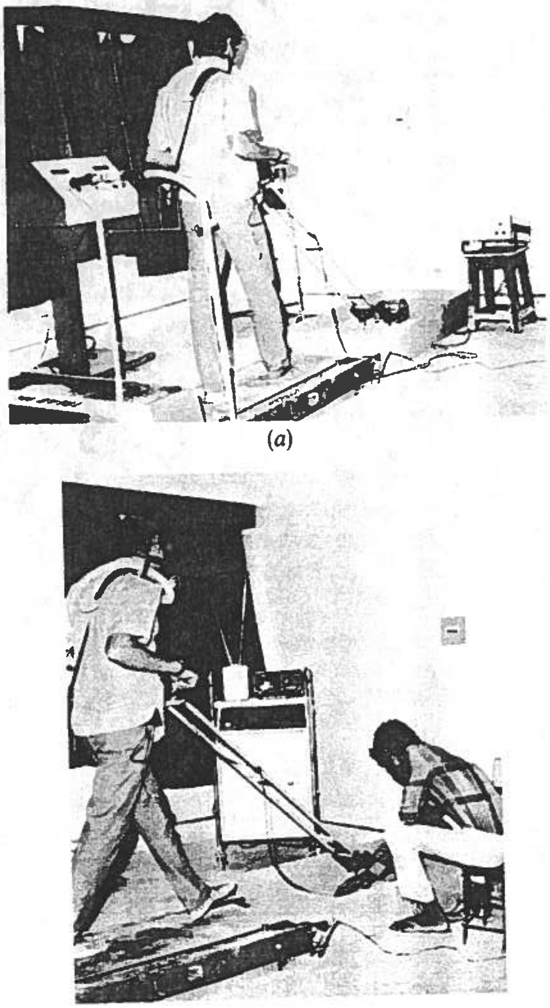
2. Methods

The experiment was performed with eight healthy adult male subjects. All the subjects were well acquainted with weeder operation. Their mean age, height, shoulder height and weight were 32·1 (s.d. 6·1) years, 162·7 (s.d. 3·54) cm, 134·6 (s.d. 3·10) cm, and 51·6 (s.d. 11·78) kg, respectively. During the experiment the mean climatic conditions were 'comfortable' (ASHARE 1974) with an air temperature of 22·1 (s.d. 1·6)°C, a relative humidity of 66·0 (s.d. 8·3)% and air velocity of less than 50 cm/s.

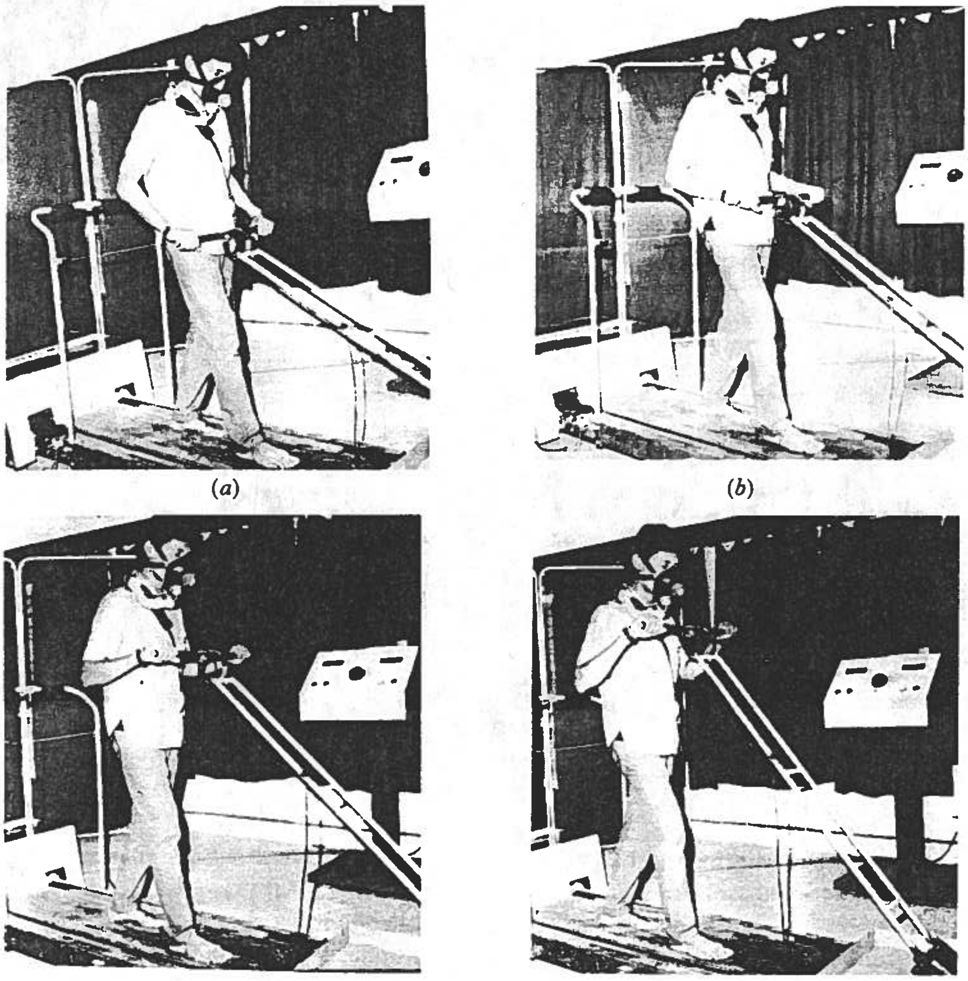
A laboratory set-up for simulating weeder operation was constructed (figure 1). Each subject was asked to walk over a treadmill operating at a speed of 2 km per hour. While walking, the subject had to operate the experimental dryland weeder in a sand tray. The frequency of movement of weeder varied from 44 to 48 strokes per min. A force measuring transducer was fitted to the handle and the effort was measured. The depth of sand in the tray was controlled in such a way that the horizontal force at the



(a)

(b)

Figure 1. (a) Laboratory set up for simulating weeder operation. (b) Experiment in progress.


(*a*) (*b*)

(*c*) (*d*)

Figure 2. Operating the weeder at four different handle heights: (*a*) 0·6 SH; (*b*) 0·7 SH; (*c*) 0·8 SH; (*d*) 0·9 SH.

handle was always about 98 N for all the trials. This was the force required normally to operate the weeder in the field.

The physiological observations made during the experiment were energy expenditure and cardio-respiratory response of the subjects. The oxygen consumption and energy expenditure were determined by using Morgan Oxylog (Harrison *et al.* 1982). Heart rate was recorded continuously throughout the experiment by a UNI-INSTA ECG Telemetry system. The Borg (1970) 15-point category scale was used to measure the ratings of perceived exertion.

The subjects, who were given a prior indoctrination on the experimental requirements so as to enlist their full cooperation, reported in the laboratory in a post-absorptive stage at 0830 h. After the subject had rested for 30 min, he was made ready for the experiment by fixing ECG electrodes on the chest, fitting the transmitter on the waist and mounting the oxylog. After a period of 10 min, his resting pulse rate, ventilation volume, and oxygen consumption were noted. Depending on shoulder height (SH), the working handle height, i.e., 0·6 SH, 0·7 SH, 0·8 SH and 0·9 SH, were fixed, and the subject was asked to maintain the same during the respective trials (figure 2). Necessary adjustments were also made in the experimental weeder to get the particular work height. After the subject commenced weeder operation in the sand tray, steady state was attained in 3–4 min. Therefore, readings for heart rate, ventilation volume, and oxygen consumption were taken from 5th to 10th min and averaged to get the data for that work height. Immediately after completion of the 10 min trial the subject was asked to give his rating of perceived exertion for that particular work load. Then the subject was allowed to rest for 15 min and the next trial was started. To minimize bias, training effects, fatigue effects, etc., the handle heights were presented at random to all the subjects. All the trials were conducted between 1000 to 1300 h each day.

3. Results

The observed values of the physiological parameters, i.e., heart rate, ventilation rate, oxygen consumption, and RPE of the eight subjects while working with four different handle heights were tabulated and the mean and standard deviation computed. The same are presented in table 1.

The energy expenditure was calculated using the calorific value of oxygen as 20·88 kJ/litre of oxygen (Nag *et al.* 1980) and the same is depicted in figure 3.

The data on each parameter from eight subjects and at four work heights were examined with a single factor repeated measures analysis of variance (Winer 1982) and table 2 gives the ANOVA results. A Scheffe's post-hoc comparison test was used to probe significance amongst different handle heights and the results are given in table 3.

4. Discussion

The analysis of variance (table 2) establishes that there was a clear physiological difference between working with different handle heights. All these variations in the values of observed parameters resulting from a change in working height are highly significant, i.e., at 1% level. Working handle height affects all the parameters, whereas individual variations influenced the cardio-pulmonary parameters and energy expenditure only. Ratings of perceived exertion did not significantly vary among the subjects for these four work heights.

Among the four handle heights, working at 0·7 SH was least strenuous as indicated by the lowest heart rate (103·5 beats/min) and RPE (11·5). However, results of Scheffe's post-hoc analysis (table 3) showed that handle height of 0·7 SH and 0·8 SH are on a par in respect of physiological cost as well as overall exertion rating.

Table 1. Means and standard deviations of physiological parameters of subjects and RPE values while working with four different handle heights.

Working handle height	HR beats/min	$\dot{V}E$ l/min	$\dot{V}O_2$, STPD l/min	RPE
0·6 SH*	112·9 (11·3)	31·22 (5·81)	0·849 (0·126)	16·4 (1·5)
0·7 SH	103·5 (12·1)	27·94 (3·31)	0·801 (0·103)	11·5 (1·7)
0·8 SH	108·1 (11·2)	28·16 (4·08)	0·791 (0·078)	12·1 (2·3)
0·9 SH	125·5 (14·4)	37·44 (7·58)	1·002 (0·141)	18·3 (1·2)

* SH: shoulder height.

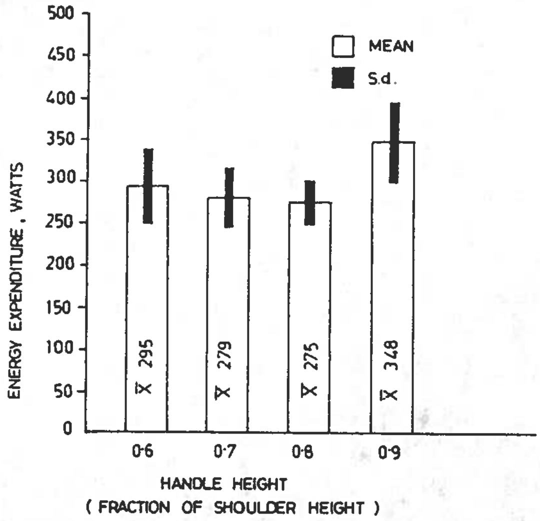


Figure 3. Energy expenditure while operating the weeder at four handle heights.

Table 2. Analysis of variance of the physiological data from experiments of working at four handle heights.

	Sum of squares	df	Mean square	*F*	Significance
HR (beats/min)					
Handle heights	2152·8	3	717·6	25·83	*
Subjects	3656·8	7	522·4	18·80	*
$\dot{V}E$ (l/min)					
Handle heights	470·4	3	156·8	14·97	*
Subjects	612·8	7	87·5	8·36	*
$\dot{V}O_2$ (l/min)					
Handle heights	0·226	3	0·0750	13·63	*
Subjects	0·258	7	0·0368	6·70	*
RPE					
Handle heights	257·6	3	85·9	41·58	*
Subjects	38·9	7	5·6	2·68	ns

* Values are statistically significant ($p<0·01$): ns-values are not statistically significant ($p>0·05$).

Table 3. Statistical comparison of working handle height using Scheffe's method ($p<0·05$).

	Working handle height			
Parameter	0·6 SH	0·7 SH	0·8 SH	0·9 SH
HR		————	————	
	+++++++++++		+++++++++++	
$\dot{V}E$	————	————	————	
$\dot{V}O_2$	————	————	————	
RPE		————	————	
	+++++++++++			+++++++++++

The neutral position for the arm when a person is standing is with the arm hanging straight down at the side with the palms inwards (Murrell 1975). Herberts *et al.* (1980) reported a general increase in localized muscle fatigue as the working hand level is increased from waist to shoulder and above. As the working handle height increased from 0·7 SH to 0·9 SH, there was increased cardiac stress and local muscular fatigue as evident from the heart rate and RPE data. The lower handle height of 0·6 SH, was, however, not suitable for operating the weeder as the subjects felt it strenuous and complained about the severe muscular fatigue in their forearms. The same was reflected in heart rate and RPE readings which were significantly higher than 0·7 and 0·8 SH. While working at four handle heights, i.e. from 0·6 to 0·9 SH, the subjects had to apply a push ranging from 112 N to 158 N in order to get a 98 N horizontal force as the handle length was kept the same and only the angle was changed. This was also one of the reasons for higher heart rate at increased work height.

Oxygen uptake depends on physical workload. The lowest oxygen consumption was reported at 0·8 SH, though it was not significantly different from the oxygen consumption at 0·6 SH and 0·7 SH working heights. Operating the weeder at 0·9 SH, however, required significantly higher oxygen uptake.

As seen earlier, 0·7 SH to 0·8 SH is the most suitable working height for operation of a push-pull type weeder from ergonomic considerations. The available anthropometric data of Indian population (Gite and Yadav 1985) give 5th and 95th percentile shoulder height values as 123·1 cm and 145·6 cm, respectively. If the working handle height is kept as 100 cm, it will be 0·69 SH of the 95th percentile man and 0·81 SH of the 5th percentile man.

5. Conclusion

For operating a push-pull type weeder, the handle height should be within 0·7 and 0·8 of shoulder height so that the physiological cost and muscular fatigue will be minimum. Considering this range and the available anthropometric data, a handle height of 100 cm is recommended for Indian workers.

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Manuscript received 25 January 1989.
Revised manuscript received 3 October 1989.

A l'Institut Central d'Ingénierie Agricole de Bhopal, on a conduit une étude pour déterminer la hauteur optimale du bras d'une machine à désherber manuelle de type push-pull. Quatre hauteurs de bras, soit 0,6; 0,7; 0,8 et 0,9 de la hauteur de l'épaule (SH) ont été comparées chez 8 sujets, pour une poussée horizontale de 98 N sur la machine. Au cours de l'expérience, on a relevé la fréquence cardiaque, la fréquence respiratoire, la dépense énergétique et le jugement de l'effort perçu (RPE). La fréquence cardiaque et le RPE les plus bas ont été observés pour 0,7 SH, la consommation d'oxygène la plus basse pour 0,8 SH. Cependant, aucune différence significative n'a été trouvée dans le coût physiologique et l'effort perçu lors du travail avec une hauteur de bras de 0,7 SH et 0,8 SH. Le travail avec 0,9 SH a produit la fréquence cardiaque et la consommation d'oxygène les plus élevées, les sujets percevant le travail comme très dur. Une hauteur fixée à 0,6 SH s'avérait trop basse pour les sujets, puisqu'elle entraînait une fatigue musculaire accrue et une fréquence cardiaque trop élevée comparée à 0,7 et 0,8 SH. Compte tenu des données anthropomètriques des travailleurs indiens, on peut donc recommander une hauteur de barre située à 100 cm au-dessus du sol, pour ce type de machine.

Eine Laborstudie wurde am Central Institute of Agricultural Engineering (CIAE), Bhopal durchgeführt, um mit Hilfe ergonomischer Überlegungen die optimale Griffhöhe für einen manuell zu bedienenden Schiebe-/Zieh- Unkrautjätmaschinentyp zu ermitteln. Vier Griffhöhen, 0·6, 0·7, 0·8 und 0·9 mal der Schulterhöhe (SH), wurden bei acht Versuchspersonen in einem Laboraufbau verglichen, wobei eine horizontale Betätigungsdruckkraft von 98 N zur Bedienung der Jätmaschine erforderlich war. Während der Versuche wurden die Herzschlagfrequenz, die Atemfrequenz, der Energieumsatz und die Einstufung der empfundenen Anstrengung (RPE) aufgenommen. Die niedrigste Herzschlagfrequenz und RPE wurden beim Arbeiten bei 0·7 SH und der geringste Sauerstoffverbrauch bei 0·8 SH beobachtet. Jedoch ergaben sich keine signifikanten Unterschiede bei der physiologischen Wirkung und der empfundenen Anstrengung zwischen der Arbeit bei 0·7 und 0·8 SH Griffhöhe. Arbeiten bei 0·9 SH bewirkte die höchste Herzschlagfrequenz und den größten Sauerstoffverbrauch, und die Versuchspersonen empfanden die Arbeit als sehr anstrengend. Eine Griffhöhe von 0·6 SH erwies sich als zu niedrig für die Probanden, was, verglichen mit 0·7 und 0·8 SH, in zunehmender Muskelermüdung und höherer Herzschlagfrequenz resultierte. Aus den Versuchsergebnissen und den verfügbaren anthropometrischen Daten der indischen Arbeiter wird eine Griffhöhe von 100 cm für den untersuchten, manuell bedienten Schiebe-/Zieh- Unkrautjätmaschinentyp empfohlen.

押し引き式手動乾燥地除草器の最適取っ手高さを人間工学的に求めるために，ボパールの中央農業研究所（CIAE）で実験室研究を実施した。4つの取っ手高さ，すなわち肩高さ（SH）の0.6，0.7，0.8，0.9，を実験室装置を使用して8名の被験者で比較した。被験者は除草器を動かすのに98 N の水平押し力を加えた。実験中に測定したのは心拍数，換気数，エネルギー消費，知覚努力評点（RPE）であった。0.7 SH での作業時に最低の心拍数と RPE が観察され，0.8 SH で最低の酸素摂取量が観察された。0.7と0.8 SH の取っ手高さでの作業の間には生理的負担と認知努力に有意差は認められなかった。0.9 SH での作業時に心拍数と酸素摂取量が最大になり，被験者は作業が非常にきついと感じた。0.6 SH の取っ手高さは被験者にとって低すぎ，0.7と0.8SH に比較して筋肉疲労と心拍数が増えた。本実験結果とインド労働者の身体計測データに基づいて，100cm の取っ手高さを研究対象の押し引き式手動乾燥地除草器に推奨する。

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Center for Academic Publications Japan. Printed in Japan.

COMPARISON OF GRIP STRENGTH AND ISOMETRIC ENDURANCE BETWEEN THE RIGHT AND LEFT HANDS OF MEN AND THEIR RELATIONSHIP WITH AGE AND OTHER PHYSICAL PARAMETERS

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Maximum handgrip strength and endurance of fatiguing isometric handgrip muscle contraction at 40% of maximum voluntary contraction of the dominant hand were assessed separately for both right and left hands of 99 right-handed men aged 7–73 years. Subjects below 10 years ($n=6$) could not follow up the endurance test methods and were excluded. The relationship of handgrip strength and endurance with age and other physical parameters was also assessed. Maximum grip strength and endurance of fatiguing submaximal contraction of the right hand were significantly greater than that of the left hand for most age groups. Grip strength was positively correlated with age from 7–19 years ($r=0.94$ for right and $r=0.89$ for left) and was negatively correlated with age from 20–73 years ($r=-0.74$ right and $r=-0.69$ left). Grip strength was positively correlated with the weight ($r=0.86$ right and $r=0.87$ left), height ($r=0.88$ right and $r=0.87$ left) and body surface area ($r=0.9$ for both) of the subjects. Endurance of contraction of both hands did not show any relationship with age, different physical parameters or grip strength of the subjects.

Isometric strength varies with the age, size and sex of the individual (FISHER and BIRREN, 1947; ASMUSSEN and HEEBÖLL-NIELSEN, 1955, 1956, 1962; ÅSTRAND and RODAHL, 1970). Studies showing no change of strength with aging in men is also available (PETROFSKY and LIND, 1975). Isometric exercise fatigues muscles rapidly whenever the contraction tension exceeds 10–15% of the muscle's maximal voluntary strength (MERTON, 1954; ROHMERT, 1960a, b; FUNDERBURK *et al.*, 1974).

Received for publication October 26, 1990.

It has been also reported that the endurance time is independent of the sex of the subjects (ROHMERT, 1968) and of previous dynamic training (HANSEN, 1967), as long as the subjects work at the same percentage of their own maximum strength.

The fact that age does not affect the capacity of muscle to sustain a contraction at a known fraction of maximum strength has been reported by MULLER (1961) and ROHMERT (1960a, b). PETROFSKY and LIND (1975) and PETROFSKY *et al.* (1975) reported that aging was associated with a significant rise in endurance in women but not in men. Although CALDWELL (1963, 1964) and START and GRAHAM (1964) suggested that no variation in the holding time among various levels of strength would occur between stronger and weaker individuals when the same relative weight load was used for each of them, TUTTLE *et al.* (1950) and CARLSON (1969) reported lower holding times in stronger individuals.

A comparison of grip strength and isometric endurance between the right and left hands of men is of interest. A survey of the literature indicates that there have been few studies of different age groups, particularly with regard to Indian subjects.

The present investigation has the following objectives:

1. To determine whether the difference in grip strength and isometric endurance between the right and left hands of right-handed men is significant.
2. To determine whether there is any relationship between maximum handgrip strength and endurance contraction with age and other physical parameters.

MATERIALS AND METHODS

Ninety-nine normal healthy male subjects of six different age groups participated in the present investigation. The lowest age group (7–9 years $n=6$) could not take part in the endurance test procedures, and its members participated only in the strength test experiment.

The subjects were sedentary. No individual was accepted as subject if he had a history of any cardiovascular or pulmonary disorder or displayed an irregular electrocardiogram or abnormal blood pressure in the pre-exercise resting state. The subjects who were unable to continue the whole series of the experiment were also excluded. All the subjects were requested to refrain from eating and in engaging in any strenuous physical work for at least 1 hr before the experiment. The purpose of the experiment was explained to them to stimulate the participants' interest and to encourage them to perform the various tasks to their utmost ability. After an initial half-hour rest, the subjects' physical characteristics, including age, height, weight and health-oriented case history, were noted. The body surface area (BSA—m^2) was estimated for each individual using the DuBois formula ($S = W^{0.425} H^{0.725} \times 0.007184$) for the weight in kilograms and height in centimeters.

Two maximal voluntary handgrip contractions (MVC) at an interval of 1 min and with a duration of less than 3 sec were performed by each subject at the start of each experiment. A simple handgrip dynamometer (INCO made in India) was utilized for the grip strength measurements. The sustained handgrip contraction involved as little shortening of the forearm flexor muscles as possible. Maximum strength was taken to be the stronger of the two contractions. The MVC was measured to the nearest 0.1 kg. During the test the subjects were in the sitting position with the upper arm dependent and the forearm held horizontally. The MVC of the left hand of the same individual was determined in the same way after resting at least half an hour. The dynamometer was standardized by another dynamometer (CLARKE *et al.*, 1958) before and after the experiment. It was also standardized using the investigator's own known handgrip strength.

During the subsequent experimental phase each subject exerted a handgrip contraction on the dynamometer at a tension of 40% of the MVC of dominant hand (right) until he could no longer maintain the tension. The participants performed this static effort with their right hand on the first day and with their left hand at same tension the next time they visited the laboratory. Before and during the contraction the subjects were instructed about the importance of maintaining a steady tension and were continuously encouraged by one investigator to maintain the tension to the point of fatigue. A second observer constantly observed the subjects during the exercise and encouraged them to relax the muscles of all body parts other than the exercising forearm.

The subjects were examined in Calcutta from January, 1981 to January, 1983. The laboratory temperature was 28±1°C.

The statistical analysis primarily involved the calculation of means, standard deviations and regression lines. Comparisons were made using the F test and the unrelated t test as appropriate. The difference method was applied to determine the difference between the data achieved by the static efforts of the two hands each subject. The level indicating statistical significance was $p<0.05$.

RESULTS

The mean height, weight, body surface area (BSA), ages and grip strength of the 99 men who participated in the grip strength experiment are given in Table 1. Figure 1 shows the maximum handgrip strength of the right and left hands of the subjects.

The strength of the right handgrip was greater than that of the left hand. For age groups 7–9 years, 40–49 years and 50 and above, the difference between the two hand strengths was not statistically significant (Table 1). For the rest three age groups and for the subjects as a whole, however the difference was statistically significant.

Figure 2 shows the regression lines relating the handgrip strengths of both the

Table 1. Isometric handgrip strength of right hand and left hand of men of different age groups and their physical parameters.

Age groups	Age (yrs.) Mean±SD	Height (cm) Mean±SD	Weight (kg) Mean±SD	B. S. A. (m^2) Mean±SD	MVC of right hand (kg) Mean±SD	MVC of left hand (kg) Mean±SD	Mean of strength difference (kg)	Level of significance
10–19 years $n=41$	14.43±2.80	156.55±13.93	39.67±10.38	1.33±0.23	27.06±5.87	25.44±5.55	1.62	$p<0.001$
20–29 years $n=25$	24.56±2.32	168.38± 5.73	53.75± 6.70	1.60±0.01	34.94±2.51	33.42±2.68	1.56	$p<0.001$
30–39 years $n=8$	33.37±2.92	164.72± 5.42	51.31± 6.07	1.54±0.09	33.69±2.20	32.19±1.96	1.37	$p<0.05$
40–49 years $n=7$	44.57±1.98	163.11± 6.95	53.35± 6.75	1.50±0.10	31.36±3.31	30.36±2.78	1.00	NS
50 and above yrs. n=12	67.16±6.89	164.60± 8.72	51.20±11.19	1.54±0.18	28.58±3.12	27.46±3.12	1.12	NS
Total subjects $n=99$ including 6 members of age group 7–9 years	26.62+18	159.11+16.06	45.23+12.78	1.42+0.26	29.09+7.17	27.65+6.99	1.44	$p<0.001$

NS=not significant.

By difference method was applied to compare the difference between the strength of right hand and left hand of individual persons.

The lower age group 7–9 years is too small ($n=6$) to support significancy in difference between the strength of the two hands and is excluded from determining the statistical significance separately.

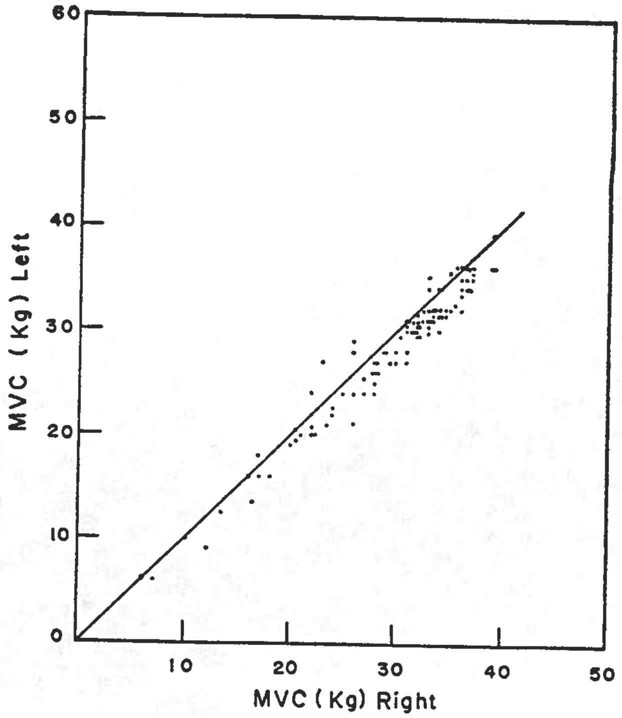

Fig. 1. Maximum handgrip strength of each of 99 men. It shows clearly that on the whole MVC (right) is somewhat greater than MVC (left) of same person.

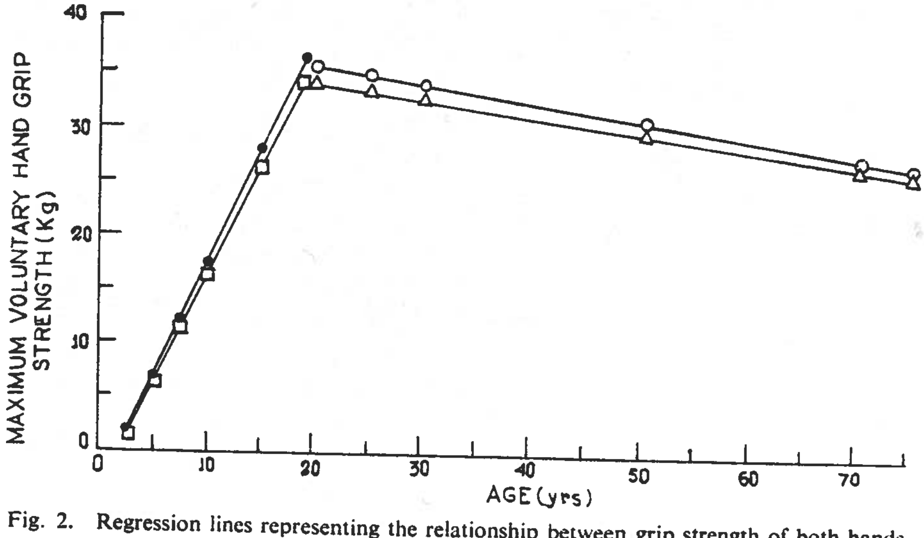

Fig. 2. Regression lines representing the relationship between grip strength of both hands and ages of 99 men. ●, MVC (right) below 20 yrs. ($y=-3.4373+2.0982x$); □, MVC (left) below 20 yrs. ($y=-3.5026+1.9892x$); ○, MVC (right) 20 yrs. and above ($y=38.8412-0.1572\,x$); △, MVC (left) 20 yrs. and above 20 *yrs.* and above ($y=36.9857-0.1442\,x$).

Table 2. Relationship of MVC with age, weight, height and body surface area of 99 men.

Relationship		Regression equations	r-values
MVC (right) with age	($n=47$)	$y= -3.4373+2.0982x$ (below 20 years)	+0.94
	($n=52$)	$y= 38.8912-0.1572x$ (20 years and above)	−0.74
MVC (left) with age	($n=47$)	$y= -3.5026+1.9892x$ (below 20 years)	+0.89
	($n=52$)	$y= 36.9857-0.1442x$ (20 years and above)	−0.69
MVC (right) with weight	($n=99$)	$y= 7.249+0.483x$	+0.86
MVC (left) with weight	($n=99$)	$y= 6.031+0.478x$	+0.87
MVC (right) with height	($n=99$)	$y=-32.958+0.39x$	+0.88
MVC (left) with height	($n=99$)	$y= 32.652+0.379x$	+0.87
MVC (right) with B. S. A.	($n=99$)	$y= -4.976+23.891x$	+0.9
MVC (left) with B. S. A.	($n=99$)	$y= -5.735+23.41x$	+0.9

Note: for all r-values $p<0.001$.

Table 3. Endurance of isometric handgrip muscle contraction of right hand and left hand of 93 men at tension of 40% of MVC of dominant hand (right).

Age groups	Endurance (sec) of right hand Mean±S D	Endurance (sec) of left hand Mean±S D	Mean of differences in endurances (sec) of two hands	Level of significance
10–19 years $n=41$	162.8±38.2	148.8±29.3	13.9	$p<0.001$
20–29 years $n=25$	156.2±53.0	139.6±40.2	16.6	$p<0.01$
30–39 years $n=8$	164.1±42.2	154.5±46.4	9.6	$p<0.05$
40–49 years $n=7$	161.0±41.6	131.0±33.3	30.0	$p<0.001$
50 and above ages $n=12$	162.5±42.3	144.5±41.9	18.0	$p<0.001$
*All ages	161.0±42.9	144.9±35.8	16.0	$p<0.001$
*[Mean age 27.86±17.89 Height (cm) 161.96±11.55 Weight (kg) 46.97±11.07 B. S. A. (m^2) 1.46± 0.21]				

By difference method is applied to signify the difference between the endurance of two hands of individual persons.

right and left hands to the age of the subjects. Strength was positively correlated with age up to the age of 19 years and was negatively correlated with age from 20–73 years.

Table 2 illustrates the regression lines relating maximum grip strength (right and left) to the age, weight, height and body surface area of the subjects. The

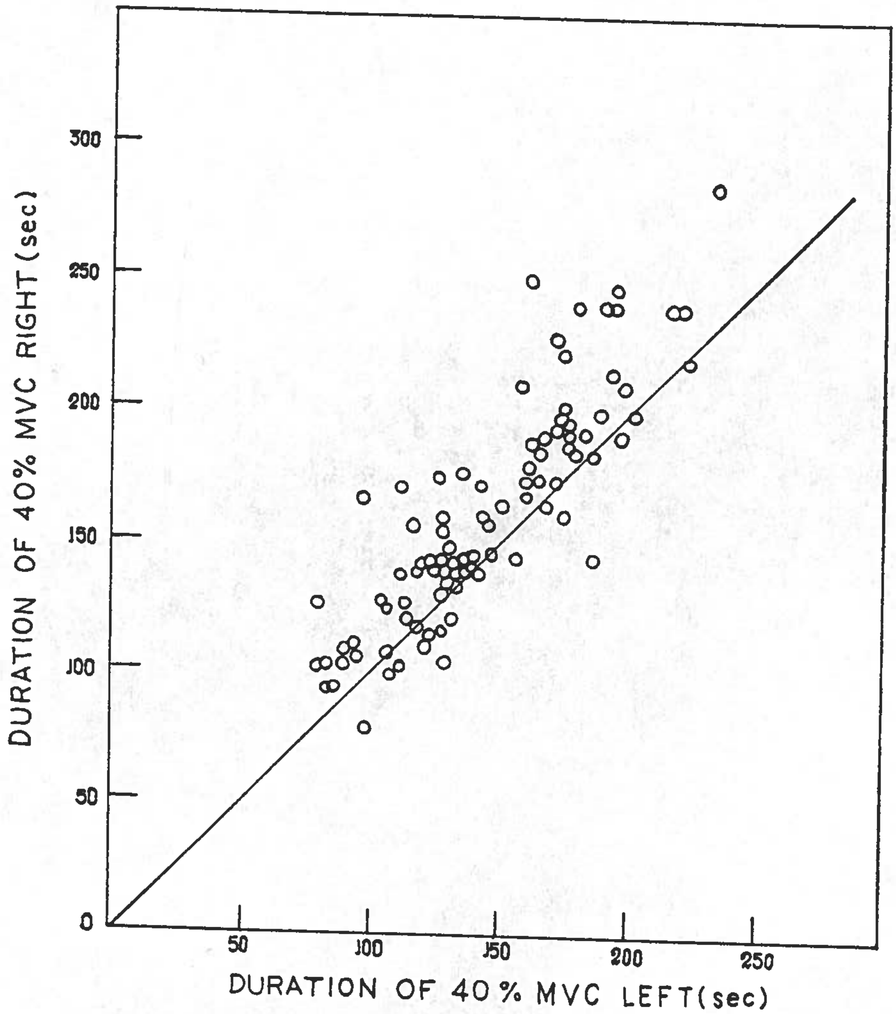

Fig. 3. Figure illustrating the individual duration of 40% MVC isometric contraction of the right and left hands of each of the 93 men.

MVC was positively correlated with the weight, height and body surface area of the subjects.

The mean endurance times of the both the right and left hand contractions at 40% of the MVC of the dominant hand (right) for 93 men belonging to five different age groups are illustrated in Table 3. There was no significant difference ($p>0.05$) in endurance for different age groups. Figure 3 represents the endurance of the right and left hands of 93 subjects. For all age groups and for the subjects as a whole the mean endurance time of the right hand contraction was significantly greater than that of the left hand contraction. For all subjects, the mean difference in the endurance of the contraction between the two hands of the individual subjects was 16 sec ($p<0.001$).

No relationship was found between the endurance of isometric contraction and the age, weight, height, body surface area or MVC of the individual subjects.

DISCUSSION

The earlier reports on the relationship between age and the maximum voluntary handgrip strength are almost unanimous that from about the age of 20 until 60 years there is a gradual decline in strength (Asmussen and Heeböll-Nielsen, 1955, 1956, 1962). Our findings agree with those results. Petrofsky and Lind (1975) reported no change in muscle strength with age in male homogenous subjects. Individual variations in MVC may be attributed to the wide differences in the mechanical advantage achieved by different hand sizes on the fixed dimension of the dynamometer. Progressive lack of training (Richardson, 1953), reduced urinary excretion of testosterone (Hettinger, 1961; Simonson, 1971), cell death in the brain and loss of nerve cell in the spinal cord (Critchley, 1942) and a reduction of total number of muscle fibres with aging (Gutman and Hanzlekova, 1972) could account for the reduction of muscle strength with age.

In the present study, the weight, height and body surface area of the subjects show a positive correlation with MVC. In this respect our findings agree with the findings of Asmussen and Heeböll-Nielsen (1962).

In our findings the MVC values achieved by subject's right hand were significantly greater than those of the left hand. For age groups 7–9 years, 40–49 years and 50 and above, the above differences were not statistically significant. This is probably due to the small number of subjects in those groups. Because all our subjects were right handers, their right hand should be stronger than the left. The same idea also has been proposed by Lind and McNicol (1968). Greater utilization of the right hand in the performance of daily activities and the subsequent training effect has led to the dominance of the right hand muscles over the left hand in right-handed individuals.

The endurance of handgrip contractions in our investigation are in agreement with the results obtained by other authors (Rohmert, 1960a, b; Lind *et al.*, 1964; Bruce *et al.*, 1968; Wiley and Lind, 1971; Funderburk *et al.*, 1974; Petrofsky *et al.*, 1975). The balance of the evidence favors the theory that fatigue is metabolic in origin (Merton, 1954; Simonson, 1971). The fact that age does not affect the capacity of muscles to sustain a contraction at a known fraction of maximum strength has been reported by Muller (1961) and Rohmert (1960a, b). Those findings are supported by the results of the present investigation. Reasons for the absence of any relationship between the endurance of handgrip contraction and different physical parameters and MVC should be the same as those discussed with regard to age effects.

In our findings, the endurance of right hands was greater than that of left hands. The dominance of right hand endurance over left hand endurance was statistically significant for all ages and for all age groups. As the absolute load was same for each arm, the muscles of the left arm would have to contract at a greater proportional tension in comparison with the dominant right hand. Thus the contraction at greater tension by the weaker arm caused the lower endurance during left-hand contraction in the right-handed subjects.

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