Anthropometric considerations of farm tools/machinery design for tribal workers of northeastern India

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Abstract: Anthropometric body dimensions play a significant role in human-machine interaction. The overall working efficiency of human-machine environment and resultant discomfort has severe impact while using farm tools and machinery in hills. The northeastern region of India is predominantly hilly and inhabited by tribal population. This study presents the anthropometric data of the agricultural workers of Meghalaya, which helps to develop/modify the tools and machinery suitable for the people of this Region. In total 1027 subjects (566 male and 461 female) of five different tribes known as Khasi, Garo, Jaintia, Hajong and Koch from 35 different villages were selected randomly from seven districts. Thirty-four body dimensions useful for agricultural equipment design were selected and measured. The average weight of female workers was found to be about 10.1% lower than the male workers and the average stature of male was nearly 6.9% higher than the female. Similar trend was observed in most of the measured body dimension. The collected data showed non-significant difference among various body dimensions while comparing with other northeastern states. The efforts have been made to illustrate the application of anthropometric data in the design of farm equipments through some examples.

Keywords: Anthropometry, farm machinery design, farm tools

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1 Introduction

Anthropometric dimensions vary considerably across gender, race and age. The anthropometry also differs within a particular group due to nutritional status and nature of work. Thus to achieve better performance and efficiency along with higher comfort and safety to the operator, it is necessary to design tools, equipments and workplaces keeping in view of the anthropometric data of the agricultural workers. It is very important for a designer to consider physical dimensions and human capabilities while designing farm equipments for better output and safety, because the man-machine interface decides the ultimate performance of the equipment.

In this region, mostly animal draft power source is utilized for performing agricultural operations due to inherited constraints like difficult terrain, wide variation in slopes and altitudes, land tenure systems and cultivation practices. Majority population of the region is tribal and prone to excessive drudgery of farm operation due to the number of biophysical, infrastructural and socio-economic problems resulting into low productivity of most of the food grains as well as horticultural crops as compared to the other parts of the country. One of the main reasons of lower agricultural productivity in the region is due to prevalence of traditional method of cultivation and lower mechanization level. Tools and equipment are being manufactured by local artisans and small-scale manufacturers without application of ergonomic principles which are low in working efficiency and often failed to reduce the

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drudgery of operation in hills. Constraints have been experienced in other parts of the country while introducing improved machineries for adoption. Therefore the adopted implements need to be modified according to the comfortability of agricultural workers of the region, for which knowledge of body dimension limits of local population plays a vital role.

Most of the farm operations in this region are equally shared by both genders due to matrilineal form of society (Singh et al. 2002). Singh reported that farm operations such as ploughing, puddling, leveling are exclusively done by male workers while weeding, uprooting seedlings, transplantation are done by female. However, few operations such as fertilizer and chemical application, harvesting, threshing, transportation are done by both genders. Therefore, anthropometric body limitations of both genders have to be taken in to consideration for designing any tools or machinery designated to perform a specific agricultural operation. Thus to bridge this gap, anthropometric body dimensions of agricultural workers were collected for both male and female workers and further regrouped based on their utility for certain implement designs.

2 Materials and methods

Agricultural workers were randomly selected from the seven different districts which were Ri-Bhoi, East Khasi Hills, West Khasi Hills, West Garo Hills and Jaintia Hills of Meghalaya state. Total 1027 subjects of the age group ranging from 19 to 51 years were selected from 35 different villages, out of which 44.9% were females. The number of subjects selected from different groups is presented in Table 1. Before collection of anthropometric data, the whole process for data collection was explained to the workers to maintain accuracy in measurements and to seek full cooperation from them. Integrated Composite Anthropometer (ICA) developed by Indian Institute of Technology, Kharagpur was used for measurement of various body dimensions. Weighing scale with the accuracy of 0.1 kg and capacity of 120 kg, measuring tapes, Vernier caliper and wooden conical shape device for measuring grip diameter were also used to record some parameters. In this study, altogether 34 body parameters including body weight were measured which are useful in designing farm machinery. Various measured dimensions are listed in Table 2.

Table 1 Details of subject selection from different tribes

Sl. No.	Name of district	Name of tribe	Number of subjects		
			Male	Female	Total
1.	Ri bhoi	Khasi	66	55	121
2.	East khasi hills	Khasi	111	106	217
3.	West khasi hills	Khasi	30	26	56
4.	Jaintia hills	Jaintia	150	151	301
5.	West garo hills	Garo, Hajong, Koch	120	74	194
6.	East garo hills	Garo	37	33	70
7.	South garo hills	Garo	52	16	68
Total			566	461	1,027

Table 2 Selected anthropometric body dimensions for measurement

Sl. No.	Anthropometric parameter	Purpose
1.	Weight	General body description
2.	Stature	
3.	Acromial height	Handle design of walk behind type equipment
4.	Elbow height	
5.	Olecranon Height	
6.	Knee Height	
7.	Elbow-Elbow breadth	
8.	Fore arm hand length	
9.	Coronoid fossa to hand length	
10.	Hand length	
11.	Palm length	
12.	Elbow grip length	
13.	Waist back length	For design of back pack carriage of tools/sprayer container etc
14.	Scapula to waist back length	
15.	Wall to acromian distance	
16.	Bi-acromial breadth	
17.	Inter scye breadth	
18.	Waist breadth	
19.	Waist circumference	
20.	Bi-deltoid breadth	
21.	Sitting Height	For sitting posture tool design
22.	Sitting acromion height	
23.	Sitting popliteal height	
24.	Elbow rest height	
25.	Buttock knee length	
26.	Buttock popliteal height	
27.	Hip breadth sitting	
28.	Foot length	For pedal dimensions
29.	Instep length	
30.	Foot breadth (balls of foot)	
31.	Grip diameter (inside)	Handle/Tool grip dimension
32.	Grip Diameter(outside)	
33.	Hand breadth across thumb	
34.	Hand breadth at metacarpal III	

Standard terminologies and measurement techniques

of NASA anthropometric source book (reference publication no.1024) and proposed action plan of All India Anthropometric Survey of Agricultural Workers developed by Gite and Chaterjee (2000) was utilized for collection of data. At the beginning of the study, it was decided to keep the gender ratio sample as 70:30 (male: female). However during the survey, it was observed that the female are main workforces in this region and their participation in various agricultural operations is equal. So the sample selected from male to female ratio was increased to nearly equal.

The measurements were taken by a group of three engineers and one anthropologist. Body dimensions of the subject were measured from the right hand side and the women investigator collected the data on female workers. For those measurements where it was relevant, the head was positioned in the Frankfurt Horizontal Plane as described by Lohman et al. (1988). While measuring the dimensions in standing posture, the subjects were in erect position with the weights equally distributed on both feet, whereas in sitting position the knee and hip angles were controlled to be about 90 degree. A data sheet was developed for the sequence of measurement of different parameters with minimum change of posture. Before starting the measurements, the different tools and techniques were standardized to reduce both inter and intra investigator variability. During the data collection, two independent measurements were performed for each dimension and subject. If the difference between the two measurements exceeded the acceptable level, the third measurement was performed to exclude the recording error.

The role of percentile in design problems is to provide a basis for judging the proportion of a group of individuals who exceed or fall below some possible design limit, therefore, apart from mean, 5^{th} and 95^{th} percentile values of body dimensions were calculated to decide various possible design limits of farm machinery and workspace layout to be operated by male and female workers.

3 Results and discussion

The body dimensions measured during the study were analyzed for mean, standard deviation, range and percentile values of male and female agricultural workers. The mean and standard deviation values for male and female workers suggest that there exists a remarkable difference in anthropometric dimensions of male and female agricultural workers of Meghalaya (Table 3). Analysis of data shows that the mean weight and stature of female agricultural workers (47.7 kg and 150.8 cm) is significantly lower than their male counterparts (53.7 kg and 161.4 cm). The mean weight and stature of female were found to be 89.8% and 93.1% in comparison with male workers. The stature is an important dimension for its relevancy in determining several other body dimensions. However, the 5^{th} and 95^{th} percentile values of stature for male agricultural workers are found to be 151.6 and 170.5 cm, which suggest that the design parameter should not exceed the range making it cumbersome for the user.

Table 3 Anthropometric data of male (N=566) and female (N=461) workers of Meghalaya

SN	Body Dimensions**	Male		Female	
		Mean	SD	Mean	SD
1.	Weight, kg	53.7	6.3	47.0	7.1
2.	Stature	161.4	6.3	150.8	4.9
3.	Acromial height	132.7	5.5	124.2	4.8
4.	Elbow height	101.4	4.1	96.0	3.5
5.	Olecranon height	98.9	4.1	93.7	3.6
6.	Knee height	45.8	2.6	42.8	2.5
7.	Waist back length	42.9	2.8	39.2	2.6
8.	Scapula to waist back length	73.1	3.6	69.1	4.0
9.	Wall to acromion distance	10.9	1.3	10.5	1.3
10.	Bi-acromial breadth	31.0	1.8	28.7	1.9
11.	Bi deltoid breadth	39.7	2.0	37.3	2.1
12.	Inter scye breadth	28.2	2.2	26.2	2.0
13.	Waist breadth	23.3	1.9	22.5	1.9
14.	Waist circumference	74.6	5.8	72.4	6.3
15.	Sitting height	84.8	4.5	78.4	4.5
16.	Sitting acromial height	58.8	4.7	53.4	4.5
17.	Sitting popliteal height	41.7	2.4	39.4	2.5
18.	Elbow rest height	24.6	7.1	22.7	2.9
19.	Coronoid fossa to hand length	36.0	7.4	34.8	1.7
20.	Buttock knee length	52.5	10.8	51.3	2.7
21.	Buttock popliteal height	43.1	9.6	42.3	2.7
22.	Hip breadth sitting	30.0	7.0	30.5	1.9
23.	Elbow- elbow breadth sitting	34.9	7.4	34.5	2.3
24.	Elbow grip length	31.0	6.6	30.3	1.6
25.	Fore arm hand length	40.9	8.1	39.5	1.7
26.	Hand length	16.9	3.8	16.1	0.8
27.	Hand breadth at metacarpal-III	7.8	1.8	7.4	0.5

SN	Body Dimensions**	Male		Female	
		Mean	SD	Mean	SD
28.	Hand breadth across thumb	9.1	2.2	8.6	0.6
29.	Palm length	8.9	2.4	9.2	0.6
30.	Foot length	23.5	7.0	22.2	0.9
31.	Instep length	17.5	3.6	16.6	0.9
32.	Foot breadth (balls of foot)	9.4	2.2	8.8	0.6
33.	Grip diameter (outside)	7.8	1.8	6.3	0.6
34.	Grip diameter (inside)	4.0	1.1	3.6	0.3

Note: **All dimensions in cm except mentioned.

Further analysis of data shows the mean acromial height, elbow height, knee height, waist back length, scapula to waist back length, bi-acromial breadth, inter scye breadth of female workers were found to 92%-93% of corresponding body dimensions of male workers. While sitting height, sitting eye height and sitting acromial height, elbow rest height of female workers were found to be about 90%-91% of the corresponding dimensions of the male. However, palm length and hip breadth sitting of female workers were found to be 1%-4% higher than that of male workers. The difference in some of the body dimensions such as elbow-elbow breadth, buttock popliteal length, buttock knee length, etc was only 1%-2% between male and female workers.

3.1 Variation in anthropometric body dimensions across the region

Table 4 presents the comparison of important body dimensions of male and female workers of Meghalaya with different states of this region. The perusal of the data indicates that various body dimensions values do not vary considerably across the states of the region. Therefore, tools and equipments designed based on data collected can effectively utilized by workers of the whole region. The comparison of anthropometric dimensions with other parts of the country (Table 5) suggest that body dimensions of people of the region has lower body dimensions as compared to other parts of the country. The lower body dimensions may lead to have uncomfortable postures adopted while working with implements and machinery leading to low work output. The average stature of male workers of Gujarat was found to be highest i.e. 167.6 cm followed by Madhya Pradesh, Orissa and Tamilnadu while the mean stature of male workers of Meghalaya was found to be only 161.4 cm. Similar trend was observed in case of weight and other body dimensions. However, comparing the average body dimensions of female workers in different parts of the country it was found that average stature and weight has no significant difference across the states. Therefore, implements often designed for the male workers at other places in the country, needs to be modified with suitable adjustments in seat, handle height and grip dimensions, strap design, seat dimensions, control placement, etc.

Table 4 Comparison of mean anthropometric dimensions of male and female agricultural workers of Meghalaya with other parts of the region

SN	Body Dimensions**	Male			Female		
		Arunachal Pradesh*	Mizoram*	Meghalaya	Arunachal Pradesh*	Mizoram*	Meghalaya
1.	Weight, kg	56.6	57.4	53.7	48.5	46.5	47.0
2.	Stature	162.2	160.9	161.4	152.5	153.1	150.8
3.	Acromial height	135.1	133.1	132.7	126.4	129.2	124.2
4.	Elbow height	100.7	99.5	101.4	95.7	96.7	96.0
5.	Olecranon height	98.3	97.4	98.9	93.1	97.1	93.7
6.	Knee height	46.2	41.8	45.8	40.9	39.8	42.8
7.	Bi-acromial breadth	40.5	37.3	31.0	33.4	33.9	28.7
8.	Bi deltoid breadth,	43.1	41.2	39.7	36.2	36.3	37.3
9.	Hip breadth	30.9	31.1	28.6	29.3	30.8	28.1
10.	Sitting height	83.5	84.4	84.8	80.2	80.2	78.4
11.	Sitting acromion height	58.1	55.8	58.8	54.7	54.8	53.4
12.	Sitting popliteal height	40.7	36.4	41.7	44.8	44.9	47.1
13.	Elbow rest height	21.6	22.4	24.6	23.1	22.1	22.7
14.	Buttock knee length	53.0	51.8	52.5	50.3	50.7	51.3
15.	Buttock popliteal height	42.4	39.0	43.1	37.8	39.7	42.3

SN	Body Dimensions**	Male			Female		
		Arunachal Pradesh*	Mizoram*	Meghalaya	Arunachal Pradesh*	Mizoram*	Meghalaya
16.	Hip breadth sitting	32.7	29.8	30.0	30.5	31.4	30.5
17.	Elbow- elbow breadth sitting	43.0	49.0	34.9	37.3	37.5	34.5
18.	Elbow grip length	37.4	35.9	31.0	33.1	31.1	30.3
19.	Fore arm hand length	44.8	43.3	40.9	40.7	39.9	39.5
20.	Hand length	17.7	17.2	16.9	16.6	16.3	16.1
21.	Hand breadth at metacarpal –III	7.4	7.5	7.8	6.5	6.5	7.4
22.	Hand breadth across thumb	9.9	9.9	9.1	8.8	9.2	8.6
23.	Hand thickness at metacarpal-III	3.0	2.9	3.8	2.8	2.6	3.5
24.	Palm length	10.0	9.6	8.9	9.1	8.8	9.2
25.	Grip diameter (inside)	4.9	4.7	4.0	4.4	4.4	3.6
26.	Grip diameter (outside)	8.1	7.9	7.8	7.4	7.1	6.3
27.	Foot length	24.1	23.9	23.5	22.8	22.4	22.2
28.	Instep length	16.3	17.1	17.5	16.4	15.4	16.6
29.	Foot breath (balls of foot)	10.0	9.8	9.4	9	8.7	8.8

Note: * Prasad, N. et al. ,1999; **All dimensions in cm except mentioned.

Table 5 Comparison of mean anthropometric dimensions of male and female agricultural workers of Meghalaya with other states of the country

SN	Body Dimensions**	Male					Female			
		Tamil nadu#	Madhya pradesh$$	Meghalaya	Gujarat$	Orissa##	Meghalaya	Tamil nadu#	Madhya pradesh$$	Gujarat$
1.	Weight, kg	55.9	51.4	53.7	61.2	56.3	47.0	47.3	45.2	46.4
2.	Stature	162.9	164.6	161.4	167.9	163.0	150.8	150.8	151.2	151.6
3.	Acromial height	137.5	137.3	132.7	141	134.8	124.2	125.8	126.2	126.4
4.	Elbow height	101.9	104.7	101.4	106.4	100.9	96.0	96.6	96.0	95.0
5.	Olecranon height	98.9	101.1	98.9	105.2	99.7	93.7	93.4	93.5	93.1
6.	Knee height	47.9	47.0	45.8	50.5	46.4	42.8	44.2	43.3	46.1
7.	Bi-acromial breadth	30.9	31.7	31.0	36.1	33.9	28.7	28.2	27.9	29.1
8.	Bi deltoid breadth	41.4	41.6	39.7	47.3	38.8	37.3	36.1	38.0	37.4
9.	Sitting height	73.9	84.6	84.8	81.6	81.9	78.4	60.1	77.4	78.9
10.	Sitting acromion height	50.7	57.6	58.8	55.3	57.0	67.4	47.9	67.7	67.8
11.	Sitting popliteal height	42.2	41.8	41.7	44.5	44.1	39.4	39.6	38.9	43.1
12.	Knee height sitting	50.6	50.7	49.6	52.4	49.4	53.4	37.4	52.7	53.3
13.	Elbow rest height	20.2	21.5	24.6	18.8	23.4	47.1	47.4	46.9	48.5
14.	Buttock knee length	54.0	54.8	52.5	57.1	50.3	51.3	52.5	52.3	52.6
15.	Buttock popliteal length	45.2	46.3	43.1	46.1	43.0	42.3	44.1	45.7	42.4
16.	Hip breadth sitting	30.0	30.8	30.0	35.4	31.0	30.5	28.6	31.3	30.9
17.	Elbow- elbow breadth sitting	35.5	37.5	34.9	34.6	38.9	34.5	35.7	36.4	34.8
18.	Elbow grip length	36.2	34.8	31.0	38.7	36.4	30.3	32.9	32.6	32.5
19.	Fore arm hand length	45.5	46.5	40.9	47.5	44.5	39.5	41.9	42.6	42.9
20.	Hand length	18.0	18.6	16.9	18.6	16.3	16.1	16.6	17.2	17.1
21.	Hand breadth at metacarpal -III	8.1	8.3	7.8	9.1	8.1	7.4	7.5	7.5	7.6
22.	Hand breadth across thumb	9.8	9.9	9.1	11.3	9.5	8.6	8.9	8.8	10.0
23.	Palm length	10.2	10.6	8.9	10.5	10.3	9.2	9.3	9.8	10.0
24.	Grip diameter (inside)	5.0	5.3	4.0	5.2	5.0	3.6	4.6	4.9	4.0
25.	Grip diameter (outside)	8.2	10.1	7.8	10.7	8.1	6.3	6.5	9.1	8.2
26.	Foot length	23.9	25.3	23.5	26.8	24.0	22.2	21.8	23.0	22.9
27.	Instep length	18.9	18.6	17.5	19	17.2	16.6	16.5	16.4	14.6
28.	Foot breath (ball of foot)	8.8	9.7	9.4	10.7	9.2	8.8	8.3	8.7	8.9

Note: $ Yadav et al (2000), $$ Anonymous (2005), # Anonymous (2005), ## Anonymous (2002). **All dimensions in cm except mentioned.

3.2 Variation in anthropometric body dimensions across ethnic population of the world

The comparison of major anthropometric dimensions of male subjects of the north eastern region of India with those of other ethnic groups from China, Japan, Germany, Britain and the USA (Table 6) reveals that most of the dimensions are smaller for male farm workers of the north eastern region indicating a unique and distinct nature of the anthropometry of the region. Dewangan et al. (2005) revealed similar variations in anthropometric data of different countries.

Table 6 Comparison of anthropometric data of northeastern male workers with other ethnic population of the world

Body dimensions	Indian	Chinese[a]	Japanese[b]	German[c]	British[d]	American[e]
Stature	161.40	168.82	165.80	174.50	173.81	175.54
Eye height	-	158.53	-	-	-	164.31
Acromial height	132.70	142.10	134.50	146.40	-	143.51
Sitting height	84.80	89.65	90.40	92.10	91.90	91.28
Sitting eye height	-	79.40	78.50	80.20	80.27	79.94
Sitting acromial height	58.80	-	-		62.11	59.07
Popliteal height	41.70	40.13	40.20	45.40	-	43.10
Buttock popliteal length	34.90	42.29	-	-	--	-
Fore arm hand length	40.90	-	-	-	46.87	47.91

Note: [a]Shao and Zhou (1990); [b]Yokohori (1972); [c]Jurgens et al. (1972); [d]Haslegrave (1980); [e]Hertzberg et al. (1954).

3.3 Grip dimensions

In hill agriculture most of the tools are manually driven, so proper grip is required for effective force application while working with these tools. The grip dimensions of most of the hand tools such as *dao*, weeders, handles of wheel hoe, etc need to be relooked based on anthropometric dimensions. The 5^{th}, 50^{th} and 95^{th} percentile values of grip diameter (inside) of male and female agricultural workers of Meghalaya was found as 3.7, 4.2 and 4.7 cm for male and 3.3, 3.6 and 4.1 cm for female workers, respectively. The comfortable holding of the grip needs to be designed in such a way that a person with 5^{th} percentile body dimensions could properly grip the handle. Therefore, the minimum diameter of the grip should be 3.7 cm for male and 3.3 cm for female workers.

The length of grip depends upon breadth of palm of the population and it should be decided based on 95^{th} percentile person operating the equipment so that he/she is able to hold the grip properly. The minimum handle grip length should be 9.9 cm for male and 9.5 cm for female operated tools.

3.4 Handle holding height

The handle holding height depends upon the elbow height of the population and permitted range of elbow angle. Grandjean (1988) suggested that comfortable range of elbow angle should be $100\text{-}110^0$. The elbow height (standing) for male and female agricultural workers of Meghalaya was found to be 94.7, 101.6 and 107.6 and 90.6, 96.1 and 101.2 cm for 5^{th}, 50^{th} and 95^{th} percentile, respectively. With known elbow grip length, the handle height at given elbow angle of $100\text{-}110^0$ can be calculated. At 100^0 elbow angle, the handle height should be 89.5 cm for male and 85.7 cm for female workers with 5^{th} percentile body dimensions. Workers with 95^{th} percentile body dimension the handle height should be 95.6 and 101.2 cm above ground for male and female workers respectively. In order to maintain elbow angle 110^0 the corresponding handle heights 81.0 and 84.6 cm for 5^{th} percentile and 89 and 95.6 cm for 95^{th} percentile for male and female workers. However, in case of implements such as wheel hoe, which has certain working depth, necessary correction needs to be made in handle height to have comfortable holding height in working condition.

3.5 Strap design

Carrying of load on backpack mode is a common way of transporting the material from one place to other in hills and it is common for both male and female workers. The anthropometric values of scapula to waist back length and waist circumference of the workers of Meghalaya have been taken in to consideration. The 5th

and 95th percentile values of scapula to waist back length were found to be 67.5 and 78.8 cm for male and 63.5 and 74.6 cm for female workers. Therefore, the strap length should be minimum 78.8 cm so that persons with 95th percentile values can also be able to utilize the strap properly.

The waist belt if any provided should be of length equal to 95th percentile values of waist circumference. The 95th percentile value of waist circumference was found to be 84.5 cm for male and 83.2 cm for female workers. While 5th percentile waist circumference for male and female workers were found to be 66.5 and 63.8 cm respectively. Therefore, waist strap must have minimum length of 84.5 cm (i.e. 95th percentile value of male) with adjustment of tying the same should be up to 63.8 cm so that 95% persons in the population group should be able to use the given strap.

The fitting of strap should be such that they should fit to waist breadth of all workers. The straps fitted too apart leads to inconvenience while too closely fitted straps leads to undue stresses on shoulders of the operator having higher body dimensions. Therefore, the strap should be fitted with (23.1±3.4) cm for male and (22.3± 2.4) cm for female workers.

4 Conclusions

Application of ergonomic approach while designing farm implements and machinery is not very much in practice in developing countries like India due to lack of proper anthropometric database of the user group. Since a non-significant variation was observed in the anthropometric body dimension across the various states of the region, the anthropometric data thus will help the research engineers and agricultural implement manufacturers for designing, development and batch production of improved tools and implements suitable for the workers of north-eastern region. Since women's' participation in various agricultural operations in the state is relatively more than other parts of the country, there is a real need to develop improved tools and equipments suiting the capabilities of female agricultural workers. This data bank will also be useful in incorporating suitable modifications in improved tools and equipment being introduced in northeastern states from other parts of the country. Moreover, the data gathered will also serve as baseline study for design made for user group having similar ethnic origin in neighboring countries.

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