Isometric muscular strength data of Indian agricultural workers for equipment design: Critical analysis

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Abstract: Human muscular strength is extensively used in Indian agriculture for operating various push-pull type farm tools and equipment. Incompatibility between operators' physical capabilities (anthropometric and biomechanical) and demands of physical task to operate tools/equipment often leads to poor performance, low productivity and safety problems. Although anthropometric data are generally being considered, an inadvertent negligence of using strength database for agricultural tools/equipment design is very common in developing countries like India. Therefore, in present paper an attempt has been made to statistically analyze available strength data (pooled and regional/state wise data) of male and female Indian agricultural workers to understand nature of variability of those data in terms of difference between pooled Indian data vs. individual state data; difference between male vs. female data across various states of India; and for determining safe operational force limits for handling various agricultural tools/equipment. Critical evaluation of male and female strength data revealed that there are significant differences (p<0.01 or p<0.05) between mean values of pooled Indian data vs. individual state data for almost all strength variables under study. It has also been observed that average muscular strength of female is significantly lower (in general 2/3rd of male) than their male counter parts across all states. Thus, present study concluded that regional variations and gender variation of isometric strength data are crucial ergonomic consideration for using percentile strength data during calculation of operational force limits for designing various agricultural tools/equipment to be used by targeted user populations from various parts of a country like India with huge ethnic diversity.

Keywords: ergonomics, muscular strength, tools and equipment, agricultural workers, India

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1 Introduction

A large section of the Indian population engaged in agriculture spreading over 640,000 villages, represents about 10% (225 million) of the total world workforce in agriculture (Nag and Nag, 2004). With the advancement of farm mechanization, improved farm tools and equipment are being used in India for different farming operations. In spite of rapid farm mechanization in the last century, the vast resource-poor farming families still rely on human power (muscular strength) which plays a major role in tasks that require hard labor. Physical strain and fatigue due to heavy physical workload might result in accidents and injuries. Further, awkward working postures i.e. stooping, bending, twisting, kneeling etc. along with overloading of muscle-tendon-bone-joint system may also cause injury to workers. Unfortunately, these are overlooked very often by agricultural equipment/machine designers and manufactures. Ergonomics has always been focused on study of 'fitting the task to the human' and, to identifying and quantifying threats to human health in diverse work environments, so that these threats can be mitigated through user centered product design (Chowdhury et al.,

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2012). Many researchers have already shown that numerous risk factors in agricultural work can successfully be prevented using ergonomics approaches (Waters, 2012; Miles and Steinke, 1993; Patel et al., 2013). Ergonomically design tools and equipment is regarded as a way out to reduce human drudgery and to enhance agricultural productivity. During designing of farm tools and equipment, expected variability in strength parameters is used to indicate how much adjustability or what range of forces are to be considered to accommodate the intended population of agricultural workers.

In the present era, user centric tools and equipment design for Indian farmers, considering ergonomic aspects such as anthropometric and strength variability are of utmost need. Due attention is needed to be given towards capabilities and limitations of the targeted user group during design and operation of various farm equipment to enhanced productivity, comfort and safety. Muscular strength data vary according to race, sex, age, body weight and lifestyle (Gite and Singh, 1997). Therefore, knowledge of human strength capabilities and understanding of the key elements involved in design is an important consideration (Mital and Kumar, 1998). Large amount of strength required for performing a task; or failure to include variability in its range can produce degraded results which can affect musculoskeletal system by physical overloading. This ultimately leads to discomfort, fatigue, pain, injury and illness. Although there are fairly extensive strength databases in Western countries (Xiao et al., 2005; Yadav et al., 2010), availability of strength data of Indian agriculture workers are not only limited (Mehta et al., 2007; Agrawal et al., 2009; 2010; Yadav et al., 2010; Tiwari et al., 2010; Gite et al., 2009; Dewangan et al., 2010) but also rarely in use. This paper analyzed available muscular strength data (electronics and hardcopy documents) of male and female agricultural workers of different states of India and outlined strategy of using these data for efficient design and modifications of agricultural tools and equipment from ergonomics perspective.

2 Methodology

To analyse isometric muscular strength data of male and female Indian agricultural workers, a systematic literature search was conducted up to December 2013 from electronic databases e.g. Sciencedirect, Tandfonline and Google Scholar using the key words: 'ergonomics in tools and equipment', 'muscular strength', 'isometric force' and combinations of these terms. Available printed journals and books were also gone through. Search was limited to research paper published in English language. Finally three main sources (given below) were identified and muscular strength databases of Indian agricultural folk were extracted for current study.

- Strength data of Gujarat (GU), Jammu and Kashmir (JK), Madhya Pradesh (MP), Maharashtra (MH), Orissa (OR) and Tamil Nadu (TN) reported by Gite et al. (2009)
- Strength data of Meghalaya (ML) reported by Agrawal et al. (2009)
- Strength data of Arunachal Pradesh (AR) reported by Dewangan et al. (2010)

3 Biomechanical principles in tools and equipment design

In a large number of industrial and agricultural occupations, manual materials handling (MMH) is a primary component of many activities. Typically it involves lifting, lowering, pulling, pushing and carrying objects by hand. Nearly half of all MMH activities involve pushing and/or pulling forces (Baril-Gingras and Lortie, 1995; Kumar et al., 1995). An unintended negligence of human factors in design process reduces efficiency of operation and creates safety problems and discomfort for operators (Gite and Singh, 1997). Design of tools and equipment can be improved through research on biomechanics of human body. Application of biomechanical principles would be useful for implementing comprehensive and logistic user-friendly solutions to ensure workers' strength, skills and abilities, through improved equipment and working methods. In other words, ergonomics design of tools and equipment is a compromise between operator's physical capabilities and energy/force demands by tools and equipment (Dhimmar et al., 2011; Chandra et al., 2013). Many manual tasks performed in agriculture involve awkward postures which are undesirable according to ergonomics work method. Biomechanical disorders due to inappropriate posture; and mismatch of tools and equipment with operators are commonly presumed to be prevalent in agriculture (Rainbird and O'Neill, 1995). Many risk factors can be reduced if tools and equipment are designed with emphasis on user comfort and safety. Therefore, for designing of farm tools and equipment, databases of hand push/pull forces or leg/foot forces exerted by operators are found to be of immense importance to designers and engineers (Agrawal et al., 2009) to prevent incidence of musculoskeletal injuries (Mital and Kumar, 1998).

3.1 Isometric push/pull strength of male and female agricultural workers

In Indian agriculture, along with male workers, women also play a significant and crucial role in various agricultural activities like seeding, planting, weeding, irrigating, processing, harvesting, and threshing operations. Various types of agricultural tasks (operation of manual ridgers, rotary dibblers, rice transplanters/seeders, push/pull weeders, field rakes, long-handled tools, chaff cutters, groundnut/castor decorticators etc.), transportation of loads using manual carts and wheel-barrows etc. involve pushing and/or pulling forces (Tiwari et al., 2010; Agrawal et al., 2010). Leg and foot operated controls on machinery and equipment such as the foot operated sprayers, threshers and dibblers are highly used in India (Yadav et al., 2010). These activities impose a lot of physical and mental stress upon farm workers. Therefore, sixteen strength variables (Table 1) were recommended by All India Coordinated Research Project (AICRP) on Ergonomics and Safety in Agriculture (ESA), India (Gite and Chatterjee, 1999) for ergonomic design of farm tools and equipment.

Isometric muscular strength data (compiled mean ±SD values from aforesaid sources) of male and female Indian agricultural workers has been shown in Table 2. This table represents data from all zones of India viz., Northern India (Jammu and Kashmir), Southern India (Tamil Nadu), Eastern India (Orissa), Western India (Gujarat and Maharashtra), Northeast India (Meghalaya and Arunachal Pradesh) and Central India (Madhya Pradesh), respectively.

Table 1 Strength variables of agricultural workers (male and female) with reference code

Code No.	Strength Parameters
1	Hand grip strength-R
2	Hand grip strength-L
3	Push strength in standing posture-BH
4	Pull strength in standing posture-BH
5	Push strength in sitting posture-RH
6	Push strength in sitting posture-LH
7	Pull strength in sitting posture-RH
8	Pull strength in sitting posture-LH
9	Leg strength in sitting posture-R
10	Leg strength in sitting posture-L
11	Foot strength in sitting posture-R
12	Foot strength in sitting posture-L
13	Torque strength in standing posture-PH
14	Torque strength in standing posture-BH
15	Torque strength in sitting posture-BH
16	Hand grip torque-PH

Note: R-right; L-left; RH-right hand; LH-left hand; BH-both hands; PH-preferred hand.

To understand variability of data for each muscular strength variable, standard deviations (SD) were expressed as percentage of mean value across various populations under study (Figure 1). It was found that variations were less than 15% in some variables e.g. left and right hands grip strength, both hands push/pull strength in standing posture, left and right hand push/pull strength in sitting posture etc. compared to other variables where more than 15% and up to 32% variation were noticed across the nation. Minimum and maximum variability (SD as %age of mean) were noted for push strength in standing posture in both hands (9%) and handgrip torque in preferred hand (32%).

From Figure 2, similar observations were also noted for female agricultural workers but variability (SD as %age of mean) across the regions were noted less than 15% only for right hand grip strength and left/right leg strength in sitting posture. The minimum and maximum variability were found 12% for right hand grip strength and 43% for preferred hand grip torque, respectively.

Table 2 Mean (SD) isometric muscular strength data of male (♂) and female (♀) agricultural workers

Code No.	India		GU		JK		MP		MH		OR		TN		ML		AR	
	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
1	360 (92)	224 (80)	-	-	313 (52)	140 (33)	404 (110)	242 (88)	326 (66)	180 (44)	336 (82)	225 (69)	412 (87)	275 (70)	-	-	300.3 (71)	-
2	340 (93)	210 (83)	-	-	294 (51)	120 (29)	377 (110)	211 (89)	313 (65)	167 (42)	326 (79)	207 (57)	388 (106)	274 (73)	-	-	286.1 (72)	-
3	224 (56)	143 (39)	252 (47)	171 (13)	228 (41)	110 (15)	243 (59)	176 (42)	218 (59)	141 (37)	233 (50)	161 (33)	202 (48)	131 (29)	277 (55)	180.8 (40)	226.8 (54)	-
4	218 (46)	158 (39)	227 (43)	142 (12)	239 (43)	124 (18)	227 (43)	186 (35)	202 (45)	142 (30)	236 (44)	169 (34)	219 (46)	167 (39)	202.7 (62)	121.7 (30)	191.5 (51)	-
5	77 (17)	62 (19)	76 (19)	44 (7)	84 (12)	66 (17)	79 (18)	57 (14)	72 (17)	66 (22)	73 (18)	52 (15)	-	-	228.6 (55)	138.1 (44)	118 (30)	-
6	74 (17)	58 (19)	94 (15)	58 (7)	75 (12)	55 (16)	75 (17)	53 (13)	68 (16)	63 (22)	72 (19)	46 (11)	-	-	168.2 (60)	120.7 (40)	112.4 (30)	-
7	92 (19)	71 (18)	77 (19)	50 (6)	91 (13)	71 (17)	93 (20)	69 (15)	94 (20)	75 (20)	84 (21)	58 (16)	-	-	176.1 (63)	95.15 (29)	148.9 (42)	-
8	88 (19)	68 (19)	96 (15)	66 (7)	81 (14)	62 (17)	88 (19)	65 (14)	92 (21)	72 (21)	81 (20)	57 (15)	-	-	105.8 (32)	104.7 (44)	141.5 (43)	-
9	429 (103)	319 (89)	369 (52)	-	366 (61)	275 (51)	388 (91)	276 (72)	461 (93)	306 (79)	401 (100)	270 (69)	512 (106)	376 (88)	525.6 (40)	334.1 (44)	363.2 (85)	-
10	425 (108)	304 (85)	301 (38)	-	330 (57)	245 (48)	399 (97)	279 (72)	452 (95)	301 (81)	412 (96)	281 (76)	523 (101)	341 (89)	464.5 (49)	274 (43)	300.4 (82)	-
11	332 (103)	242 (86)	329 (52)	-	271 (56)	203 (42)	287 (80)	198 (60)	370 (103)	238 (82)	268 (80)	167 (55)	428 (93)	331 (62)	342.9 (49)	199.4 (29)	271.4 (95)	-
12	308 (95)	226 (80)	252 (41)	-	250 (55)	177 (37)	292 (82)	200 (58)	363 (105)	232 (85)	250 (76)	146 (73)	415 (80)	295 (64)	282.4 (45)	153.8 (28)	240.1 (79)	-
13	176 (59)	137 (40)	183 (29)	91 (9)	148 (33)	100 (10)	171 (36)	137 (29)	150 (40)	111 (22)	163 (48)	108 (17)	273 (52)	181 (32)	100.9 (40)	96.53 (30)	48 (47)	-
14	210 (71)	158 (40)	210 (27)	118 (10)	182 (41)	119 (8)	196 (40)	159 (32)	181 (48)	140 (27)	199 (52)	142 (16)	329 (63)	217 (19)	136.1 (54)	128.7 (42)	56 (61)	-
15	287 (71)	193 (57)	285 (47)	188 (13)	282 (60)	137 (35)	282 (79)	203 (52)	278 (62)	169 (42)	281 (81)	169 (39)	318 (74)	226 (56)	311.1 (38)	234.4 (51)	59 (72)	-
16	33 (14)	19 (10)	38 (10)	29 (5)	24 (10)	14 (5)	38 (14)	24 (10)	29 (10)	19 (10)	38 (10)	29 (10)	52 (5)	48 (5)	-	-	5 (8)	-

Note: Unit of all variables are in Newton; '-' data not available.

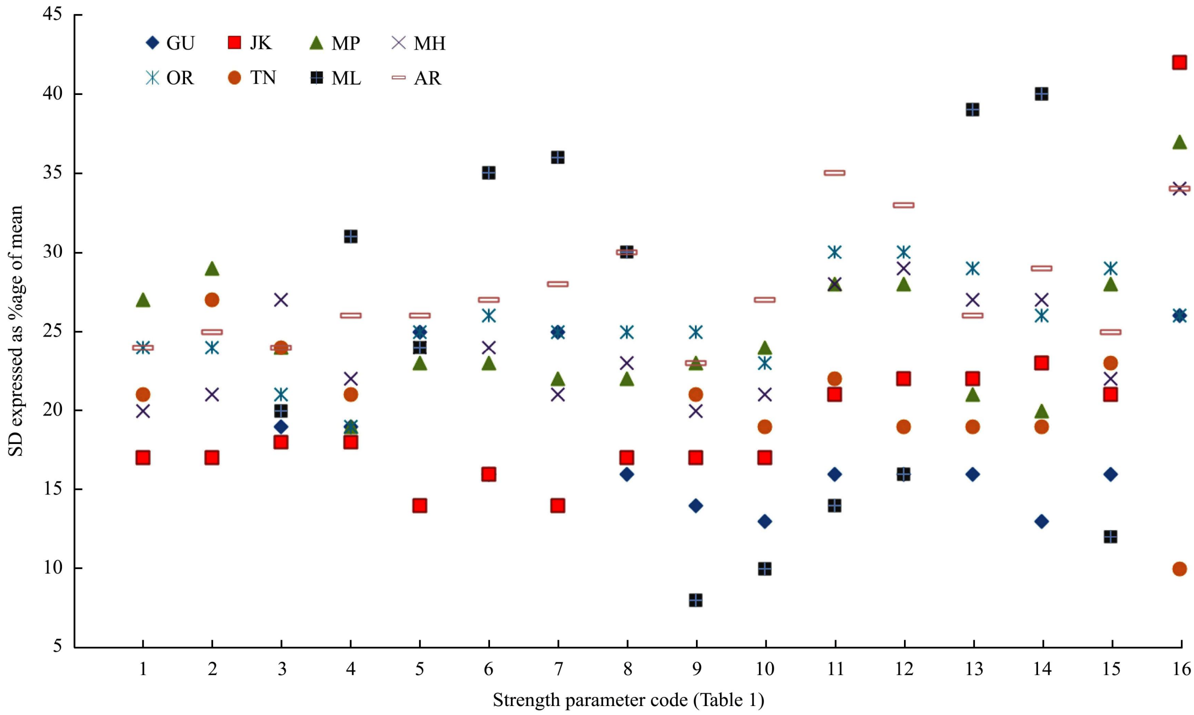

Figure 1 SD expressed as %age of mean value of strength parameters for male agricultural workers from various states

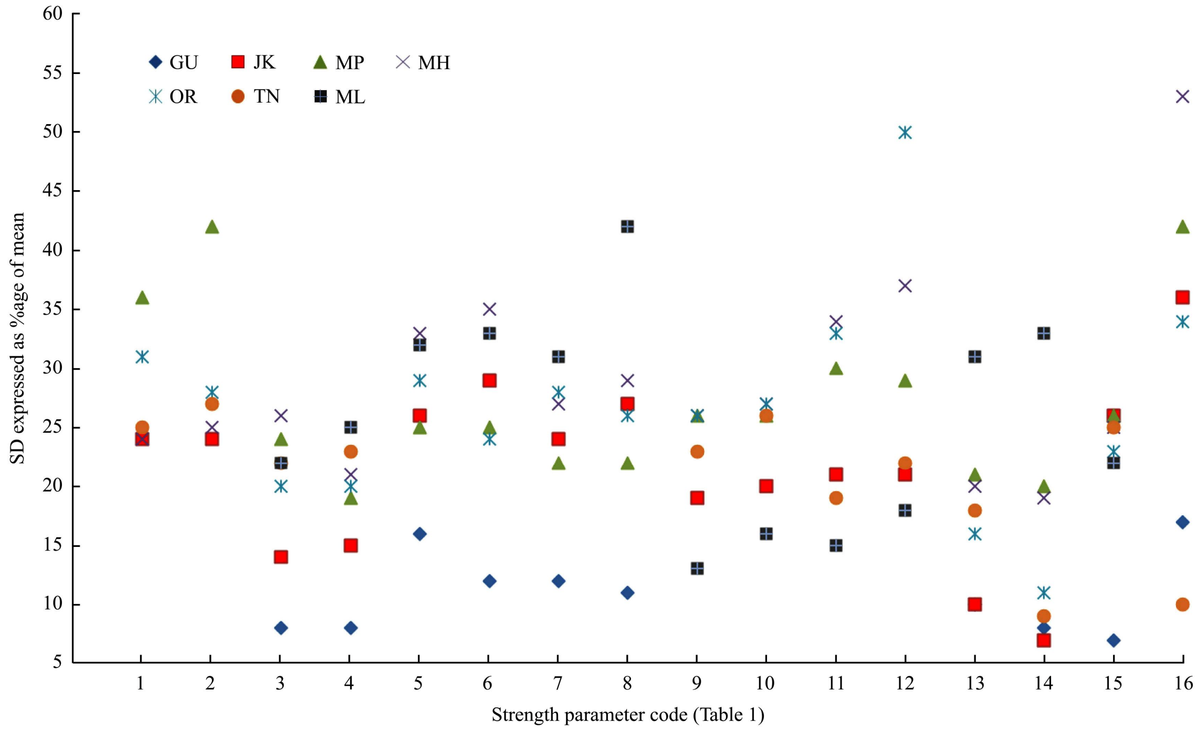

Figure 2 SD expressed as %age of mean value of strength parameters for female agricultural workers from various states

3.1.1 Comparison of male and female muscular strength

All sixteen strength variables from eight states (Gujarat, Jammu and Kashmir, Madhya Pradesh, Maharashtra, Orissa, Tamil Nadu, Meghalaya and Arunachal Pradesh) for male and female (except Arunachal Pradesh) were compared with pooled Indian data and significance of difference were checked by t-test. The results of t-test are presented in Table 3. For male, muscular strength of most of the groups (states) were found significantly (either p<0.01 or p<0.05) different from pooled Indian male data in respect to right and left hand grip strength (except Orissa), push with both hands (except Jammu and Kashmir and Arunachal Pradesh), pull with both hands (except Gujarat and Tamil Nadu), right hand push in sitting posture (except Gujarat), left hand push in sitting posture (except Jammu and Kashmir, Madhya Pradesh and Orissa), right hand pull in sitting posture (except Jammu and Kashmir and Madhya Pradesh), left hand pull in sitting posture (except Madhya Pradesh), right and left legs strength (except Orissa), right foot strength (except Gujarat and Meghalaya), left foot strength (except Meghalaya), torque strength with preferred hand (except Gujarat), torque strength with both hands in standing posture (except Gujarat and Arunachal Pradesh), torque strength with both hands in sitting posture (except Gujarat, Jammu and Kashmir, Madhya Pradesh, Orissa and Arunachal Pradesh) and hand grip torque respectively.

Similar to the previous section, comparisons were also made for muscular strength of female agricultural workers between pooled Indian data; and data from individual state. In this comparison, Arunachal Pradesh was not considered since relevant female data were not available in published literature. Statistical analysis (t-test) revealed that muscular strength of most of the groups were statistically (either p<0.01 or p<0.05) different for right handgrip strength (except Orissa), left handgrip strength (except Madhya Pradesh and Orissa), push with both hands (except Maharashtra), pull with both hands, right hand push in sitting posture, left hand push in sitting posture (except Gujarat), right hand pull in sitting posture (except Jammu and Kashmir), left hand pull in sitting posture (except Gujarat), right leg strength (except Meghalaya), left leg strength (except Maharashtra), right foot strength (except Maharashtra), left foot strength (except Maharashtra), torque strength with preferred hand (except Madhya Pradesh), torque strength with both hands in standing posture (except Madhya Pradesh), torque strength with both hands in sitting posture (except Gujarat) and hand grip torque (except Maharashtra).

Table 3 Comparison (t-test result) of muscular strength data of male and female agricultural workers of India (pooled) versus individual states of India

Code No.	GU		JK		MP		MH		OR		TN		ML		AR	
	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
1	-	-	**	**	**	**	**	**	**	NS	**	**	-	-	**	-
2	-	-	**	**	**	NS	**	**	NS	NS	**	**	-	-	**	-
3	**	**	NS	**	**	**	**	NS	*	**	**	**	**	**	NS	-
4	NS	*	**	**	**	**	**	**	**	**	NS	**	*	**	**	-
5	NS	**	**	**	**	**	**	**	**	**	-	-	**	**	**	-
6	**	NS	NS	*	NS	**	**	**	NS	**	-	-	**	**	**	-
7	**	**	NS	NS	NS	*	**	**	**	**	-	-	**	**	**	-
8	**	NS	**	**	NS	**	**	**	**	**	-	-	**	**	**	-
9	**	-	**	**	**	**	**	**	**	**	**	**	**	NS	**	-
10	**	-	**	**	**	**	**	NS	NS	**	**	**	**	*	**	-
11	NS	-	**	**	**	**	**	NS	**	**	**	**	NS	**	**	-
12	**	-	**	**	**	**	**	NS	**	**	**	**	NS	**	**	-
13	NS	**	**	**	*	NS	**	**	**	**	**	**	**	**	**	-
14	NS	**	**	**	**	NS	**	**	*	**	**	**	**	**	NS	-
15	NS	NS	NS	**	NS	**	**	**	NS	**	**	**	*	**	NS	-
16	**	**	**	**	**	**	**	NS	**	**	**	**	-	-	**	-

Note: '*' Significant (*p*<0.05); '**' Significant (*p*<0.01); 'NS' Not Significant; '-' data not available.

3.1.2 Region-wise comparison between male and female muscular strength data

Strength data of different regions/states including pooled Indian data were analyzed to find out percentage difference between male and female agricultural workers as shown in Table 4.

Table 4 Region-wise strength data comparison (%difference) between mean values of male and female agricultural workers

Code No.	India	GU	JK	MP	MH	OR	TN	ML
1**	38	NA	55	40	45	33	33	NA
2**	38	NA	59	44	47	29	37	NA
3**	36	32	52	28	35	35	31	35
4**	28	37	48	18	30	24	28	40
5**	19	42	21	28	8	NA	29	40
6**	22	38	27	29	7	NA	36	28
7**	19	42	21	28	8	NA	29	46
8**	23	31	23	26	22	NA	30	1
9**	26	NA	25	29	34	27	33	36
10**	28	NA	26	30	33	35	32	41
11**	27	NA	25	31	36	23	38	42
12*	27	NA	25	31	36	23	38	46
13**	22	50	33	18	26	34	33	4
14**	25	44	34	20	23	35	29	5
15**	33	33	51	27	38	28	41	25
16**	43	25	40	38	33	9	25	NA

Note: %Difference = 100× (Male strength data-Female strength data)/ Male strength data. '*' Significant at *p*<0.05; '**' Significant at *p*<0.01; 'NA'- data not available.

Comparisons (t-test) made between male and female values were found highly significant for all 16 muscular strength variables at $p<0.01$ except left foot strength in sitting posture which was found to be significant at $p<0.05$ for all regions including pooled Indian data. Percentage difference between male and female strength were noticed more than 20% for all sixteen parameters except very few variables from some states which showed percentage difference less than 10%, such as pull strength of left hand in sitting posture, torque strength of preferred hand in standing posture and torque strength of both hands in standing posture for Meghalaya; push strength of right hand in sitting posture and push strength of left hand in sitting posture for Maharashtra; hand grip torque of preferred hand for Tamil Nadu etc. These large differences in strength capability between male and female in regional/state wise data as well as all India pooled data clearly indicate that the tools and equipment design should be gender specific based on male and female requirements.

4 Discussion

It is true that efficient and effective design of tools and equipment takes into account not only the physical human body dimensions but also strength capabilities of intended users. Strength data have greatest importance in design and development of ergonomic farm tools and equipment (Vyavahare and Kallurkar, 2012). Percentile data of task specific muscular strength of a desired agricultural worker population is a fundamental requirement for deciding operational force of machine/ equipment. Depending on application, this can involve, for example, specific percentile of strength data to ensure that majority of the worker population would be able to perform a given task (viz., clutch and brake, gear shift lever, gear control lever, accelerator pedal, manually operated push-pull equipment etc.) without undue fatigue and discomfort. Requirement of heavy and/or repetitive muscle strength to perform physical tasks are potent predictor for any kind of musculoskeletal disorders. Therefore, agricultural activities of a repetitive nature executed by both males and females should be designed such that the force requirement does not exceed 30% of the 5th percentile value of maximum strength capability of female workers. This will ensure force requirement not exceeding safe limits. Force exertion may rise up to 50% as long as the effort is not prolonged for more than five minutes (Agrawal et al., 2009; Gite et al., 2009; Tiwari et al., 2010). In Indian scenario, although females are actively participated (55% to 66% of the total labor) in agricultural activity (Reddy, 2013) but heavy agricultural equipment and machines such as combine harvester, tractor etc. are mainly operated by male counterpart only. In such instances where physical tasks are performed predominantly by male agricultural workers (e.g. operation of tractor clutch, brake, steering etc.) operational force requirement should be fixed at 5th percentile of maximum strength value of male workers.

The maximum force that a muscle or muscle group can generate is greatest during an isometric contraction, provided it is performed at an optimal joint angle. For example, the maximum force capabilities of the knee extensors may be found at approximately 60 degrees lower than full knee extension (Kumar, 2004). It is well documented that male possess greater muscle strength and produce superior power output than their female counterparts (Agrawal et al., 2009; Gite et al., 2009; Tiwari et al., 2010). Average muscular strength of female expressed as percentage of average strength of male agricultural workers is depicted in Table 5. It's very clear that female workers generally produce about two-thirds the amount of total isometric strength exerted by male workers. This difference is due to male's larger muscle fibers and more cross-sectional area of muscle or muscle groups in comparison to female (Miller et al., 1993). Further, there are also observable differences between muscles of female and male during prolonged intense activity leading to fatigue. It has been reported that in such situations; female muscles are more fatigue resistant and recover faster than male muscles (Glenmark et al., 2004; Fulco et al., 1999).

Table 5 Average muscular strength of female expressed as percentage of average strength data of male agricultural workers

Code No.	India	GU	JK	MP	MH	OR	TN	ML
1	62	-	45	60	55	67	67	-
2	62	-	41	56	53	63	71	-
3	64	68	48	72	65	69	65	65
4	72	63	52	82	70	72	76	60
5	81	58	79	72	92	71	-	60
6	78	62	73	71	93	64	-	72
7	77	65	78	74	80	69	-	54
8	77	69	77	74	78	70	-	99
9	74	-	75	71	66	67	73	64
10	72	-	74	70	67	68	65	59
11	73	-	75	69	64	62	77	58
12	73	-	71	68	64	58	71	54
13	78	50	68	80	74	66	66	96
14	75	56	65	81	77	71	66	95
15	67	66	49	72	61	60	71	75
16	58	76	58	63	66	76	92	-

Threshold level of muscular strength and endurance limit is very important in determining the user's ability to perform various agricultural operations safely. Individuals lacking requisite strength may not be able to perform activities comfortably. Hence, it is important to consider functional limitations among male and female farmers of all regions to prevent or minimize many of the work-related injuries, illnesses and musculoskeletal disorders. It has been found that there is a significant variation between male and female muscular strength variables across different states. Further, comparison between all Indian statistics (pooled data) and corresponding data for various states showed significant (p<0.01) variation in most of the muscular strength variables. Therefore, safe and more user friendly tools and equipment should be designed considering either region specific strength database of male and female agricultural workers or the safe limit range of strength database to cover wide range of workers from various states i.e. 5th to 95th percentile values of male or female pooled Indian data. Here, it is worthy to note that consequent increase in variability for accommodating wide range of population may exacerbate existing design problems. For example, pedal resistance must be within the strength capability of the weakest operator but must not be too low as to make control difficult for a strongest operator (Pheasant and Harris, 1982). Recommended force values for performing various agricultural operations by Indian male and female agricultural workers, available from different sources are described in Table 6.

Table 6 Recommended value of force for various operations

Operation	Gite et al., 2009	Agrawal et al., 2009	Dewangan et al., 2010	Present Study
Sickle	12	-	-	9.6
Grubber	29	-	-	26.4
Fertilizer broadcaster	37	30	-	22.5
Wheel hoe	24#/29++	41#/61++	-	24#/26.4++
Brake pedal	<260	276	363.2	237
Clutch pedal	<125	200	300.4	187
Steering wheel	51	<75	84.8	44.4
Gear selection lever	49	-	70.6	43

Note: All dimensions are in Newton; # push force; ++ pull force, - not reported.

Sickle is used by both male and female Indian agricultural workers and mode of operation is characterized by constant pull/sawing action forces throughout the work period. Therefore, 5th percentile value of pull force with right hand in sitting posture for female workers was recommended considering 30% criterion of maximum force. Thus, the operational force for this type of pull/sawing action may be taken as 9.6 N. However, Gite et al. (2009) recommended pull force with right hand in sitting posture 12 N for Indian population. Tractor is operated mainly by male workers. Hence, strength capability of male tractor driver is needed to be considered for design of various controls such as clutch/brake pedals, steering wheel, gear selection lever etc. These controls are operated for short durations and therefore operational force requirement may be limited to the 30% of the 5th percentile strength value. It may rise to 50% as long as the effort is not prolonged for more than 5 min. Recommended left leg strength for clutch pedal operation in sitting posture was found to be lower in the present study compared to the data reported by Agrawal et al. (2009) and Dewangan et al. (2010) but higher than the data reported by Gite et al. (2009). Similarly, other safe limit of force calculated in present study for various others operations such as grubber, fertilizer broadcaster, wheel hoe, brake pedal, clutch pedal, steering wheel and gear selection lever etc. were found to be relatively lower than the recommendations by other researchers (Agrawal et al., 2009; Gite et al., 2009; Dewangan et al., 2010). Thus it appears that recommended force limits by various researchers do not coincide. Tt is expected that baseline information suggested in the present study would be helpful for designers towards designing or design modification of agricultural tools and equipment in terms of operation force within safe limit.

5 Conclusions

Secondary data regarding strength capabilities of male and female agricultural workers of India (pooled and regional/state wise data), have been gathered from different literature sources and analyzed statistically to understand nature of variability of those data in terms of difference between pooled Indian data vs. individual state data; difference between male vs. female data across various states of India; and for determining safe operational force limits for handling various agricultural tools/equipment.

India being a country with population of diverse ethnic background, Indian agricultural workers vary widely in their strength capabilities across various regions/states. The regional climate and nutritional level also influence this variation. In some states, variations of strength variables are much more prominent than others (Figure 1 and Figure 2). Present study revealed that these are significant differences between mean values of pooled Indian data vs. individual state data for almost all strength variables under study (Table 3). This is true for data of both male and female population. This observation implies that considering pooled Indian strength data (either male or female) for designing agricultural equipment might be injustice towards regional population with varying force exertion capabilities. If region specific targeted users can be identified during design development of agricultural tools, it would be better to concentrate of strength data of that particular region/state. It has also been noticed from analyzed data (Table 4) that average muscular strength of female is significantly lower than their male counter parts across all states. In general female strength capability for all strength variables under discussion is only about two-thirds of male values (Table 5). Thus, gender variation should be taken proper consideration during application of strength data in design purposes. There is need to redesign agricultural tools/equipment to make suitable for female workers. Recommended operational force limits for operation of various agricultural tools as have been calculated in present study (Table 6) should be used as ready reference for designing equipment of same or similar muscular strength requirements. With time, Indian agricultural practices are undergoing through revolutionary changes. Traditional human and animal powered tools and equipment are being gradually replaced by mechanical and electrical powered driven tools and equipment. Thus, further research is needed to redefine comfortable/safe force limit of human power (isometric muscular strength) to operate various controls of those newly designed agricultural tools and equipment.

Agriculture is currently the biggest occupational sector in India and holds the second position in terms of agricultural production all over the world. India consists of 28 states and 7 Union Territories but region specific strength data of agricultural workers for the purpose of designing/modification of agricultural equipment have been reported only from few states (8 states) as of now. Yadav et al. (2010) recommended extensive surveys for strength data collection of both male and female farm workers in different regions of the country. It is expected that present research would make readers understand and encourage proactive integration of isometric strength data (ensuring biomechanical compatibility) in agricultural tools and equipment design in Indian context. This would surely help in reducing occupational injuries and musculoskeletal ailment which occurs due to mismatch between strength capability of the workers and operational demands of the job.

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