Analytical Study of Isometric Muscular Strength of Agricultural workers: Indian Perspective

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ABSTRACT

In agriculture, hand tools and equipment are most commonly used for various farming operations. All these devices demand a range of muscle force. Agricultural workers' muscular strength plays a significant and crucial role in performing various agricultural operations. Incompatibility between operators' physical capability (anthropometric and biomechanical) and physical task demands 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 is very common for agricultural tools/equipment design. This is not an exception for Indian agricultural scenario. Therefore, in the present paper an attempt has been made to study available/reported strength data of Indian agricultural workers' and to identify safe limit of operational muscular strength for operating various agricultural tools/equipment. Muscular strength data of Indian agricultural workers were collected/ gathered from different sources (electronic and hardcopy documents and databases) and statistically analyzed using SPSS 17.0 software package. Results showed statistically significant ($p<0.01$) differences in mean muscular strength variables between male and female workers from different region (states) of India. Further, comparison between pooled Indian data versus various regional (within India) data, revealed significant ($p<0.01$) difference in most of the muscular strength variables. Based on present study, an attempt was also made to illustrate safe limit of working force for agricultural operations with various tools and equipment (e.g. sickle, grubber, fertilizer broadcaster, wheel hoe, brake pedal, clutch pedal etc.) by wide range of population.

Key words : ergonomics, muscular strength, tools and equipment, agricultural workers

INTRODUCTION

With the development of farm mechanization, improved farm tools and equipment are being used for different farming operations. Even though agriculture has become more mechanized in the last century, a large proportion of agriculture production still relies on human power. Human's working capacity which depends mainly on muscular strength, plays a major role in tasks that require hard labor. Heavy physical workload is associated with occurrence of musculoskeletal injury. Awkward working postures i.e. stooping, bending, twisting, kneeling etc. along with overloading of muscle-tendon-bone-joint system may cause injury to the workers. Unfortunately, these are overlooked very often. Many researchers have already shown that numerous risk factors in agricultural works can successfully be addressed/ prevented using ergonomics approaches [1, 2]. Ergonomically design tools and equipment is regarded

as outcome to reduce the human drudgery and enhance the agricultural productivity. Hand tools and equipment design based on anthropometric and biomechanical databases play a major role in the reduction of many risk factors leading to occupational injury. In the design of farm tools and equipment, expected variability in strength parameters is used to indicate how much adjustability or what range of forces are required to accommodate the intended agricultural workers. Muscular strength data vary according to race, sex, age, body weight and lifestyle [3]. Therefore, knowledge of human strength capabilities is an important consideration for the design of tools and equipment [4]. In contrast, failure to include variability in range of strength or an insufficient amount of strength that is required to perform a task can produce misleading results that can cause physical overloading and affect musculoskeletal system. This also leads to discomfort, fatigue, pain, injury and illness to workers. This paper analyzed available muscular strength data (electronics and hardcopy documents) of male and female agricultural workers of different states of India and outlines the significance of using these data for the efficient design and modifications of agricultural tools and equipment from ergonomics perspective.

METHODOLOGY

Muscular strength data of Indian agricultural workers were searched from different sources (both electronic and hardcopy databases). Three main sources (given below) for Indian strength data were identified and statistically analyzed using SPSS 17.0 software.

- Strength data of Gujarat (GU), Jammu & Kashmir (J&K), Madhya Pradesh (MP), Maharashtra (MH), Orissa (OR) and Tamil Nadu (TN) reported by Gite et al. (2009) [5],
- Strength data of Meghalaya (ML) reported by Agrawal et al.(2009) [6] and
- Strength data of Arunachal Pradesh (AR) reported by Dewangan et al. (2010) [7]

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 manual materials handling activities involve pushing and/or pulling forces [8, 9]. An inadvertent negligence of human factors in design process has reduced the efficiency of operation and created safety problems and discomfort for the operator [3]. The design of tools and equipment can be improved through research on biomechanics of human body. Application of biomechanical principles might be useful for implementing comprehensive and logistic user-friendly solutions to ensure workers strength, skills and abilities, through improved equipment and working methods. Ergonomics design of tools and equipment is a compromise between operator's physical capabilities and energy/ force demands by tools and equipment [10, 11]. Many manual tasks performed in agriculture involve awkward postures which are undesirable according to ergonomics criteria. Biomechanical disorders due to inappropriate posture and mismatch of tools and equipment

with operators are commonly presumed to be prevalent in agriculture [12]. Many risk factors can be reduced if tools and equipment are designed with emphasis on user comfort and safety: that is, if they are ergonomically designed. Therefore, for designing of such tools and equipment, database of push/pull forces or leg/foot strength exerted by operator are found to be of immense importance to the designer [6] to prevent incidence of musculoskeletal injuries [4].

Isometric push/pull strength of male and female agricultural workers

Traditionally, only limited attention has been given to operator's capabilities and limitations during design of agricultural hand tools and equipment in India. Agriculture/farming activities imposes a lot of physical and mental stress upon farm workers. If farm tools and equipment are not properly designed with due consideration of human muscular capability, work performance may be poor and there is also a possibility of early fatigue, discomfort, accidents and musculoskeletal disorders. For farm tools and equipment design purposes, sixteen strength variables (Table 1) were recommended by All India Coordinated Research Project (AICRP) on Ergonomics and Safety in Agriculture (ESA), India [13]. Isometric push/pull strength plays an important role for performing 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.,), for transporting loads using manual carts and wheel-barrows etc. which involve pushing and/or pulling in a standing posture [14, 15].

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

Code No.	Strength Parameters	Code No.	Strength Parameters
1	Hand grip strength-right	9	Leg strength in sitting posture-right
2	Hand grip strength-left	10	Leg strength in sitting posture-left
3	Push strength in standing posture-both hands	11	Foot strength in sitting posture-right
4	Pull strength standing posture-both hands	12	Foot strength in sitting posture-left
5	Push strength in sitting posture-right hand	13	Torque strength in standing posture-preferred hand
6	Push strength in sitting posture-left hand	14	Torque strength in standing posture-both hands
7	Pull strength in sitting posture-right hand	15	Torque strength in sitting posture-both hands
8	Pull strength in sitting posture-left hand	16	Hand grip torque-preferred hand

During comparative analysis of various strength variables across various populations under present study, it was found that variations were more in case of few variables e.g. handgrip strength (both right and left), legs strength (both right and left) in sitting posture, foots strength (both right and left) in sitting posture as compared to pull and push strength (with both hands) in standing postures (Fig. 1). The variation in strength parameters such as push strength of right and left hands in sitting posture, pull strength of right and left hands in sitting posture and hand grip torque of preferred hand were found less in case of all regions except Meghalaya and Arunachal Pradesh. Further from Fig. 2, similar observation were also noted for female farm agricultural workers except right and left handgrips strength, pull and push strength in standing postures with both hands and torque strength of both hands in sitting posture. In this case, variations among different regions were found more as compared to male workers. Right and left hands push strength in sitting posture, right and left hands pull strength in sitting posture were noticed more in Meghalaya than others states.

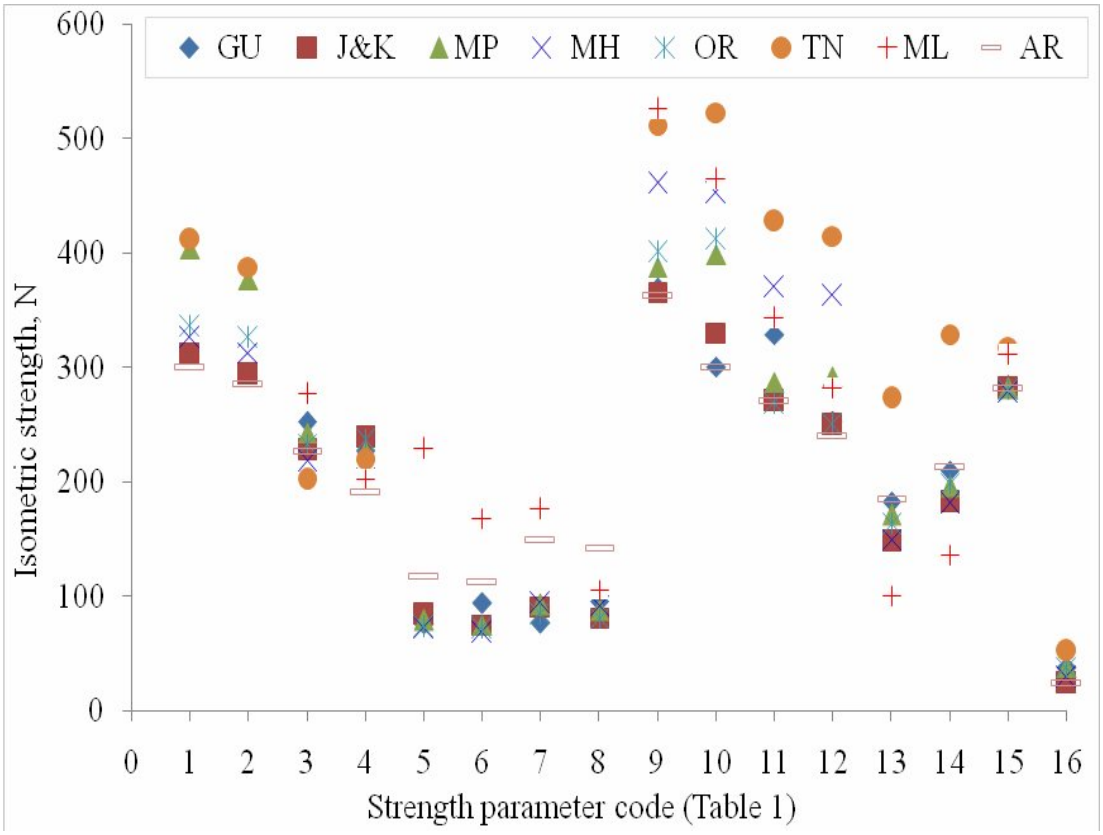

Fig 1: Scatter plot for strength parameters for male agricultural workers of various states

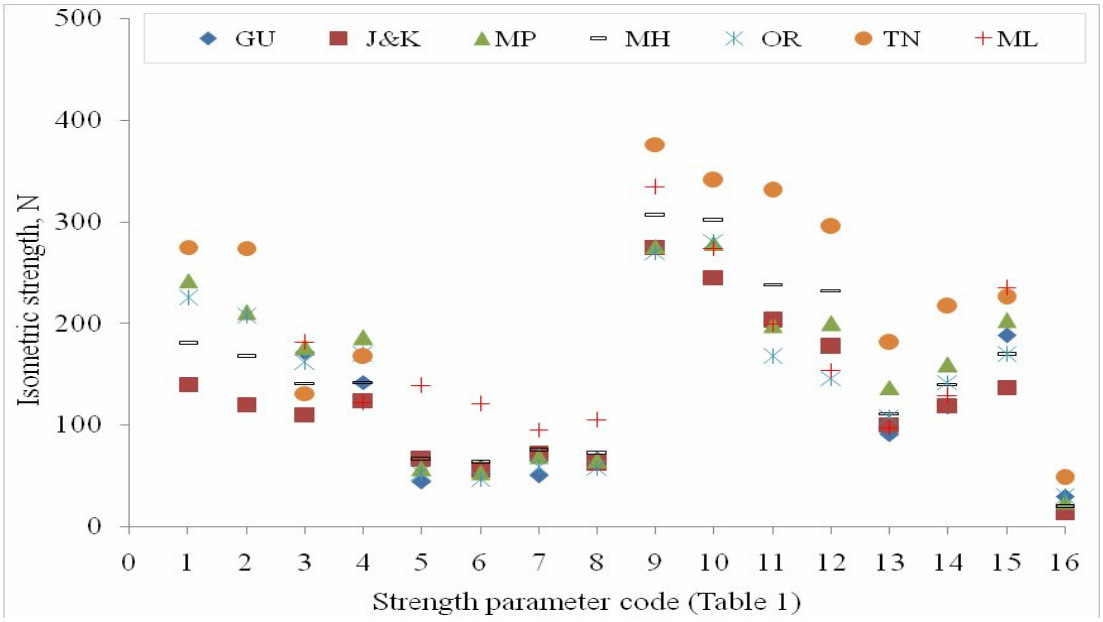

Fig 2: Scatter plot for strength parameters for female agricultural workers of various states

Comparison of male and female muscular strength

All the strength variables (16 no.) from eight states (Gujarat, Jammu & Kashmir, Madhya Pradesh, Maharashtra, Orissa, Tamil Nadu, Meghalaya and Arunachal Pradesh) for male and female (except Arunachal Pradesh) were compared with pooled Indian data by t-test and results are presented in Table 2. For male, muscular strength of most of the groups (states) were found significantly ($p < 0.01$ and $p<0.05$) different from pooled Indian male data in respect to right and left hand grip strength(except Orissa), push with both hands(except Jammu & Kashmir and Arunachal Pradesh), pull with both hands(except Gujarat and Tamil Nadu), right hand push sitting posture (except Gujarat), left hand push sitting posture (except Jammu & Kashmir, Madhya Pradesh and Orissa), right hand pull sitting posture(except Jammu & Kashmir and Madhya Pradesh), left hand pull sitting posture (except Madhya Pradesh), right leg strength, left leg 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 standing (except Gujarat and Arunachal Pradesh), torque strength with both hands sitting posture (except Gujarat, Jammu & Kashmir, Madhya Pradesh, Orissa and Arunachal Pradesh) and hand grip torque respectively.

Table 2: Comparison (t-test result) of muscular strength data of male (M) and female (F) agricultural workers of India (pooled) versus individual states of India.

Code	GU		J&K		MP		MH		OR		TN		ML		AR	
No.	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
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	**	**	**	**	-	-	**	-

*Significant ($p<0.05$); ** Significant ($p<0.01$); 'NS' not Significant; '-' data not available

Similar to 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 data for female were not available in published literature. Statistical analysis (t-test) revealed that muscular strength of most of the groups were statistically ($p<0.01$ and $p<0.05$) 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 & Kashmir), left hand pull in sitting posture(except Gujarat), right leg strength (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 standing (except Madhya Pradesh), torque strength with both hands sitting (except Gujarat) and hand grip torque (except Maharashtra).

DISCUSSION

It is believed that good design needs to take into account not only the physical human body dimensions but also strength capability which determine whether a person can perform a physical job requirement without undue fatigue and discomfort. Muscle strength capabilities and the strength required to perform physical tasks are potent predictor for any kind of injury.

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 strength value of female workers, so that force requirement does not exceed safe limits. Force exertion may rise to 50% as long as the effort is not prolonged for more than 5 min [14, 6, 5]. In some instances, physical task is performed only by male agricultural workers such as operation of tractor clutch, brake and steering etc. In such cases force requirement of 5th percentile strength value of male workers should be considered.

Threshold level of muscular strength and endurance limit is very important in determining the ability to perform various agricultural operations safely. Individuals lacking requisite strength may not be able to perform activities safely. 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 (MSDs). It was found that there is a significant variation between male and female muscular strength parameters within different states. Further, comparison between all India statistics and corresponding data for various states showed very significant ($p<0.01$) variation in most of the muscular strength parameters. Therefore, safe and more user friendly tools and equipment should be designed considering either as per 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. The consequent increase in variability of user population will exacerbate existing design problems. For example, pedal resistance must be within the strength capability of the weakest operator but must not be so low as to make control difficult for a strongest operator [16]. Recommended force values for performing various agricultural operations by Indian male and female agricultural workers, available from different sources are given Table 3.

Table 3: Recommended value of force for various operations

Operation	Gite et al., 2009 [5]	Agrawal et al., 2009 [6]	Dewangan et al., 2010 [7]	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

All dimensions in Newton (N); # push force; ++ pull force, - not reported

For example, sickle is used by both male and female 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 operation force for this type of pull/sawing action may be taken as 9.6 N. However, Gite et al. (2009) [5] recommended pull force with right hand in sitting posture 12 N for all India. The left leg strength in sitting posture was lower in the present study compared with the data that was reported by Agrawal et al. (2009) [6] and Dewangan et al. (2010) [7] but higher than the data that was reported by Gite et al. (2009) [5]. 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 data reported by other researchers [5, 6, 7]. It is expected that present study will provide baseline information which may be utilized for design, or design modification of agricultural tools and equipment in terms of operation force within safe limit.

CONCLUSION

This paper presents an analytical study of strength variable data of male and female agricultural workers of different states of India. Muscular strength of male agricultural workers is greater than that of female workers. Most of the muscular strength variables of male and female workers of Tamil Nadu appeared to be higher as compared to others states except push and pull strength in standing posture for both hands, push strength in sitting posture for right and left hands and pull strength in sitting posture for right and left hands respectively. In India, hand tools and equipment are most commonly used for various agriculture operations. Therefore, in countries like India, there is an urgent need for designing/re-designing agricultural tools and equipment in harmony with ergonomics guidelines considering safe force exertion limit for both male and female. Integration of isometric strength data (for ensuring biomechanical compatibility) proactively in agricultural tools and equipment design will surely help in reducing occupational injuries which are caused by mismatch between physical capability of workers and demands of the job.

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