# Isometric Push/Pull Strength of Agricultural Workers of Central India

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**ABSTRACT**

Operation of many manually operated farm tools and equipment requires exertion of push/pull force in horizontal plane. However, very little data are available on push/pull strength of agricultural workers of India. A study was therefore, carried out to collect these data on male as well as female agricultural workers in the state of Madhya Pradesh. A strength measurement set-up developed at CIAE, Bhopal was used for the purpose. Data were collected on 1701 subjects from 20 selected districts representing various agro-climatic zones of Madhya Pradesh state of which 944 were male and 757 were female workers. The mean age, stature and mass of the male subjects were 29.8 ± 9.5 years, 1649 ± 59 mm and 51.2 ± 6.4 kg whereas for female subjects the values were 33.7 ± 8.2 years, 1519 ± 54 mm and 45.0 ± 7.3 kg, respectively. The isometric push/pull strength of male subjects was higher than those of female subjects. The mean values for isometric push and pull strength in standing posture with both hands (in horizontal plane) were 242.4 ± 56.4 N and 231.0 ± 42.5 N, respectively for male workers and 175.5 ± 33.9 N and 159.4 ± 42.9 N, respectively for female workers. Mass of the subjects indicated a positive correlation with isometric push/pull strength. The 5$^{th}$ percentile push and pull strength values were 149.7 N and 161.2 N, respectively for male workers and 119.7 N and 88.8 N, respectively for female workers. These values can be used to set limits in the design of manually operated farm tools and equipment as well as for manual materials handling activities involving push/pull forces depending on the frequency of movement. Considering the ergonomical requirement of 30% of the 5$^{th}$ percentile strength for frequent exertions, the design limits of push and pull strengths for male workers will be 45 and 48 N and for female workers these values will be 36 and 27 N, respectively. For the occasional exertions the limit of push and pull strength can be 60% of the strength i.e. for male workers 90 and 96 N and for female workers 72 and 54 N, respectively.

*Key Words:* Push/pull strength, agricultural workers, central India, agricultural machinery

## 1. INTRODUCTION

Pushing and pulling are most common human activities in several occupations involving manual materials handling. Nearly half of all manual materials handling activities involve pushing and/or pulling forces (Baril-Gingras and Lortie, 1995, Kumar, *et al.* 1995). Many agricultural activities such as the operation of manual ridgers, rotary dibblers, rice transplanters/seeders, push/pull weeders, field rakes, long-handled tools, chaff cutters, groundnut/castor decorticators *etc.*; transporting loads using manual carts and wheel-barrows and fetching water from well using a rope and pulley involve pushing and/or pulling in standing posture. Researchers have pointed out that pushing and pulling is at least partly responsible for high physical workload and, moreover, for musculoskeletal complaints affecting the low back and upper extremities (Frymoyer, *et al*. 1980, Damkot, *et al.* 1984, Harber, *et al.* 1987, van der Beek, *et al.* 1993, Fuorts, *et al.* 1994, Hoozemans, *et al.* 1998, Kuiper, *et al.*, 1999). Damkot, *et al.* (1984) cross-sectionally investigated the relationship between the exposure to pushing and low back pain, in which the pushing exposure was derived by multiplying the mass of pushed objects by number of pushing efforts required for each day. About 64% respondents reported moderate to severe low back pain. The results showed a significant relationship between pushing exposure and low back pain. Hoozemans, *et al.* (1998) pointed out that about 20% of overexertion accidents resulting in low back injuries involve pushing and pulling activities. NIOSH (1981) reported that 20% of the injury claims for low back pain are associated with pushing and pulling.

Designing the job to fit the worker could reduce up to one-third of industrial back injuries (Snook, 1978). Further, the job design was found to be significantly more effective in controlling low back injuries than selecting the worker for the job or training the worker to fit the job. Mittal, *et al.* (1997) suggested that during pushing and pulling activities one should exert forces that would not exceed the guidelines for this type of manual materials handling to prevent adverse effects on the musculoskeletal system. Despite such a common practice of pushing/pulling activities, risk factors involved during these activities and importance of job design for manual materials handling activities the data available on push/pull strength are very scanty.

According to Chaffin (1987), there are two types of hazards due to pushing and pulling, which may induce the risk of health complaints. On the one hand, when the force requirement for an activity exceeds the limiting value of force generation, the musculoskeletal system may become physically overexerted. On the other hand, since pushing and pulling activities are always accompanied by an increased risk of accidents due to slipping/tripping, such activities can cause injuries to the musculoskeletal system. Snook (1978) reported that 7% of low back injuries are associated with slipping/tripping accidents. Therefore, it is necessary to quantify the exposure to pushing and pulling to gain an insight into the causal relationship between health complaints and such activities.

The determination of human strength capabilities is an important consideration in the development of ergonomic guidelines for pre-employment screening of workers performing manual materials handling jobs (NIOSH, 1981). Methods for measuring and predicting isometric and isokinetic strengths have already been developed to match muscular capabilities of workers with the force requirements of a particular job. It is also widely believed that such a testing is necessary and can be carried out safely, reliably, and easily (Mital and Ayoub, 1980). Ergonomic studies on pushing and pulling that have been performed for the design of manual materials handling tasks, report results in terms of hand force exertions. When designing a pushing or pulling task, knowledge of the push/pull forces exerted by an user is of immense importance and a designer must determine the maximum force required to do the task so that the hand forces needed to push/pull do not exceed the safe limits. The design should be such that the user having 5$^{th}$ percentile strength value is able to operate the machine, where as it must be able to withstand the forces exerted by the strongest user. Studies reported on push/pull forces (Ayoub and McDaniel, 1974; Kroemer, 1974; Davis and Stubbs, 1977; Chaffin, *et al.,* 1983; Kumar *et al.*, 1995, van der Beek, *et al*., 2000) are mostly from Western population and for specialised working groups other than the agricultural workers. In these studies the effect of variables such as body mass, height of force application, frequency of exertion, volitional postures and gender differences on push/pull forces have been studied. Kroemer (1974) studied horizontal push/pull force exertion when standing in working positions on various surfaces. These studies were performed in standing posture when the subjects had their feet anchored to a rigid footrest on the floor, or stood on various surfaces. Alvi (1971) carried out a study with Indian and American subjects to measure physiological responses in pushing and pulling activities with both hands at different speeds and concluded that pushing or pulling with both arms horizontally against the same range of forces were not different from each other on the basis of the physiological stress imposed and the gross efficiency of muscular work achieved.

The anthropometric and strength data of Indian agricultural workers were not available. The All India Coordinated Research Project (AICRP) on Ergonomics and Safety in Agriculture (ESA) collected such data for agricultural workers from Madhya Pradesh (Central India) state through one of its centres located at Central Institute of Agricultural Engineering, Bhopal. Data on seventy-five body dimensions, four skin-folds thickness and sixteen strength parameters useful for the design of agricultural machines and equipment were collected, compiled and analysed. This paper presents the data on push/pull strength (in standing posture) of agricultural workers of Madhya Pradesh state and outlines the significance of using these data for the design of agricultural equipment and hand tools operated in pushing/pulling modes.

## 2. MATERIALS AND METHODS

### 2.1 Subjects

The study was carried out in twenty districts from six agro-climatic zones of Madhya Pradesh (Central India) state. The districts were Rewa, Panna, Shahdol, Jabalpur and Balaghat from Kymore Plateau & Satpura Hills zone; Chhindawara and Betul from Satpura Plateau zone; Bhopal, Guna, Sagar and Raisen from Vindhya Plateau zone; Hoshangabad from Central Narmada Valley zone; Gwalior from Gird zone; Tikamgarh from Bundelkhand zone; West Nimar from Nimar Valley zone; Jhabua from Hills Zone and Mandsaur, Ujjain, Dewas and Rajgarh from Malwa Plateau zone. Data were collected for 1701 subjects (944 male and 757 female) from different communities including tribal population. The subjects were randomly selected from among the healthy agricultural workers in the age group of 18 to 65 years. All the subjects were free from physical abnormalities and were in good health. Table 1 and 2 present the relevant anthropometric data of the subjects included in the study. Due attention was given to the standards and terminologies listed for anthropometeric data collection ISO: 7250 (1996) and recommendations of the conference on standardization of anthropometeric techniques and terminologies (Hertzberg, 1968).

### 2.2 Tasks

The subjects were required to perform a two handed push/pull on a horizontal handle bar in standing posture. They were instructed to apply their maximum push/pull force in horizontal plane evenly without jerks. As per the protocol for strength data collection, the subjects were required to reach their maximum strength within first two seconds and then maintain the maximum strength for next three seconds (Kumar *et al*, 1995). During a preliminary trial it was observed that some stimulus in the form of light/sound is required to guide the subjects for applying the push/pull force for the desired time duration. Therefore, a five seconds timer with a red light signal and beeping sound (developed at CIAE, Bhopal) was used during force application. The subjects were asked to release the applied force on the handle smoothly as the red light went off and the beep stopped after 5 seconds.

### 2.3 Equipment and procedure

A survey team of four well qualified staff (2 male and 2 female) experienced in measurement of anthropometric dimensions and human strength parameters, collected the complete data of 1701 subjects. Two female Senior Research Fellows were involved for the measurement of anthropometric dimensions of female workers, one male Human Physiologist for the measurement of anthropometric dimensions of male workers and a male Agricultural

Engineer (M. Tech.) for the measurement of isometric strength of both male and female agricultural workers. The complete survey work was carried out in continuous supervision of one of the three Scientists of the Institute involved in the project.

The anthropometric dimensions and the skin-fold thickness were measured using Harpendens Anthropometer and Holtain Skinfold Caliper, respectively adopting the procedure formulated by AICRP on ESA (Gite and Chatterjee, 1999) basaed on the ISO: 7250. Standard terminologies given in the Anthropometric Source Book (NASA, 1978) were used. The four skin-fold thickness were used to calculate body density (BD) using the equation:

$$\text{Body Density (BD)} = 1.1599 - (0.0717 \times \log \Sigma \text{ four skin-fold thickness}) \qquad \ldots(2.1)$$

The four skin-folds for which the data were collected were bicep, tricep, sub-scapular and supra iliac. The percent body fat was calculated from the body density using the following equation proposed by Siri (1959).

$$\text{Percent Body Fat (\%BF)} = (495/\text{BD}) - 450 \qquad \ldots(2.2)$$

The absolute body fat was calculated using the equation:

$$\text{Absolute Body Fat} = (\text{Body mass} \times \text{\%BF})/100 \qquad ..\ .(2.3)$$

The lean body mass of the subject was calculated by subtracting the absolute body fat from total body mass as:

$$\text{Lean Body Mass} = \text{Total Body mass} - \text{Absolute Body Fat} \qquad \ldots(2.4)$$

A strength measurement set-up developed at CIAE, Bhopal for measuring 14 human strength parameters useful for the design of agricultural machinery was used in the study. The set-up mainly consisted of the following:

- A wooden platform of 2300 × 810 mm size.
- Two vertical posts (1500 mm height) made up of 48.5 mm diameter mild steel pipes erected at a spacing of 385 mm. These posts were bolted to the wooden platform. Another vertical post made up of mild steel box section of 40 x 40 x 4 mm size and having the same height as the circular posts was erected in between the posts. This vertical post was provided with 5.5 mm holes at a spacing of 25 mm on the rear side and had a pulley at its top.
- Two braces made of mild steel angle iron for supporting the vertical posts.
- A height adjustable horizontal bar made up of 40 x 40 x 4 mm size box section, was provided to slide over the circular posts with the help of two collars welded on the bar.
- A wire rope was connected to the middle of the horizontal bar, which passed over the pulley mounted at the top of the middle vertical post. The other end of the wire was provided with a hook to anchor it in to the desired hole of the middle post to adjust the height of the horizontal bar. A slot was provided on the front side of the horizontal bar to mount the load cell assembly with the help of two nuts and bolts. The load cell assembly could be shifted laterally by sliding the bolts in the slot.
- A load cell assembly made up of a 40 × 40 × 4 mm size box section of 460 mm length was provided with a pulley at its extreme end. The load cell was mounted between two wire ropes of which first has a fixed end at horizontal bar and the second has been

anchored to a handle at the other end. Turning the second wire rope around the end pulley could reverse the direction of force application to make it a push force.

A Novatech load cell (1 kN) of tension and compression type with digital load indicator was used for measuring the push/pull strength of the subjects. Readings obtained during the 3 s force application were noted continuously and the most stable value of force, which appeared for maximum duration in the load indicator, was noted for the trial. The complete human strength measurement set up along with anthropometer and other accessories was carried to each survey site for survey work.

**2.4 Experimental Protocol**

The strength measurement set-up used in the present study was designed for the measurement of maximum push/pull strength exerted by a subject in his/her comfortable standing posture. Most studies reported maximum exerted horizontal push forces for handle heights from one meter to shoulder height (Ayoub and McDaniel, 1974, Snook 1978, Warwick, *et al.* 1980, Mittal, *et al.* 1997, Kumar, 1995, Kumar, *et al.* 1995). For pulling forces, lower handle heights resulted in larger exerted forces (Ayoub and McDaniel, 1974; Snook, 1978; Warwick, *et al.* 1980, Mittal, *et al.* 1997; Kumar, 1995; Kumar, *et al.* 1995). Ayoub and McDaniel (1974) and Chaffin, *et al.* (1983) reported an increase in maximum pushing force by placing the feet further away from the point of force application or by placing one foot in front of the other. Therefore, during push force application, the subject was asked to attain the posture as defined in Fig. 1. The posture was such that the upper part of the body up to waist was erect with the arms horizontal and in level with the acromion. Thus the point of force application was slightly below the shoulder height. The feet were placed farther apart from each other. The left foot of the subject was put forward and the leg was bent at knee such that the lower leg was in vertical position. The right foot was put backward tilted at right angle from the direction of force application with leg in straight position. The spacing between the feet was not fixed and each subject was free to choose the spacing as per his/her own comfort for force application.

An increased maximum pulling force was achieved by decreasing the distance between the feet or, if possible, by placing the feet in front of the hands (Ayoub and McDaniel, 1974). However, in actual field conditions such pulling activities are rare and there is a risk for slipping. Therefore, during pull force application, the subject was asked to adopt the posture as defined in Fig. 2. The posture was such that the subject leaned backward on the left leg with the arms horizontal and in level with the acromion. The feet were placed apart from each other such that the left foot was put forward ahead of the hands with leg in inclined position and the right foot was placed backward tilted at right angle from the direction of force application and the leg slightly bent at knee as per the subject's own decision for better comfort.

**Fig.1 Measurement of push force with both hands in standing posture in horizontal plane**

The height adjustable horizontal bar with load cell assembly was adjusted to the acromial height of the subject, which was attained after adopting the posture defined in Fig. 1 (for push) and Fig. 2 (for pull) for maximum force exertion. This height was different for pushing and pulling activities.

The subject looked straightforward during the application of push/pull force. With the start of electronic timer the subject applied the force, to attain the maximum in first 2 s and hold it until the light/sound signal stopped finally after 5 s. Throughout the 5 s duration, the subject was strictly prohibited to change the prescribed posture or dislodge his legs. The subject was bare footed on the plywood surface of the strength measurement set-up. The exertions were replicated thrice for pushing as well as for pulling and the mean value of these replications was taken as the value of push/pull forces A rest of 2 min was given in between two successive trials for each subject (Kumar, 1991).

**Fig. 2 Measurement of pull force with both hands in standing posture in horizontal plane**

**2.5 Data Analysis**

The anthropometric as well as the push/pull strength data for male and female subjects were analysed to get mean, standard deviation, coefficient of variation, standard error of mean, $5^{th}$ and $95^{th}$ percentile values and minimum and maximum values, using the Windostat statistical tool. The calculated percentile values were true percentile values for which the following standard equations given in Anthropometric Source Book (NASA, 1978) were used:

$5^{th}$ percentile value = Mean - 1.645 × SD …(2.5)

$95^{th}$ percentile value = Mean + 1.645 × SD …(2.6)

The push/pull data were statistically analysed to know the effect of mode of force application and also the gender effects. Paired t-test was used for comparisons. Multiple regressions were developed between age, mass, stature, lean body mass and acromial height of the subjects with push/pull strengths for male and female subjects.

## 3. RESULTS

**3.1 Anthropometric parameters of agricultural workers**

Table 1 and 2 present the mean, standard deviation, coefficient of variation, standard error of mean, $5^{th}$ and $95^{th}$ percentile values and minimum and maximum values for relevant anthropometric parameters of male and female agricultural workers, respectively. The mean age, stature and mass of male subjects were 29.8 ± 9.5 years, 1649 ± 59 mm and 51.2 ± 6.4 kg, respectively while the corresponding parameters for female subjects were 33.7 ± 8.2 years, 1519

± 54 mm and 45.0 ± 7.3 kg. In general the male subjects were heavier and taller than female subjects. The mean lean body mass of male subjects was also higher than female subjects.

Table 1. Anthropometric parameters of male (N= 944) agricultural workers participated in the study

| Parameters | Mean | SD* | CV† | SE of Mean‡ | Percentile | | Range | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 5th | 95th | Min | Max |
| Age, yrs | 29.8 | 9.5 | 31.88 | 0.31 | 14.1 | 45.5 | 18.0 | 65.0 |
| Body mass, kg | 51.2 | 6.4 | 21.48 | 0.21 | 40.6 | 61.8 | 35.0 | 77.0 |
| Lean body mass, kg | 44.7 | 4.7 | 10.51 | 0.15 | 36.9 | 52.4 | 32.5 | 66.0 |
| Stature, mm | 1649 | 59 | 3.58 | 1.92 | 1552 | 1747 | 1424 | 1854 |
| Acromial height, mm | 1376 | 56 | 4.07 | 1.82 | 1284 | 1468 | 1102 | 1564 |
| Chest circumference, mm | 840 | 50 | 5.95 | 1.63 | 758 | 921 | 700 | 1010 |
| Thigh circumference, mm | 436 | 39 | 8.94 | 1.27 | 373 | 500 | 310 | 575 |

Table 2 Anthropometric parameters of female (N=757) agricultural workers participated in the study

| Parameters | Mean | SD* | CV† | SE of Mean‡ | Percentile | | Range | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 5th | 95th | Min | Max |
| Age, yrs | 33.7 | 8.2 | 24.33 | 0.30 | 20.2 | 47.2 | 18.0 | 60.0 |
| Body mass, kg | 45.0 | 7.3 | 21.66 | 0.27 | 32.9 | 57.0 | 28.0 | 77.0 |
| Lean body mass, kg | 38.5 | 5.7 | 14.81 | 0.21 | 29.1 | 47.9 | 24.5 | 64.4 |
| Stature, mm | 1519 | 54 | 3.55 | 1.96 | 1430 | 1607 | 1383 | 1687 |
| Acromial height, mm | 1265 | 49 | 3.87 | 1.78 | 1184 | 1346 | 1214 | 1422 |
| Chest circumference, mm | 810 | 72 | 8.89 | 2.62 | 692 | 929 | 620 | 1120 |
| Thigh circumference, mm | 431 | 51 | 8.94 | 1.85 | 347 | 515 | 280 | 665 |

* Standard deviation; † Coefficient of variation; ‡ Standard error of mean.

### 3.2 Push/pull strength of agricultural workers

Table 3 presents the mean, standard deviation, coefficient of variation, standard error of mean, 5th and 95th percentile values and minimum and maximum values of push and pull strength of male and female agricultural workers. The mean values for push and pull strengths in standing posture with both hands (in horizontal plane) were 242.4 ± 56.4 N and 231.0 ± 42.5 N for male subjects. These values indicated that men were significantly stronger in pushing in comparison to pulling ($p<0.01$). This is in agreement with the findings reported by Grandjean, (1980) and van der Beek, *et al.* (2000). The mean values for push and pull strength in standing posture with both hands were 175.5 ± 33.9 N and 159.4 ± 42.9 N, for female subjects.

Table 3 Push/pull strength of male and female agricultural workers

| Parameters | Mean | SD* | CV† | SE of Mean‡ | Percentile | | Range | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 5th | 95th | Min | Max |
| **Male (n = 944)** | | | | | | | | |
| Push, N | 242.4 | 56.4 | 23.27 | 1.84 | 149.7 | 335.1 | 95.2 | 498.3 |
| Pull, N | 231.0 | 42.5 | 18.4 | 1.38 | 161.2 | 300.9 | 124.6 | 557.2 |
| **Female (n = 757)** | | | | | | | | |
| Push, N | 175.5 | 33.9 | 19.32 | 1.23 | 119.7 | 231.3 | 93.2 | 327.7 |
| Pull, N | 159.4 | 42.9 | 26.91 | 1.56 | 88.8 | 229.9 | 82.6 | 480.7 |

* Standard deviation; † Coefficient of variation; ‡ Standard error of mean.

## 4. DISCUSSION

### 4.1 Push/pull strength of male and female agricultural workers

Different studies on push/pull strength have shown that muscular strength plays an important role in most push/pull tasks. Some anthropometric dimensions viz. age, body mass, stature, acromial height, chest circumference as well as the posture adopted during force application also affect the maximum push/pull force exertion without any musculoskeletal injury. In the present study the strength for pushing is higher than pulling for male workers, which is in agreement with the results reported by Snook (1978) and Warwick *et al.* (1980). The higher value for push strength is due to more active participation of muscles in the thigh, waist, chest and upper hand in force generation. Bicep, tricep and scapular muscles acted simultaneously during pushing activity. During pulling activity as the subject leans on his left leg, the right leg muscles are almost inactive due to the restrictions posed by the posture adopted while pulling. In this posture the mass of the subject is major contributing factor in generation of pull force.

According to NASA (1978) and Grandjean (1980) women can generally exert push/pull forces about 2/3 of that exerted by men. A close perusal of the mean values of push/pull strengths of agricultural workers in the present study shows that female workers can exert 72 and 69% of push and pull forces, respectively of those exerted by male workers. This is mainly because male and female subjects differ in anthropometric characteristics: men are heavier and taller than women.

### 4.1 Design considerations

The maximum work tolerance on a working day can be indirectly obtained from the maximum isometric push/pull strength for a single exertion (Waters *et al.* 1993). The determination of maximum acceptable forces depends on the assumption that an individual can estimate his/her maximum work tolerance without experiencing health complaints during a certain work period. In terms of external exposure, frequency of a certain pushing or pulling activity and working hours are controlled during the experiments, while the subjects are given control of the level of the exposure. The subject adjusts his/her maximum acceptable push/pull force depending on his/her own feelings of exertion or fatigue. In general the risk of developing musculoskeletal disorders increases when exerted forces on a working day approximate the maximum strength and when maximum acceptable forces are exceeded.

In terms of work-related factors, the exposure to pushing and pulling can be expressed with three dimensions: intensity (magnitude and direction), frequency and duration. The risk of musculoskeletal disorders increases, if any of these dimensions deviates from its optimum value. On the other hand, a combination of sub-maximal values of all three dimensions may together also increase the risk of health complaints. Therefore, these dimensions must be examined in view of maximal as well as the combinations of their sub-maximal values.

One of the problems encountered by a designer is that in most cases the posture of the user during force exertion cannot be adequately anticipated. The force that can be exerted is influenced to a high degree by the subject's posture. Standardized postures are generally used, though the methods of description tend to vary considerably. Pushing and pulling capability depends on a complex interaction of posture, shoe/floor friction, and subject anthropometry (Ayoub and McDaniel, 1974; Snook, 1978; Warwick, *et al.*, 1980). Generally, it is recognized that persons with large arm reach and high body mass can achieve higher push/pull force capability if enough space is available to lean appropriately. Push/pull capability is also highest when the point of application of force is in between shoulder and waist heights.

The 5$^{th}$ percentile push and pull strength values for male workers are 149.7 and 161.2 N, respectively. According to van Wely (1970), the dynamic effort of repetitive nature should not exceed 30% of the maximum value, although it may rise to 50% as long as the effort is not prolonged for more than 5 minutes. Considering this limitation it may be concluded that agricultural activities performed by reciprocating action such as operating a standing type groundnut decorticator or a push/pull type weeder, should not require a push force greater than 45 N or pull force greater than 49 N with male workers, if the operation is to be performed by 95% of the population. If the force required for the operation of the equipment is greater than 45 N the operators have to take frequent rest breaks in between the work bouts. Gite and Agarwal (2001) reported that for operating a standing type groundnut decorticator (batch type) the push/pull force required at the start of the batch is 72 N, which decreases with time of operation. In this case the operator gets sufficient resting time during filling the next batch of groundnut pods in the decorticator after finishing the previous one. Since the 72 N force is required only for a minute (first 10 strokes) and then it reduces to even less than 5 N as the operation progresses, the 60% criterion may be adopted and the design force for push/pull may be taken as about 96 N. Thus it may be concluded that the design of the standing type groundnut decorticator is on safer side as far as the push/pull force is concerned.

On the other hand the operation of push/pull type weeder continues for hours (with scheduled rest breaks) and push/pull forces also remain almost constant throughout the work period, therefore in such cases the 30% criterion may be adopted. Thus the design force may be taken as 45 N and the width of the soil-working element may be decided accordingly. Equipment, which require either push or pull force continuously (a push or pull type manual seeder, fertilizer broadcaster) should be designed such that the force requirement is well below the 45 N value to compensate for the static loading of the muscles and to avoid the muscular fatigue. In such cases the operators should also have frequent rest pauses between the work bouts.

The 5$^{th}$ percentile push and pull strength values for female workers are 119.7 and 88.8 N, respectively. Considering the 30% limit as proposed by van Wely (1970) the agricultural activities of repetitive nature should not require push and pull forces of more than 36 and 27 N, respectively if it is to be performed by 95% of the women population. Any push/pull activity of repetitive nature requiring more than 36 N force must be interrupted with rest breaks. The sitting type groundnut decorticator (batch type) specially designed for women workers requires 47 N force at the beginning of the batch (Gite and Agarwal, 2001). However, as mentioned earlier this force requirement continues only for a minute, therefore, the design criterion should be based on 60% of 5$^{th}$ percentile force value which comes to about 72 N for push and 54 N for pull force. Thus, the force requirement for the equipment is well within the acceptable limits.

Henceforth for the design of any equipment, which is to be operated by male as well as female workers continuously for 8 hours (with scheduled rest breaks), the push/pull force required should not exceed 36 N. If the force required is higher, the operator should have frequent rest pauses depending upon the workload. In cases where the force exertion is not continuous i.e. less than 5 minutes, the dynamic effort of repetitive nature may be up to 50% of the maximum strength of 5$^{th}$ percentile force value for female worker and it works out to 62 N. In many agricultural activities, this is the situation and therefore, 62 N can be taken as the upper limit for design purpose.

## 5. CONCLUSIONS

The study indicated that the push/pull strength of male agricultural workers is higher than those of female workers. The mean values for isometric push and pull strength in standing posture with both hands (in horizontal plane) are 242.4 ± 56.4 N and 231.0 ± 42.5 N, respectively for male workers and 175.5 ± 33.9 N and 159.4 ± 42.9 N, respectively for female workers. The 5$^{th}$ percentile push and pull strength values are 149.7 and 161.2 N, respectively for male workers and 119.7 and 88.8 N, respectively for female workers. Agricultural activities of repetitive nature should be designed such that the force requirement does not exceed 30% of the 5$^{th}$ percentile strength value (vanWely, 1970), although it may rise to 60% as long as the effort is not prolonged for more than 5 minutes. Agricultural activities requiring continuous force application should be designed such that the force requirement is below 30% of the 5$^{th}$ percentile strength value to have a margin for static loading of the muscles.

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