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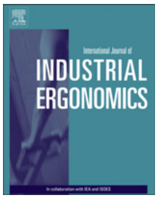

Push/pull strength of agricultural workers in central India

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ABSTRACT

An agricultural worker has to exert push/pull force in the horizontal plane while operating many farm tools and equipment. However, very little data are available on push/pull strength of agricultural workers. A study was therefore carried out to collect these data on male as well as female agricultural workers. A strength measurement setup developed at CIAE, Bhopal was used for the purpose. Data were collected on 920 subjects from different parts of Madhya Pradesh State in central India of which 604 were male and 316 were female agricultural workers. The mean age, stature and weight of the male subjects were 29.6 ± 8.9 years, 1646 ± 59 mm and 51.4 ± 6.5 kg whereas for female subjects the values were 32.6 ± 8.1 years, 1512 ± 52 mm and 45.3 ± 7.2 kg, respectively. The isometric push/pull strength of male subjects was higher than that of female subjects. The mean values for isometric push and pull strength in a standing posture with both hands (in the horizontal plane) were 253.8 ± 52.8 N and 234.2 ± 43.0 N, respectively for male subjects and 183.1 ± 35.6 N and 185.1 ± 30.8 N, respectively for female subjects. Weight of the subjects indicated a positive correlation with isometric push/pull strength. The 5th percentile push and pull strength values were 167.0 N and 163.5 N, respectively for male subjects and 124.4 N and 134.4 N, respectively for female subjects. 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 pushing/pulling, depending on the frequency of movement.

Relevance to industry: The strength values and design criteria presented in this paper may be used for setting limits for design of manually operated tools and equipment involving push/pull activities in agriculture as well as in other industrial jobs.

1. Introduction

Pushing and pulling are the 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 a well using a rope and pulley involve pushing and/or pulling in a 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 weight of pushed objects by the number of pushing efforts required for each day. About 64% of 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 involved pushing and pulling activities. NIOSH (1981) reported that 20% of the injury claims for low back pain are associated with pushing and pulling.

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

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(1978) reported that 7% of low back injuries were 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. 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. Mital et al. (1997) suggested that during pushing and pulling activities one should exert forces that are within the recommended limits for this type of manual materials handling jobs to prevent adverse effects on the musculoskeletal system. Although push/pull activities are very common and important for safe and efficient manual materials handling jobs, however, data on push/pull strength are very scanty (Chaffin et al., 1983; Snook, 1978).

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 testing is necessary and can be carried out safely, reliably, and easily (Mital and Ayoub, 1980). When designing a pushing or pulling task, knowledge of the push/pull forces exerted by a worker 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 a user within the 5th percentile strength value is able to operate the machine, whereas 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 the Western population and for specialized working groups other than the agricultural workers. In these studies the effect of variables such as body weight, 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 a standing posture when the subjects had their feet anchored to a rigid footrest on the floor, or were standing on various surfaces.

Anthropometric and strength data for 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 state (central India) through one of its centres located at the Central Institute of Agricultural Engineering, Bhopal. Data on 75 body dimensions, four skin-fold thicknesses and 16 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 a standing posture) of agricultural workers of Madhya Pradesh State and outlines the significance of using these data for the design of agricultural equipment operated in pushing/pulling modes.

2. Materials and Methods

2.1. Subjects

The study was carried out in 11 districts from six agro-climatic zones of Madhya Pradesh state (central India). The districts were Rewa, Panna, Shahdol, Jabalpur and Balaghat from Kymore Plateau and Satpura Hills zone; Bhopal and Raisen from Vindhya Plateau zone; Hoshangabad from central Narmada Valley zone; Gwalior from Gird zone; Tikamgarh from Bundelkhand zone; and Rajgarh from Malwa Plateau zone. Data were collected for 920 subjects (604 male and 316 female) from different communities including tribal populations. The subjects were randomly selected from among the healthy agricultural workers in the age group of 18–65 years. All the subjects were free from physical abnormalities and were in good health. Table 1 presents the relevant anthropometric data for male and female subjects, included in the study.

Table 1
Anthropometric parameters of male ($N = 604$) and female ($N = 316$) agricultural workers participating in the study.

Parameters	Male			Female		
	Mean	SD	CV	Mean	SD	CV
Age (years)	29.6	8.9	30.0	32.6	8.1	24.8
Weight (kg)	51.4	6.5	12.6	45.3	7.2	15.9
Lean body mass (kg)	44.9	4.7	10.5	39.0	5.0	12.8
Stature (mm)	1646	59	3.6	1512	52	3.4
Acromial height (mm)	1373	57	4.2	1262	48	3.8
Chest circumference (mm)	845	49	5.8	813	73	9.0
Thigh circumference (mm)	437	38	8.7	441	45	10.2

SD, standard deviation; CV, coefficient of variation.

2.2. Tasks

The subjects were required to perform a two handed push/pull on a horizontal handle bar in a standing posture. They were instructed to apply their maximum push/pull force in the horizontal plane evenly, without jerks. As per the protocol for strength data collection, the subjects were required to reach their maximum strength within first 2 s and then maintain the maximum strength for next 3 s (Kumar et al., 1995). Readings during the last 3 s of force application were noted and the mode value of those readings was taken as a strength value for that particular trial. During a preliminary trial it was observed that some stimulus in the form of light/sound is required to guide the subjects in applying the push/pull force for the desired time duration. Therefore, a 5 s 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 s.

2.3. Equipment and procedure

A survey team of four well qualified staff (two males and two females) experienced in measurement of anthropometric dimensions and human strength parameters, collected the complete data for 920 subjects. The complete survey work was carried out under the continuous supervision of one of the three scientists of the institute involved in the project.

The anthropometric dimensions and the skin-fold thicknesses were measured using Harpendens Anthropometer and Holtain Skinfold Caliper, respectively, adopting the procedure formulated by AICRP on ESA (Gite and Chatterjee, 1999). Standard terminologies given in the Anthropometric Source Book (NASA, 1978) were used. The four skin-fold thicknesses (bicep, tricep, sub-scapular and supra iliac) were used to calculate body density (BD) using Eq. (2.1), proposed by Durnin and Womersley (1974).

$$\text{Body density}\left(\text{BD in g/cm}^3\right) = 1.1599 - (0.0717 \times \log \Sigma \text{ four skin-fold thicknesses in mm}) \tag{2.1}$$

The percent body fat was calculated from the body density using Eq. (2.2), proposed by Siri (1961).

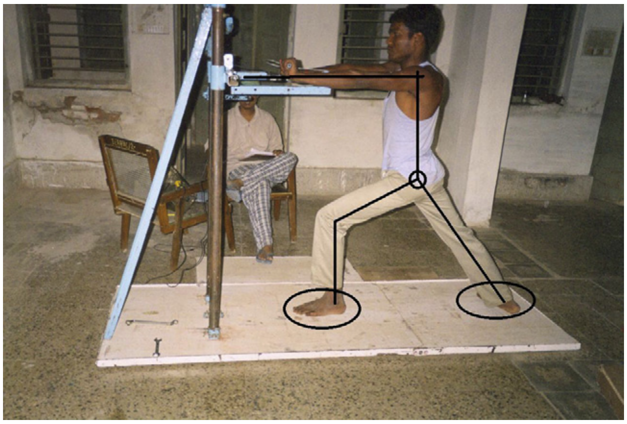

Fig. 1. Measurement of push force with both hands in standing posture in horizontal plane.

$$\text{Percent body fat (\%BF)} = (495/\text{BD}) - 450 \tag{2.2}$$

The absolute body fat was calculated using Eq. (2.3) (Sen and Banerjee, 1958).

$$\text{Absolute body fat} = (\text{body weight} \times \text{\%BF})/100 \tag{2.3}$$

The lean body mass of the subject was calculated by subtracting the absolute body fat from total body weight.

A strength measurement setup developed at CIAE, Bhopal for measuring 14 human strength parameters useful for the design of agricultural machinery was used in the study. The setup for measurement of push–pull strength mainly consisted of a wooden platform on which two vertical posts of mild steel pipes were bolted (Fig. 1). Another vertical post made of mild steel box section and having the same height as the circular posts was erected between the posts. Two braces made of mild steel angle iron supported the vertical posts from the rear.

A height adjustable horizontal bar made of box section was provided to slide over the circular posts with the help of two collars welded to the 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. The load cell assembly was provided with a pulley at its extreme end. The load cell was mounted between two wire ropes, the first of which had an end fixed to the horizontal bar, and the second was 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 the tension and compression type with a digital load indicator was used for measuring the push/pull strength of the subjects. The complete human strength measurement setup, along with an anthropometer and other accessories, was carried to each survey site for survey work.

2.4. Experimental protocol

The strength measurement setup used in the present study was designed for the measurement of the maximum push/pull strength exerted by a subject in his/her comfortable standing posture. Most studies report maximum exerted horizontal push forces for handle heights from 1 m to shoulder height (Ayoub and McDaniel, 1974; Snook, 1978; Warwick et al., 1980; Mital et al., 1997; Kumar, 1995; Kumar et al., 1995). For pulling forces, lower handle heights result in larger exerted forces (Ayoub and McDaniel, 1974; Snook, 1978; Warwick et al., 1980; Mital 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.

During push force application, the subject was asked to attain the posture as shown in Fig. 1. The posture was such that the upper part of the body, to the waist, was erect with the arms horizontal and level with the acromion. Thus the point of force application was about 50–100 mm below the acromial height. The left foot of the subject was put forward and the leg was bent at the knee such that the lower leg was vertical. The right foot was placed backward, tilted at a right angle from the direction of force application, with the leg in a 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. The subject looked straight forward during the application of push/pull force. With the start of the electronic timer, the subject applied the force to attain the maximum in the first 2 s and hold it until the light/sound signal stopped after 5 s. Throughout the 5 s duration, the subject was strictly prohibited from changing the prescribed posture or dislodging his/her legs. The subject was bare footed on the plywood surface of the strength measurement setup. The exertions were replicated three times for pushing and for pulling, and the mean value of these replications was taken as the value of maximum push/pull forces. A rest of 2 min was given in between two successive trials for each subject (Kumar, 1991).

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 of 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 level with the acromion. The height of handle was kept about 20–60 mm below the acromial height. The left foot was placed forward with the leg in an inclined position, and the right foot was placed backward, tilted at a right angle from the direction of force application and the leg slightly bent at the knee, as per the subject's own decision for better comfort. Data were collected for 5 s as per the time protocol followed during push force data collection.

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 pushing) and Fig. 2 (for pulling) for maximum force exertion. This height was different for pushing and pulling and it also varied from person to person depending on his/her anthropometric parameters.

2.5. Data analysis

The anthropometric data for male and female subjects were analysed to get mean, standard deviation and coefficient of variation, while the push/pull strength data for male and female subjects were analysed to get mean, standard deviation, coefficient of variation, and 5th and 95th percentile values. For calculation of these percentile values, the following standard equations given in the Anthropometric Source Book (NASA, 1978) were used:

$$\text{5th percentile value} = \text{mean} - 1.645 \times \text{SD} \tag{2.4}$$

$$\text{95th percentile value} = \text{mean} + 1.645 \times \text{SD} \tag{2.5}$$

The strength data were statistically analysed to find the effect of gender and the mode of force application using the two factor ANOVA with repeated measures on one factor (Winer, 1971). Linear regressions were developed between age, weight, stature, lean

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

body mass and acromial height of the subjects with push/pull strengths for male and female subjects to find any relationships between these parameters.

3. Results

3.1. Anthropometric parameters of agricultural workers

Table 1 presents the mean, standard deviation and coefficient of variation, for relevant anthropometric parameters of male and female agricultural workers. The coefficients of variation for these parameters ranged between 3.4 and 15.9 except for age where the values were higher (24.8 for female subjects and 30.0 for male subjects). This was because the age range of workers covered in the study was very large (18–65 years). The mean age, stature and weight of male subjects were 29.6 ± 8.9 years, 1646 ± 59 mm and 51.4 ± 6.5 kg, respectively while the corresponding parameters for female subjects were 32.6 ± 8.1 years, 1512 ± 52 mm and 45.3 ± 7.2 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 that of female subjects. The agricultural workers had lower body weight (51.4 kg for male workers in the present study) as against the industrial workers (57.3 kg) as reported by Tiwari et al. (2001).

3.2. Push/pull strength of agricultural workers

Table 2 presents the mean, standard deviation, coefficient of variation, *t*-value and 5th and 95th percentile values of push and pull strength of male and female agricultural workers. The forces exerted in push as well as pull mode by male subjects were significantly higher than by female subjects ($p < 0.01$). The mean values for push and pull strengths in a standing posture with both hands (in the horizontal plane) were 253.8 ± 52.8 N and 234.2 ± 43.0 N for male subjects. The coefficient of variation of the push and pull strength data ranged from 16.7 to 20.8, which was in line with those reported by Kroemer (1974). A comparison of push and pull strength values of male subjects 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).

Table 2
Push/pull strength of male and female agricultural workers.

Parameters	Mean	SD	CV	Percentile	
				5th	95th
Male (n = 604)					
Push (N)	253.8	52.8	20.80	167.0	340.6
Pull (N)	234.2	43.0	18.35	163.5	304.8
Female (n = 316)					
Push (N)	183.1	35.6	19.47	124.4	241.7
Pull (N)	185.1	30.8	16.65	134.4	235.8

SD, standard deviation; CV, coefficient of variation.

For female subjects, the mean values for push and pull strengths in a standing posture with both hands were 183.1 ± 35.6 N and 185.1 ± 30.8 N, respectively. Though the mean value of pull forces exerted by female subjects was higher than for push forces, the difference was non-significant ($p > 0.05$).

The body weights of the subjects showed a positive correlation with push/pull strength with coefficients of determination (R^2) of 0.353 and 0.519 for push and pull strengths, respectively, for male subjects and 0.355 and 0.481 for push and pull strengths, respectively, for female subjects (Table 3).

The test of significance of the correlation coefficients showed that in all these cases the force exerted and the body weight were positively correlated at 0.01 level of significance. The coefficients of determination (R^2) of regression of stature over push and pull strengths are 0.120 and 0.167, respectively, for male subjects and 0.150 and 0.177, respectively, for female subjects (Table 3).

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, such as weight, 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 for pulling for male subjects, which is in agreement with the results reported by Snook (1978), Warwick et al. (1980) and Chaffin et al. (1983). The higher value for push strength for male subjects 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. Chaffin et al. (1983) reported mean push and pull strength values as 372 ± 94 N and 267 ± 89 N for male subjects when one foot was placed in front of the other. The higher values of push and pull strengths in comparison to the present study may be because their subjects were taller and heavier (mean height 1800 mm and mean weight 75.3 kg) than the subjects who participated in the present study. During pulling activity, as

Table 3
Relationship of important anthropometric parameters with push/pull strengths.

Independent variable	Dependent variable	Intercept	Regression coefficient	Correlation coefficient (R)	Coefficient of determination (R^2)	t-value	$p<$
Male ($n = 604$)							
Age	Push	265.81	−0.406	−0.069	0.005	1.69	0.092
Weight	Push	6.12	4.822	0.594	0.353	18.11	0.000
Stature	Push	−252.74	0.308	0.347	0.120	9.08	0.000
LBM	Push	−31.49	6.355	0.560	0.314	16.59	0.000
Acromial height	Push	−123.66	0.275	0.298	0.089	7.65	0.000
Age	Pull	237.25	−0.104	−0.022	0.001	0.53	0.596
Weight	Pull	−10.47	4.763	0.721	0.519	25.49	0.000
Stature	Pull	−251.98	0.295	0.409	0.167	11.00	0.000
LBM	Pull	−34.89	5.994	0.649	0.421	20.93	0.000
Acromial height	Pull	−138.66	0.272	0.361	0.131	9.51	0.000
Female ($n = 316$)							
Age	Push	179.90	0.097	0.022	0.001	0.39	0.695
Weight	Push	49.14	2.956	0.596	0.355	13.15	0.000
Stature	Push	−222.11	0.268	0.388	0.150	7.46	0.000
LBM	Push	21.61	4.137	0.584	0.341	12.75	0.000
Acromial height	Push	−127.54	0.246	0.333	0.111	6.25	0.000
Age	Pull	175.43	0.296	0.078	0.006	1.39	0.165
Weight	Pull	50.28	2.976	0.694	0.481	17.07	0.000
Stature	Pull	−195.28	0.252	0.421	0.177	8.23	0.000
LBM	Pull	24.53	4.114	0.672	0.451	16.07	0.000
Acromial height	Pull	−102.80	0.228	0.357	0.127	6.76	0.000

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 weight of the subject is the major contributing factor in the generation of pull strength, which is evident from the higher value of coefficient of determination (0.519 for male and 0.481 for female subjects).

In the case of female subjects, although the pull strength is slightly more than the push strength, the difference is non-significant. This may be because most female agricultural workers wear sari (the traditional dress worn by rural women in India), and therefore placing the feet farther apart, as in the case of male workers, during pushing is not practicable. This restriction on posture may have reduced the force generation during pushing. Chaffin et al. (1983) pointed out that if their subjects had chosen to step back further and pushed with their elbows locked, as required by Ayoub and McDaniel (1974), they probably would have achieved a higher pushing capability, especially for the high handle position as in the present study. Further, the women are more accustomed to pulling activities than pushing activities, as fetching drinking water from the village well using a rope and pulley is a common chore for rural women, which involves pulling. Chaffin et al. (1983) reported mean push and pull strength values as 180 ± 63 N and 166 ± 49 N for female subjects when one foot was placed in front of other. The push strength values are comparable with the values reported in the present study. However, the pull strength values reported in that study are slightly lower than the pull strength values for female subjects in the present study. This may be because in the present study the subjects completely leaned backward during pulling, thus their weight was a major contributing factor in force generation.

Daams (1993) and Keyserling et al. (1980b) reported a non-significant difference between pushing and pulling against a fixed object. Keyserling et al. (1980a); Kumar et al. (1995) and Kumar (1995) reported that maximum forces for pulling were higher than those for pushing. Kumar et al. (1995) reported that for males, the isometric push and pull strengths in the sagittal plane were 216 N and 320 N, respectively. However, in both the later studies the lower extremities were stabilized, so these results can be considered as upper body push/pull strength instead of whole body push/pull strength. In another study, Das and Wang (2004) reported that the isometric push and pull strength of males were 89 N and 109 N, respectively. However, in this study the isometric push/pull strengths were also constricted to only arm force exertion. 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 subjects can exert 72% and 79% of push and pull forces, respectively, of those exerted by male subjects. This is mainly because male and female subjects differ in anthropometric characteristics: men are heavier and taller than women.

Increased push and pull strengths have been observed with an increase in body weight (Ayoub and McDaniel, 1974). However, in the present study, the body weight of the subjects predicted the maximum push/pull strengths best. Lean body mass of the subjects was also a better predictor of maximum strength when compared to stature and acromial height of the subjects. On the other hand, age of the subjects (male as well as female) was observed to be the worst predictor of maximum push/pull strengths. Furthermore, taller subjects might exert higher maximum forces. However, the relationship between stature and maximum push/pull forces is less straightforward because of the influence of the handling posture including body segment angles, position of the feet relative to the load and handle height (Lee et al., 1991).

4.2. 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 risk of developing musculoskeletal disorders increases when exerted forces on a working day approximate the maximum strength and when maximum acceptable forces are exceeded. 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 weight 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 5th percentile push and pull strength values for male subjects are 166.8 and 163.8 N, respectively. Snook and Ciriello (1991) recommended that the maximum acceptable push and pull forces for males for a 2.1 m push/pull activity performed at a height of 1440 mm at a frequency of one push/pull every 6 s should be 200 and 140 N, respectively for initial forces and 100 N and 80 N, respectively for sustained forces. With increase in frequency of force application and decrease in distance for which the force is applied the maximum acceptable limit decreases. Thus, the 5th percentile push/pull strengths in the present study may be considered as within the acceptable limits. According to van Wely (1970), dynamic effort of a 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 min. Considering this limitation it may be concluded that agricultural activities performed by reciprocating actions, such as operating a standing type groundnut decorticator or a push/pull type weeder, should not require a push force greater than 50 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 50 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 the first 10 strokes and then it reduces to even less than 5 N as the operation progresses, the 50% criterion may be adopted and the design force for push/pull may be taken as about 82 N. Thus it may be concluded that the design of the standing type groundnut decorticator is on the safe side as far as the push/pull force is concerned.

On the other hand the operation of a 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 50 N and the width of the soil-working element may be decided accordingly. Equipment that requires 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 50 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 5th percentile push and pull strength values for female subjects are 124.6 and 134.4 N, respectively. Snook and Ciriello (1991) recommended that the maximum acceptable push and pull forces for females for a 2.1 m push/pull activity performed at a height of 1350 mm at a frequency of one push/pull every 6 s should be 140 and 130 N, respectively, for initial forces and 60 N for sustained forces. With increase in frequency of force application and decrease in distance for which the force is applied (which are common in most of agricultural activities performed by women workers) the maximum acceptable limit decreases. Thus, the 5th percentile push/pull strengths of female subjects in the present study may be considered as within the acceptable limits. Considering the 30% limit as proposed by van Wely (1970), agricultural activities of a repetitive nature should not require push and pull forces of more than 37 and 40 N, respectively, if they are to be performed by 95% of women. Any push/pull activity of a repetitive nature requiring more than 37 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 few seconds, therefore the design criterion should be based on 50% of the 5th percentile force value, which comes to about 62 N for push and 67 N for pull force. Thus, the force requirement for the equipment is well within the acceptable limits.

Henceforth for the design of any equipment that is to be operated by male as well as female workers continuously for 8 h (with scheduled rest breaks), the push/pull force required should not exceed 37 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 min, dynamic effort of a repetitive nature may be up to 50% of the maximum strength of the 5th percentile force value for female workers, which is 62 N. In many agricultural activities, this is the situation and, therefore, 62 N can be taken as the upper limit for design purposes.

5. Conclusions

The study indicated that the push/pull strengths of male agricultural workers are higher than those of female workers. The mean values for isometric push and pull strengths in a standing posture with both hands (in the horizontal plane) are 254.1 ± 53.0 N and 234.5 ± 43.2 N, respectively, for male subjects and 183.4 ± 35.3 N and 185.4 ± 30.4 N, respectively, for female subjects. The weights of the subjects indicates a positive correlation with push/pull strength. The 5th percentile push and pull strength values are 166.8 N and 163.8 N, respectively, for male workers and 124.6 N and 134.4 N, respectively, for female workers. Agricultural activities of a repetitive nature should be designed such that the force requirement does not exceed 30% of the 5th percentile strength value, although it may rise to 50% as long as the effort is not prolonged for more than 5 min. Agricultural activities requiring continuous force application should be designed such that the force requirement is below 30% of the 5th percentile strength value to have a margin for static loading of the muscles.

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