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Isometric Cranking and Steering Strength of Agricultural Workers in Central India

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ABSTRACT

Hand cranking is the most common method of transferring power from human muscles to many stationery farm machines. On the other hand, steering torque is required for controlling tractors and other self-propelled machines. A study was carried out to collect isometric cranking and steering strength on male as well as female agricultural workers in Madhya Pradesh. A strength measurement set-up developed at CIAE, Bhopal was used for the purpose. The mean age, stature and weight of 944 male workers were 29.8 ± 9.5 years, 1649 ± 59 mm and 51.2 ± 6.4 kg, respectively whereas the corresponding values for 757 female workers were 33.7 ± 8.2 years, 1519 ± 54 mm and 45.0 ± 7.3 kg. The mean values for isometric cranking strength in standing posture at a crank length of 265 mm by preferred hand and both hand operation were 44.1± 9.1 N.m and 50.6 ± 10.2 N.m, respectively for male workers and 31.9 ± 8.6 N.m and 37.3 ± 10.4 N.m, respectively for female workers. The mean values of steering strength in sitting posture with a steering wheel of 420 mm diameter at 70^0 from horizontal were 64.0± 18.8 and 40.5 ± 10.0 N.m for male and female workers, respectively. The isometric cranking and steering strengths of male workers were higher than those of female workers ($p<0.001$). The 5^{th} percentile cranking strength values for preferred hand and both hands were 29.2 and 33.8 N.m, respectively for male workers and 17.7 and 20.1 N.m, respectively for female workers. The 5^{th} percentile steering strength was 33.1 and 24.0 N.m for male and female workers respectively. For continuous operation of hand crank operated machines, the cranking effort required for operation should not exceed 30% of the maximum static cranking strength by both hands. The maximum effort requirement for steering wheel (420 mm diameter) by male workers should not exceed 19.86 N-m.

In agricultural operations, rotary devices such as chaff cutter, threshers, winnowers and hand pumps can be operated by both hand and leg cranking. Though hand cranking is more strenuous job than leg cranking, it cannot be avoided in some instances. Hand cranking can be performed in both standing and sitting posture. However, when the torque required to operate the machine is high, mostly the standing mode is commonly employed. Similarly, in all self-propelled machinery, including tractors, steering is one of the most important manual controls. The torque applied on the steering wheel or cranking wheel depend upon many design factors such as cranking/steering radius, work load, capability of the operator to apply the requisite torque, posture of the operator, etc. Researchers have pointed out that excessive cranking or steering torque are responsible for high physical workload and, moreover, for musculoskeletal complaints affecting the lower back and upper extremities (Frymoyer *et al*., 1980). Das and Bhattacharya (1984) reported that with a given power requirement of a rotary device, it is possible to minimize the physiological cost of the operator by suitably locating the controls.

To achieve enhanced performance and efficiency of man–machine system along with better comfort and safety of the operators, it is necessary to design various controls and work place on tractors with due consideration to the anthropometric and strength data of Indian agricultural workers. If the operator controls are not properly adapted to his anthropometry, the performance demanded of him may quickly reach and even exceed the limits of tolerance. As a result of excessive stress, premature fatigue and impaired health; the possibility of accidents might increase. Tractor operator's comfort and safety have received considerable attention abroad. The design of tractors in India has not changed much in the past two decades, especially from ergonomics point of view (Patel *et al.*, 2000). In India, most of the tractor designs have been adopted through imported designs, which are based on the anthropometric dimensions and strength capabilities of western population. There was no consideration for anthropometric dimensions and strength limitations of Indian agricultural workers, which led to many occupational health problems and accidents with the tractor under field and road conditions. Researchers have ergonomically evaluated the tractor operator

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workplace and operator's activities (Tiwari, 2001; Yadav and Tewari, 1998; Kumar *et al*., 2009).

Some anthropometric studies have been carried out on Indian agricultural workers (Sen *et al.,* 1977; Gupta *et al.*, 1983; Gite and Yadav, 1989; Dewangan *et al*., 2005; Dewangan *et al.*, 2008; Agrawal *et al.,* 2009). A few studies have reported cranking and steering strength of agricultural workers from different states of the country. Agrawal *et al.,* (2009) reported the cranking and steering strength of agricultural workers of Meghalaya. The cranking strength of both hands was found to be 36.1±14.0 N.m and 30.2 ±8.7 N.m for male and female workers, respectively. The cranking strength was found to be 102.74±25.91and 80.04±18.80 N.m for male and female agricultural workers of Tamil Nadu (Anon, 2005). The cranking and steering strength of male workers of West Bengal was reported to be 66.04±19.24 and 70.95±17.63 N.m (Anon, 2007). Similarly, the cranking and strength of female workers of West Bengal was found to be 45.5±15.08 and 47.95±13.55 N.m. Variations were thus observed in the cranking and steering strength of agricultural workers of different parts of the country. Therefore, attempts were made to determine the cranking and steering strength of agricultural workers of Madhya Pradesh representing the central India. The work reported presents the data on cranking strength (in standing posture) and steering strength (in sitting posture) of agricultural workers of Madhya Pradesh and outlines the significance of using these data for the design of controls in self-propelled machinery and other crank operated agricultural equipment.

MATERIALS AND METHODS

Subjects

The study was carried out in 21 districts from nine agro-climatic zones of Madhya Pradesh, located in Central India. The districts selected for the survey were Rewa, Panna, Shahdol, Jabalpur and Balaghat from Kemore Plateau and Satpura Hills Zone; Bhopal, Guna, Sagar and Raisen from Vindhya Plateau Zone; Hoshangabad from Central Narmada Valley Zone; Gwalior from Gird Zone, Tikamgarh from Bundelkhand Zone; Chindwara and Betul from Satpura Plateau Zone; Mandsaur, Rajgarh, Ujjain and Dewas from Malwa Plateau Zone; West Nimar from Nimar Valley Zone and Jhabua from Jhabua Hills 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.

Tasks

The subjects were put to application of cranking force on a pre-designed stationary handle (with cranking radius of 265 mm), using preferred hand. In the other attempt, the subjects were required to apply cranking force on the same handle using both hands. The steering strength was measured in sitting posture. The subjects were seated on the seat provided in the set-up and applied maximum steering strength without jerks on a constrained steering wheel having diameter of 420 mm. 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, 1991; Kumar *et al*, 1995). During a preliminary trial, it was observed that some stimulus in the form of light/sound was required to guide the subjects to apply the 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 the force applications. The subjects were required to release the applied force as the red light went off and the beep stopped after 5 seconds.

Experimental Set-up

A survey team of four qualified staff (2 male and 2 female) experienced in measurement of anthropometric dimensions and human strength parameters, collected the complete data of 1701 subjects. The anthropometric dimensions and the skin-fold thickness were measured using Harpendens Anthropometer and Holtain Skinfold Caliper (Gite and Chatterjee, 1999). Standard terminologies were used (NASA, 1978).

A strength measurement set-up developed at CIAE, Bhopal for measuring 14 human strength parameters suitable for the design of agricultural machinery, (Fig 1) was used. The strength measurement set-up used was designed for the measurement of cranking and steering strength exerted by a subject in his/her comfortable standing posture with extended arm posture on a handle provided. Some studies (Kroemer, 1970; Bressel *et al.,* 2001; Swensen *et al.,* 1993) reported that maximum cranking strength is exerted below acromial level. The handle of the crank fixed slightly below the acromial level led to the point of force application slightly below the shoulder height. The feet were placed farther apart from each other. The left foot of the subject was put

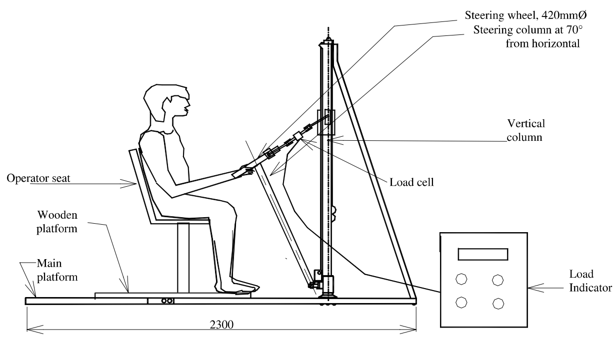

Fig. 1: Schematic diagram of experimental set-up for measurement of steering strength

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 (Fig. 2a). The load cell assembly was constrained between the crank handle and an adjustable stationery bracket so that the orientation of load cell could be made tangential to imaginary circle of crank rotation. For steering force application, the seat height was kept as 19% of the stature (Mehta *et al*. 2007). The orientation of the steering column was fixed as 70 degree from the horizontal. The load cell assembly was adjusted so that load cell remained tangential to the steering wheel. One end of the load cell was restrained with steering wheel and other end was restrained with the column fixed in load setup (Fig. 2b). The subject looked straight during the application of force. With the start of electronic timer, the subject applied the maximum force in the first 2 seconds and held until the light/sound signal stopped after 5 seconds. Throughout the duration of 5 seconds, the subject was prohibited to change the prescribed posture, dislodge the other leg or use hands

Fig. 2: (a) Measurement of cranking strength (both hands), (b) Measurement of steering strength

to take support from seat or its backrest. The subject was bare footed on the plywood surface of the strength measurement set-up. The exertions were replicated thrice and the mean value considered.

A load cell (1 kN) of tension and compression type with digital load indicator was used for measuring the cranking and steering strength of the subjects. Readings obtained during the 3s force application were noted continuously and were averaged to get the mean value for the trial. The complete human strength measurement set-up along with anthropometer and other accessories was used at each survey site.

Data Analysis

The anthropometric as well as the cranking and steering strength data for male and female subjects were analysed to obtain mean, standard deviation, coefficient of variation, standard error of mean, 5^{th} and 95^{th} percentile values and minimum and maximum values, using statistical software. The calculated percentile values were true percentile values for which the following standard equations (NASA, 1978) were used:

$$5^{th} \text{ percentile value} = \text{Mean} - 1.645 \times \text{SD} \quad \ldots(1)$$

$$95^{th} \text{ percentile value} = \text{Mean} + 1.645 \times \text{SD} \quad \ldots(2)$$

The cranking or steering strength data were statistically analysed to know the effect of mode of force application and also the gender effects. T-test was used for comparisons. Regression equations were developed between age, weight, stature, lean body mass and acromial height/shoulder grip reach of the subjects with cranking/steering strengths for male and female subjects.

RESULTS AND DISCUSSION

Anthropometric Parameters

Tables 1 and 2 present the mean, standard deviation, coefficient of variation, standard error of mean, 5^{th} and 95^{th} percentile values, minimum and maximum values for relevant anthropometric parameters of male and female agricultural workers, respectively. The mean age, stature and weight of male workers were 29.8 ± 9.5(SD) years, 1649 ± 59 mm and 51.2 ± 6.4 kg, respectively while the corresponding values for female workers were 33.7 ± 8.2 years, 1519 ± 54 mm and 45.0 ± 7.3 kg. In general, the male workers were heavier and taller than female workers. The mean lean body mass of male workers was also higher than female workers.

Table 1. Anthropometric parameters of male (N= 944) agricultural workers

Parameters	Mean	SD*	CV†	SE of Mean‡	Percentile		Range	
					5th	95th	Min	Max
Age, yr	29.8	9.5	31.88	0.098	14.1	45.5	18.0	65.0
Weight, kg	51.2	6.4	12.5	0.066	40.6	61.8	35.0	77.0
Lean body mass, kg	44.7	1.7	3.8	0.049	41.8	47.3	38.5	49.9
Stature, mm	1649	59	3.58	0.610	1552	1747	1424	1854
Trochanteric height, mm	859	43	5.01	0.442	788	930	701	1025
Functional leg length, mm	1005	45	4.48	0.462	931	1079	860	1180
Thigh circumference, mm	436	39	8.94	0.401	373	500	310	575
Calf circumference, mm	301	23	7.64	0.244	263	339	210	440

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

Table 2. Anthropometric parameters of female (N=757) agricultural workers

Parameters	Mean	SD*	CV†	SE of Mean‡	Percentile		Range	
					5th	95th	Min	Max
Age, yr	33.7	8.2	24.40	0.299	20.2	47.2	18.0	60.0
Weight, kg	45.0	7.3	16.28	0.266	32.9	57.0	28.0	77.0
Lean body mass, kg	38.5	5.7	14.84	0.208	29.1	47.9	24.5	64.4
Stature, mm	1519	54	3.47	1.920	1430	1607	1237	1687
Trochanteric height, mm	797	41	5.19	1.500	729	865	667	961
Functional leg length, mm	929	45	4.86	1.640	855	1003	805	1060
Thigh circumference, mm	431	51	11.86	1.860	347	515	280	665
Calf circumference, mm	289	27	9.41	0.991	244	334	200	400

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

Cranking and Steering Strength

Table 3 presents the mean, standard deviation, coefficient of variation, standard error of mean, 5th and 95th percentile values, minimum and maximum values of cranking and steering strength of male and female agricultural workers. The mean values for cranking strength with preferred hand and both hands were 44.1 ± 9.1 N.m and 50.6 ± 10.2 N.m for male workers, and 31.9 ± 8.6 N.m and 37.3 ± 10.4 N.m respectively for female workers. Similarly, the mean values of steering strength (in sitting posture) were 64.0 ± 18.8 N.m for male workers and 40.5 ± 10.0 N.m for female workers. These values indicated that steering strength was more than cranking strength ($p<0.01$) for both for male and female workers.

Kroemer (1970) had indicated that muscular strength plays an important role in most hand operated tasks. Some anthropometric dimensions viz. age, weight, stature, shoulder grip length, muscular built up as well as the posture adopted during force application also affect the maximum push force exertion without any musculoskeletal injury. In the present study, the strength for steering in sitting posture was higher than cranking force application in standing posture for male as well as female workers. The higher value for steering strength for workers was due to lumbar support received by the operator from the seat for higher force generation. During cranking force application, as the subject bent forward for application of the force and tried to exert force on the handle, sufficient reaction was not available to apply complete force in absence of lumbar support and consequently the muscles got restrictions posed by the posture adopted. In this posture, only the muscles of upper extremity remained effective, and the complete weight of the subject was not that effective causing force generated by the muscles gets reduced.

According to Pheasant (1981) and Grandjean (1980), women can generally exert forces about two-third of that exerted by men. A close perusal of the mean values

Table 3. Cranking and steering strength of male and female agricultural workers

Parameters	Mean	SD*	CV†	SE of Mean‡	Percentile		Range	
					5th	95th	Min	Max
Male (n = 944)								
Cranking strength (preferred hand) [#], N.m(in terms of force, N)	44.1 (169.5)	9.1 (34.8)	20.63	0.296	29.2 (112.2)	59.0 (226.8)	19.9 (76.5)	74.7 (287.4)
Cranking strength (both hands), N.m(in terms of force, N)	50.6 (194.6)	10.2 (39.4)	20.15	0.332	33.8 (129.8)	67.5 (259.5)	23.6 (90.9)	102.5 (395.3)
Steering strength##, N.m (in terms of force, N)	64.0 (298.2)	18.8 (87.8)	29.38	0.612	33.1 (154.0)	95.0 (442.3)	28.1 (130.5)	157.5 (733.5)
Female (n = 757)								
Cranking strength (preferred hand), N.m(in terms of force, N)	31.9 (122.6)	8.6 (33.3)	26.95	0.313	17.7 (67.9)	46.1 (177.3)	11.1 (42.5)	63.3 (243.3)
Cranking strength (both hands), N.m (in terms of force, N)	37.3 (143.3)	10.4 (47.7)	27.88	0.378	20.1 (77.3)	54.4 (209.3)	14.5 (55.9)	91.6 (352.2)
Steering strength, N.m(in terms of force, N)	40.5 (193.0)	10.0 (47.7)	24.69	0.363	24.0 (114.5)	57.0 (271.5)	19.4 (92.2)	81.8 (389.5)

* Standard deviation; † Coefficient of variation; ‡ Standard error of mean.# Cranking radius 265 mm. ## Steering radius 210 mm.

of cranking strength of agricultural workers in the present study shows that female workers could exert 72.0-73.7% of cranking strength of those exerted by male workers. Similarly, the female workers could exert about 64% of steering strength of male workers. This is mainly because male and female workers differed in anthropometric characteristics with men being heavier and taller than women as well as with higher lean body mass.

Increased cranking and steering strengths were observed with an increase in body weight in case of both male and female workers. The body weight of the workers had a positive correlation with cranking strength having correlation coefficients (r) of 0.440 and 0.402 for male and female workers, respectively for preferred hand and 0.439 and 0.440 for cranking strength with both hands (Table 4). Similarly, the correlation coefficients (r) of steering strength with weight were found to be 0.364 and 0.369 for male and female workers, respectively. Thus, body weight of the workers best predicted the maximum cranking and steering strength. Lean body mass of the workers was also a better predictor of maximum strength when compared to stature and shoulder grip reach of the workers. On the other hand, age of the workers (male and female) was observed to be the worst predictor of maximum cranking or steering strengths as the correlation coefficients (r) of regression of age over cranking strength (both hands) and steering strength were 0.057 and 0.070, respectively for male workers and 0.039 and 0.077, respectively for female workers. However, the relationship between stature and maximum cranking or steering strength was less straightforward because of the influence of the handling posture including body segment angles and position of the feet. The correlation coefficients (r) of regression of stature over cranking and steering strength were 0.133 and 0.242, respectively for male workers and 0.186 and 0.155, respectively for female workers.

Design Values

In terms of work-related factors, the exposure to force application can be expressed with three factors: 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 might 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. The determination of maximum acceptable forces depends on the assumption that an individual can estimate his/her

Table 4. Regressions of cranking and steering strength of male and female workers

Parameters		Coefficient of correlation(r)
Male (n = 944)		
Cranking strength (preferred hand)	Age	0.054
	Weight	0.440
	Stature	0.119
	LBM	0.448
	Shoulder grip length	0.044
Cranking strength (both hand)	Age	0.057
	Weight	0.439
	Stature	0.133
	LBM	0.419
	Shoulder grip length	0.009
Steering strength (both hands)	Age	0.070
	Weight	0.364
	Stature	0.242
	LBM	0.375
	Shoulder grip length	0.309
Female (n= 757)		
Cranking strength (preferred hand)	Age	0.083
	Weight	0.402
	Stature	0.171
	LBM	0.445
	Shoulder grip length	0.027
Cranking strength (both hand)	Age	0.039
	Weight	0.440
	Stature	0.186
	LBM	0.432
	Shoulder grip length	0.025
Steering strength (both hands)	Age	0.077
	Weight	0.369
	Stature	0.155
	LBM	0.356
	Shoulder grip length	0.085

*LBM- lean body mass

maximum work tolerance without experiencing health complaints during a certain work period. The subject adjusts his/her maximum acceptable effort depending on his/her own feelings of exertion or fatigue. The maximum work tolerance on a working day can be indirectly obtained from the maximum isometric strength for a single exertion (Waters *et al.,* 1993). In terms of external exposure, frequency of a certain activity and working hours are controlled during the experiments, while the subjects are given control on the level of the exposure. 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.

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. Cranking/steering strength capability depends on a complex interaction of posture, shoe/floor friction, cranking radius and subject anthropometry (Snook, 1978). Generally, it is recognized that persons with better muscle built-up, higher shoulder grip length and high body weight can achieve higher strength capability if proper lumbar support is provided.

The 5th percentile cranking strength with preferred and both hands for male workers were 29.2 N.m and 33.8 N.m, respectively while the 5th percentile cranking strength with preferred and both hands for female workers were 17.7 N.m and 20.1 N.m, respectively. The t-test conducted between cranking strength values of male and female workers revealed that the strength values observed for preferred and both hands was significantly different at 5% level of significance. Chaff cutters often operated by women is continuously operated, and therefore, its design may be limited to 30% of 5th percentile value of both hand cranking strength (van Wely, 1970; Pheasant, 1981). Thus, the suggested limits for the operation of chaff cutter should be 6.03 N.m with cranking radius of 265 mm. Hand operated pump is another hand crank operated control, and normally operated by the male worker. Thus, 30% of the 5th percentile value of the cranking effort of male workers (10.2 N.m) should be the suggested limit.

The 5th percentile steering strength of male workers in sitting posture was 33.1 N.m. The steering is an occasionally operated control fixed on self-propelled machinery mostly being utilized by male workers; therefore 60% of the 5th percentile value of steering strength (19.86 N.m) should be taken as the limiting value. However, the maximum effort requirement for steering wheel (420 mm diameter) should not be more than 19.86 N.m. The torque requirement should be suitably adjusted for any change in steering radius to maintain the muscular loading to its maximum strength.

CONCLUSIONS

1. The cranking and steering strength of male agricultural workers of Madhya Pradesh was higher than those of female workers. The mean values for isometric cranking strength in standing posture with preferred hand and both hands were 44.1 ± 9.1 and 50.6 ± 10.2 N.m for male workers and 31.9 ± 8.6 and 37.3 ± 10.4 N.m, respectively for female workers. The mean values of steering strength in sitting posture were 64.0 ± 18.8 N.m for male workers and 40.5 ± 10.0 N.m for female workers.
2. The body weight of the workers indicated a positive correlation with cranking and steering strength.
3. The 5th percentile cranking strength with preferred hand and both hands were 29.2 and 33.8 N.m, respectively for male workers and 17.7 and 20.1 N.m, respectively for female workers. Equipment operated by hand cranking with continuous operation should be designed with the force requirement not exceeding 30% of the 5th percentile strength value, although it may rise to 60% if the effort is not continuous in nature.

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