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Bio-mechanical analysis on selected agricultural hand tools

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Abstract: Bio-mechanical analysis of agricultural hand tools *viz.* crowbar, hand hoe, spade and sickle was conducted. Pertinent anthropometric parameters of male and female farm workers of the southern districts of Tamil Nadu were measured. A bio-mechanical analysis on the work posture indicated that the reaction force on neck for the operation of crowbar, different spades, hand hoes and sickle were 21.8, 24-26, 17-21 and 18.9 kg respectively. The crowbar and spade caused 21.8 kg and 88-110 kg of reaction forces respectively on biceps. The same for hand hoe and sickle was 41 and 2.6 kg respectively. The reaction force due to hand grip was 4.8 and 1-1.3 kg for crow bar and spade respectively. The reaction force on lumbosacral joint for spade, hand hoe and sickel was 248-394, 311-388 and 280 kg respectively. It was negligible for crow bar.

Key words : Bio-mechanics, Hand tools, Reaction force, Fatigue.

ntroduction

Human workforce contribute substantially or crop production in Indian agriculture. About per cent of the power used in agriculture nd its related activities is met by approximately 20 million workers. Among them the female vork force is 30 per cent. Though farm nechanization is in rapid pace, the operations erformed by men are mostly mechanized. Women ontinue to use the same traditional tools for heir work. Indian farmers mainly use hand ools for performing various operations and here are more than 400 million hand tools uch as spade, hand hoe, sickle, crow bar, xe etc. in use (Gite, 2000). The design of particular hand tool vary from region to egion. Non-scientific method of designing hand ools cause fatigue to the operator. If a tool nduces fatigue to the operator, it is difficult to understand which component of the tool causes fatigue and how to modify it to user friendly. The anthropometry of the operators in that region also play a major role in the design of the tools. Biomechanical analysis of hand tools help to clearly identify the reaction force caused to different body parts of the subject. This can be correlated to the kinematics of the tool to understand the parts causing fatigue to the operator. If the tool geometry is redesigned based on the bio-mechanical analysis, the fatigue caused could be reduced and tool efficiency can be improved. In this investigation, bio-mechanical analysis was done to quantify the reaction force on various body parts of the operator while using hand tools. The tools part which causes discomfort and fatigue was also identified based on the reaction force.

Materials and Methods

Anthropometric parameters

A survey was conducted among farm workers to identify the different types of hand tools used in Theni, Madurai and Kanyakumari districts of Tamil Nadu. The survey revealed that the hand tools used mainly were crow bar, short and long handled spade, hand hoe, and sickle for various agricultural operations. The pertinent anthropometric parameters of eight randomly selected male and female workers involved in the operations of the hand tools were measured in each village and the average calculated. The anthropometer, sitting height table, weighing balance and measuring tape were used for measuring anthropometric parameters. The inclination and position of body parts and tools with respect to horizontal in operating posture were also measured using measuring tape to quantify the lever arms between the tool force and point of reaction forces on respective body parts.

Table 1. Anthropometric dimensions

Sl.No.	Dimension (cm)	Male	Female
1.	Weight, kg	68.46	51.42
2.	Height	167.03	156.50
3.	Olecranon	102.00	97.92
4.	Illicrystale height	96.74	92.62
5.	Trochanteric height	84.60	83.55
6.	Knee height	47.93	44.73
7.	Waist back length	40.25	38.72
8.	Chest depth	23.53	21.31
9.	Functional leg length	98.64	97.38
10.	Forearm hand length	44.96	42.15
11.	Hand length	18.36	6.93
12.	Grip diameter (inside)	5.70	5.10
13.	Head length	18.37	18.27
14.	Head breadth	15.26	14.14

Body segmental weights

The body segmental weights are important parameters to calculate the reaction force due to the operation of the hand tools. The proportionate weights of different body parts were calculated using the average body weight of workers. The reaction force due to the body segmental weights are influenced by the centre of gravity of the body segments. The locations of center of gravity of body parts were calculated from the anthropometric measurements (Ellen *et al.* 1985).

Reaction force

The reaction forces on different body parts due to the segmental weights and the tool force were calculated by resolving the forces as shown in Fig.1 and Fig.2. The tool force was considered as 1.2, 5, 3.5 and 1 kg for crow bar, spade, hand hoe and sickle (Kumar, 1987). Thus reaction force in neck, tendon muscle of hand, upper arm and lumbosacral joint on the back was calculated (Marlene *et al.* 1995) by using the following equations.

Crowbar operation :

$$\text{Total torque, } T = TF + TW = F \times LF + W \times LW$$

Where,

TF - Torque due to F
TW - Torque due to W
LF - Force arm
LW - Load arm

This total torque develops an muscle reaction at 5 cm distance from the lumbosacral joint so

Reaction force on lumbosacral joint = Total torque / 5.

Hand tools

Reaction force on the neck

$$R = W \times LW / LF$$

Where,

Wh - Weight of the head
Lw - Load arm
RN - Reaction force on the back of the neck
LF - Force arm

Reaction on biceps

$$R = \frac{W \sin B \times LF/2 + F\sin B \times LF}{\sin 0 \times LD}$$

Where,

F - Tool operating force
RH - Reacting force on forceps
R - Vertical component of RH
LF - Force arm
LD - Distance between D and R

Reaction on fingers gripping the tool or tool handle, $R = F/\cos 15$

Coefficient of friction = Gripping force, F/ weight of the tool or handle

Reaction on the back

The compression force on the lumbosacral joint is

$$R_x = P \sin 8 + W \cos 0 + F \cos 0$$

shearing force, $R_y = P \sin 8 + W \cos 0 + F \cos 0$

The joint reaction R is given by

$$R = \sqrt{R_x^2 + R_y^2}$$

Results and Discussion

The pertinent anthropometric parameters of male and female workers are presented in Table 1. The calculated mean segment weights and segmental centre of gravity locations measured from the proximal ends for male and female farm workers are summarized in Table 2. The reaction force on body parts *viz.* neck muscle, hand grip, forceps and lumbosacral joint is

Table 2. Mean segment weights, length and location of centre of gravity in relation to body parts

Body segment	Segment weight (kg)		Location of centre of gravity from proximal end			
	Male	Female	Male		Female	
			Average length (cm)	Centre of gravity (cm)	Average length (cm)	Centre of gravity (cm)
Head	5.28	4.20	18	10.00	18	10.00
Whole trunk	35.30	27.10	15	8.25	14	7.70
Total arm	3.70	2.50	40	25.20	38	24.00
Upper arm	2.10	1.40	23	14.50	21	12.00
Fore arm	1.20	0.80	77	48.50	76	48.00
Hand	0.42	0.25	32	14.00	34	14.60
Total leg	10.70	9.40	45	19.30	42	18.00
Thigh	6.80	6.00	18	8.40	17	8.00
Leg	3.04	2.70	99	63.00	97	62.00
Foot	0.92	0.68	51	22.00	52	22.50

Table 3. Reaction force infuenced by tools

Tool	Neck muscle (kg)	Grip (kg)	Biceps (kg)	Lumbosacral joint (kg)
Male worker				
Crow bar	21.8	4.82	21.8	Negligible
Short handled spade	26.4	1.04	88.0	394.0
Long handled spade	23.8	1.29	110.0	248.0
Female worker				
Short handled hand hoe	21.0	0.77	40.0	311.5
Long handled hand hoe	16.8	0.52	41.5	388.7
Sickle	18.9	0.31	2.6	280.2

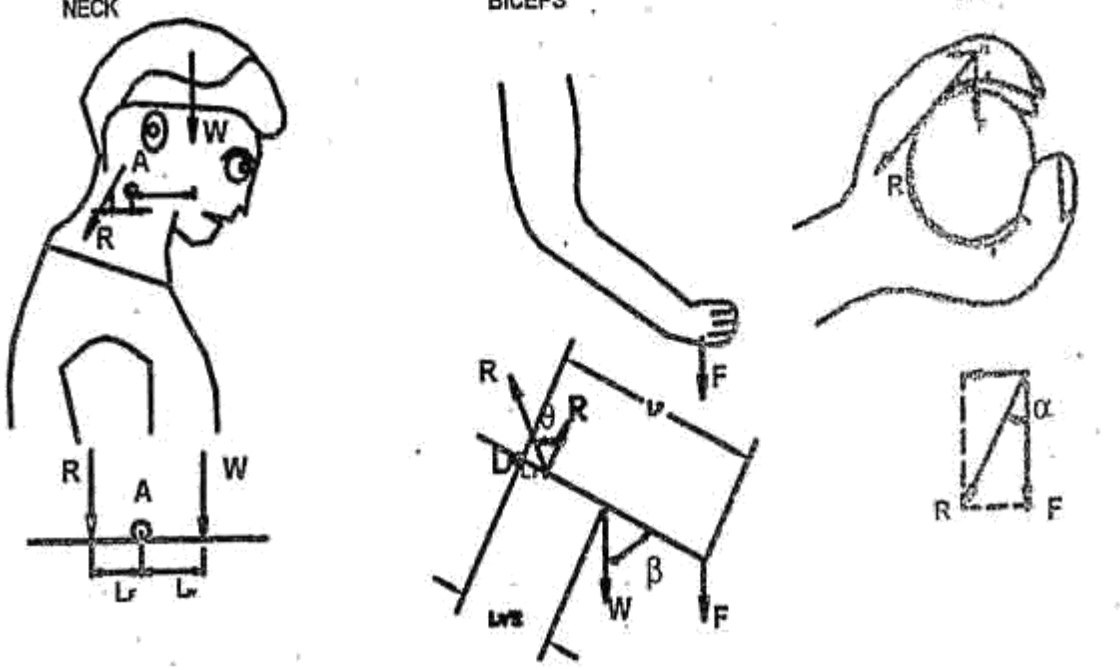
given in the Table 3. It was observed from the bio-mechanical analysis that the reaction force on neck for the operation of crowbar, different spades, hand hoes and sickle was 21.8, 24-26, 17-21 and 18.9 kg, respectively. The crowbar and spade caused 21.8 kg and 88-110 kg of reaction force, respectively on biceps. The same for hand hoe and sickle was 41 and 2.6 kg, respectively. The reaction force due to hand grip was 4.8 and 1-1.3 kg for crowbar and spade, respectively. It was at negligible level to other tools. The reaction force on lumbosacral joint for spade, hand hoe and sickle was 248-394, 311-388 and 280 kg, respectively. It was negligible for crowbar.

Reaction force on the neck

The reaction force on the neck muscle was the highest for short handled spade and hand hoe. This is due to the reaction force developed like cantilever beam by the entire head weight on the top cervical joint at complete bending posture with which the short handle tools are operated. While using long handled spade the head bends slightly towards the front of the body by which the stress on the neck is reduced by about 10 per cent. In the case of crow-bar usage, the neck reaction force was 21.8 kg which is about 17.5 per cent lower than the usage of short handled hand hoe (Table 3). The reaction force developed in crow-bar usage is due to normal standing posture. Hence the posture of the head during the operation of the tool caused the excess reaction force on the neck. It was mainly influenced by the handle length.

Reaction force due to gripping

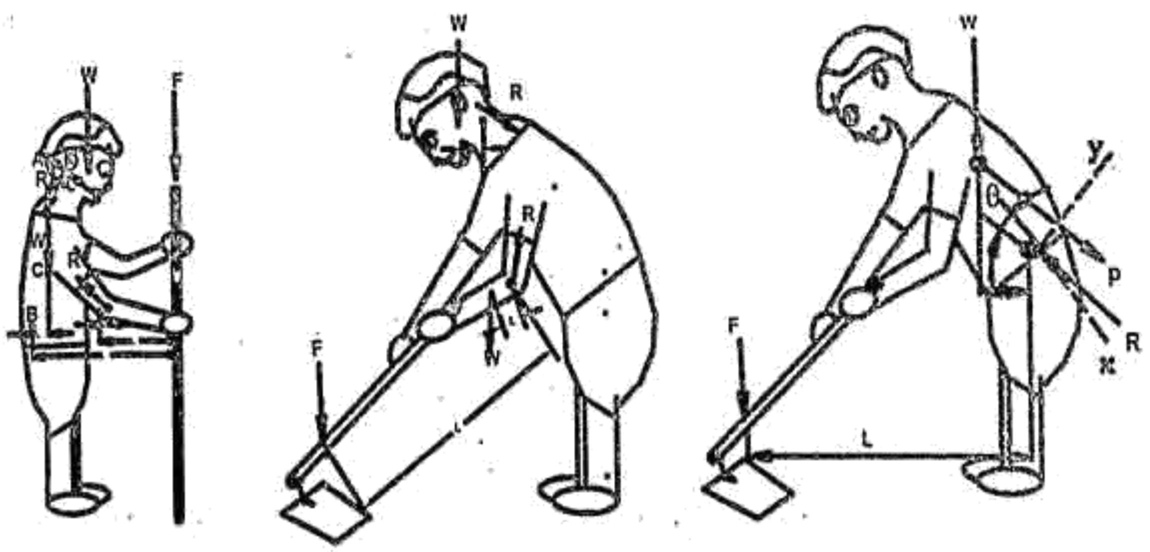
When the crow-bar is operated with gripping hand, the reaction force is developed along



W - Segmental Weight
R - Reaction Force
F - Acting Force

L_F, L_W - Lever Arms
α, β, θ - Inclination of Forces

Fig.1. Force analysis on different body parts



W - Segmental Weight
R - Reaction Force
F - Acting Force

L - Lever Arms for Respective Forces
θ - Inclination of Reaction Forces

Fig.2. Force analysis on body parts in different posture

he tendon muscle of the fingers. This is mainly lependent on the total mass of the tool with he condition that the tool or the tool handle s completely encircled by the fingers during gripping. The crow-bar developed highest reaction force on hand (4.82 kg) followed by the other tools which have masses in descending order Table 3). It is very clear that the diameter of the tool handle should be less than or equal to the diameter of the hand grip. The mass of the tool should be minimum to have lesser reaction force on hand.

Reaction force on the biceps

The reaction force on the biceps while orking with long handled spade was 22 kg igher than the short handled spade (Table 3). his is due to the tool force and the force rm which were higher than the short handled pade. Moreover the posture of the hand decides le angle of reaction force to vertical and also influences the reaction force. The operator's and weight was same for both the spades, whereas the weight arm of long handled spade s 6 cm longer than the short handled spade. Since the weight arm of long handled spade s only 6 cm longer which has little influence n reaction force due to spade operation. Both hand hoes developed almost equal reaction force. Sickle and crowbar developed reaction force of 2.61 kg and 41 kg, respectively. These analysis concluded that the reaction force on the upper arm is highly influenced by tool force and orientation of the hand besides the anthropometric dimensions. The tool force can be optimized based on the mass of the tool, rake angle and tool angle.

Reaction force on the back muscle near the lumbosacral joint

Reaction force acting on the back muscle near the lumbosacral joint changes with respect to the inclination of the body to the horizontal. The body posture while working with long handled spade was slight bending with 20 deg to vertical, whereas it was 75 deg to the vertical in the case of short handled spade. The reaction force was the highest (394 kg) for short handled spade (Table 3). The use of long handled spade reduced the reaction force by 37 per cent. As the crowbar operation requires almost erect posture of the body, the reaction force on the lumbosacral joint was negligible. In other words, the reaction force will be generally acting on erect posture of the body even without working. This is not due to the operating posture. In case of hand hoe, short handled hoe developed lesser reaction force (311.5 kg) than the long handled hoe. The long handled hoe used by the surveyed farmer had not appreciably changed the posture compared to short handled hoe. The long handled hoe had more tool force (3.5 kg) due to its higher dimensional values than short handled hoe (3.0 kg). Due to all these reasons the long handled hoe created higher reaction force than short handled hoe. The sickle developed lesser reaction force than the hand hoes, though the posture of working is almost same for its operation. The lesser reaction force is due to the lesser tool force required to operate the sickle.

Conclusions

The posture of the head during the operation of the tool caused the excess reaction force on the neck. It was mainly influenced by the handle length. The mass of the tool should be minimum to have lesser reaction force on hand. The reaction force on the upper arm due to gripping of the tool is highly influenced by tool force and orientation of the hand besides the anthropometric dimensions. Reaction force on the back muscle near the lumbosacral joint was least in sickle followed by long handled spade.

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