Ergonomics evaluation of a manually operated cassava chipping machine

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A manually operated machine for chipping cassava was evaluated. Six farmers took part in the study, with physiological, postural, and subjective measurements being taken. Using the machine resulted in drudgery and postural discomfort. Following an iterative design process and using appropriate anthropometric measurements, an improved, adjustable prototype was developed. This was tested with the six farmers and six novice users. It was found to reduce discomfort and physiological strain, allowed a faster work-rate (with novice users) and was preferred by all users. The study demonstrated how ergonomics can play an important role in reducing drudgery and improving user satisfaction in technology development and transfer in developing countries.

Keywords: agriculture, developing countries, product design

Introduction

Cassava (*Manihot esculenta Crantz*) is an important food security crop, but recently attention has been given to its role in income generation (e.g. Bokanga, 1998). Ghana has, over the past few years, been expanding its exports of cassava chips to the European Union for animal feed as a means of earning foreign exchange (Spenser and Kainaneh, 1997). Opportunities also exist in Ghana for producing cassava for domestic animal feed (Westby *et al*., 1998).

On-farm participative research has been carried out in the Brong Ahafo (BA) region of Ghana to investigate the potential of cassava processing for domestic livestock feed as a source of income generation. Good quality cassava chips were produced by a production system combining "mini-chipping," using a chipper modified from a design of the International Institute of Tropical Agriculture (IITA), and sun-drying protocols using elevated trays and black ground-sheets (Hector *et al.* 1996).

In this paper, the results of ergonomics evaluations and improvements to the design of the cassava chipping machine are reported.

Materials and methods

Chipping machine design

The cassava chipping machine was developed from an IITA design (Figure 1) to produce thin (3.5 mm) chips, 60-100mm long. A simple hand operated machine, it consisted of three principal parts, the wheel to which the chipping blade is attached, the shaft and the frame (Jeon and Halos, 1991).

In prior trials with farmers significant modifications were made to the IITA design (Hector et al. 1996). These included increasing the weight of the cutting blade and improving the bearings. These modifications increased the cutting plate momentum and allowed users, particularly women to operate the machine more easily. The shaft centre was raised from 415mm above the ground to 570mm. Production rates of between 90-100kg per hour were recorded, but fatigue restricted the overall effort to periods of 1-2 hours (Hector et al. 1996). In spite of these ad hoc modifications, problems of drudgery and discomfort associated with this machine and a similar version without a seat remained. A participatory ergonomics approach was therefore adopted to improve the design of the cassava mini-chipper. This essentially comprised of two stages:

1. Focus groups with farmers (users and non-users) including hands-on use of chippers and prototypes.
2. Prototypes developed using feedback from focus groups and appropriate anthropometric data.

The process was iterative with the users involved throughout and this 'bottom-up' redesign of technology generated much enthusiasm. The process resulted in the development of a final prototype chipping machine (Figure 2) that was essentially a modified wooden mini-chipper with the seat removed. The height of the shaft centre was made adjustable at 50mm intervals to a maximum height of 820mm. Other modifications included a hinged box attached to the machine to increase the capacity of the hopper.

In this paper, this final prototype is compared against the original IITA designed chipper.

Subjects

The study was carried out on-farm with six experienced users of the mini-chippers in the BA region in April and November 1997. In order to collect work-rate data, further lab-based trials were conducted with six novice subjects in February 1998. Personal details of the subjects are presented in Table 1.

Anthropometric measurements

Whilst anthropometric data are available for much of West Africa, they do not include Ghana (Jürgens *et al.*, 1990). Sixteen measurements described by Pheasant (1990), that were relevant to the chipping machine, were thus gathered from the local population (an opportunity sample of 35 adults from eight villages in the BA region) using the Suma'mur's tailor method (Soedirman, 1987) and used in the development of the prototype chipper. Whilst 5th and 95th percentile values are presented, they must be treated with care given the small sample size (Table 2).

Postural discomfort

A modified body map (Corlett and Bishop, 1976) with 32 parts identified (Cameroon, 1995), was used to locate postural discomfort. Due to difficulties in presenting rating scales to illiterate subjects, they were asked whether they felt any pain or discomfort in each body part, with a yes/no response. To avoid any confusion with the names of body parts, the experimenter pointed at each area in turn. This was repeated before and after chipping. Approximate measurements of the angle of spinal flexion were made from photographs taken of the working posture. Two points on the body were marked; around the 7th cervical vertebra and at the upper edge of the greater trochanter. The angle between the vertical and the points was taken to be the angle of the spinal curve.

Heart rate

Heart rate was measured using heart rate monitors (Sports Tester, Polar Electro, Finland) and logged at one minute intervals. Resting heart rates were taken, and maximum heart rate was estimated according to the formula 220-age (Rodahl, 1989). To enable a more meaningful comparison, individual differences between subjects were minimised by expressing working heart rates as a percentage of an individuals effective heart rate range (Rodahl, 1989). This was calculated from resting and predicted maximum heart rates.

Work-rate

The time required to chip 20kg of un-peeled roots was recorded as an indication of work rate. Weights were measured using a digital balance (A&D Precision Health Scales, Tokyo, Japan) with an accuracy of ± 0.05kg.

Comparison of machines

The study followed a repeated measures experimental design with two conditions, chipping with a mini-chipper and chipping with the prototype. All conditions were conducted in the morning. Before each condition, subjects were briefed about the nature of the investigation through an interpreter. They were asked to sit in a relaxed posture for 15 minutes during which time an estimate of their resting heart rate and an assessment of body-part discomfort were made.

Subjects 1-6 used whichever machine they were experienced with for one hour (Table 1). Four used the wooden machines and two used the metal machines. The distal and proximal ends of the roots were removed with a knife before chipping. The experimental procedure was repeated with the prototype which was set at a fixed height of 820mm. Differences between conditions were analysed using the Wilcoxon matched pairs statistical test.

In order to eliminate any bias in the work-rate results from training, practice or the Hawthorne effect (Rothlisberger and Dickson, 1939), the assessment of work-rates was done with novice users (subjects 7-12). The same chipping blade, sharpened prior to each trial was used on the mini-chipper and the prototype. The blade used on these trials was however lighter than those used with subjects 1-6. The order in which they used the machines was counter-balanced.

Results

Physiological and postural measurements

The mean physiological workload, expressed as a percentage of an individual's effective heart rate for operating the prototype, was 41% compared with the workload of 56% for the mini-chipper (Table 3). There was a significant reduction ($p.<0.003$) in the mean heart rates when chipping with the prototype.

Whilst recovery heart rates would have been desirable, accurate recording was not possible in the field. Recovery would have been confounded by the subjects' movements, such as brushing swarms of bees away making 'rest' impossible.

The posture adopted to operate the mini-chipper resulted in pain or discomfort over much of the body and involved considerable spinal flexion. This was particularly observed with the metal machine which had a lower shaft height (Table 3). By raising the height of the shaft centre (Table 3), the posture was straightened, significantly reducing the angle of spinal flexion by an average of almost 42% ($p.<0.01$). Results from the body maps suggested that this subsequently resulted in a decrease in the incidence of pain or discomfort in most body parts. It was interesting to note that an increase in the incidence of discomfort in the lower back following one hour's chipping was not observed as may have been expected. This is probably more a shortcoming of the methodology chosen, using a binary scale rather than incremental scale on the discomfort body map. When questioned informally about the severity of the pain, the subjects commented on how the pain was moderate before commencing chipping and more severe afterwards.

Work-rate assessment

The work-rate of the prototype chipper when used by novice users (Table 4) was significantly faster than the mini-chipper ($P<0.001$). There was a 68% improvement in the work-rate. Subject 9 withdrew from the mini-chipper trial after almost 32 minutes having chipped only 13.15kg, complaining of discomfort and fatigue.

Comparative performance over a working day

To complement the data on work-rate, a case study with one farmer was carried out over a typical working day, (considered by the farmers to be the production of sufficient chips to fill fifteen drying trays, approx. 225kg chipped weight). The experimental procedure was repeated with one farmer (Subject 5, Table 1) who had experience of operating both the mini-chipper and the prototype. He used the mini-chipper on the first day and the prototype on following day. The prototype was set at his preferred height, (770mm, 53% of shoulder height). Environmental conditions were the same on both days, and the same chipping blade, sharpened prior to use, was used on both machines. The results are presented in Table 5.

The first day's chipping was finished prematurely (after eleven trays) because of fatigue and disturbance from bees. The shortfall of four trays was made up for on the second day. As in the previous trials (Table 3) the prototype resulted in a lower physiological work rate and less body-part discomfort. This caused less fatigue and allowed the farmer to chip for a longer period of time. Work-rate (in terms of roots processed per unit time) was marginally improved. Finally, the farmer felt that it was a significant improvement to his existing machine and felt it would be his preferred choice.

Discussion

A stooping posture, as adopted during chipping with the mini-chippers, is generally considered to be undesirable, with spinal flexion causing deformation of the intervertebral disc and exerting a risk of the nucleus being extruded (Pheasant, 1991). Any mechanical advantage from the weight of the body through a tilted trunk will thus be offset by the risk of cumulative musculoskeletal damage or overexertion from such a posture. Rotating the chipping blade involves asymmetrical movement that further increases the risk of musculoskeletal damage. With spinal rotation there will be an increase in the loading on the spine, causing further deformation of the discs (Pheasant, 1991). By raising the working height of the machine, the angle of spinal flexion was significantly reduced. This resulted in a reduced incidence of musculoskeletal pain or discomfort following chipping. As all farmers complained of lower back pain before and after chipping, there was no increase in the incidence of pain or discomfort in this body part, however informal discussions with the farmers following chipping with each machine suggested that the severity of pain after using the mini-chippers was greater than that following use of the prototype.

Heart rates can provide an indication of physical strain. Analysis of the heart rate data suggests that the physiological workload in operating the prototype was less than with the mini-chipper. The heart rate data however must be treated with care, as it can also represent other strains on the body such as thermal or postural stress (Rodahl, 1989). Indeed the thermal conditions were slightly (but not significantly) more stressful during the evaluation of the mini-chipper than the prototype. This effect on heart rate may be counter-balanced by the difference in posture, an upright posture will exert a greater strain on the cardiovascular system than a stooping one (Rowell, 1986). Feedback from the subjects reflected the heart rate data. Of the twelve subjects, ten claimed they were less tired, suffered less body pains after use and could chip for a longer period of time with the prototype.

All the subjects felt that the prototype chipper was an improvement over the mini-chippers, expressing a preference for the new design. Whilst the chipping height of the prototype was adjustable (and thought to be a major improvement by users), during the trials it was extended to its maximum height. Six of the farmers were satisfied with this height, whilst the others would have liked it slightly lower. They all believed that chipping at a raised height was an advantage in terms of comfort, a reduction in drudgery and would allow them to increase their productivity. The work-rates of novice subjects were significantly faster with the prototype.

The box was considered to be an improvement by all the farmers. It allowed approximately 20kg of roots to be piled up for chipping without a loss of stability. This reduced the frequency of stoppages to pick up roots from the ground whilst chipping, an action that required considerable asymmetrical twisting and bending. Subjects did not generally place roots on the original platform as expected, preferring to take roots one by one from the box. This appeared to have the advantage of allowing a greater area for them to rest their left arm whilst chipping. One farmer also noted that with roots being held away from the hopper, there was less excess soil entering it.

In the course of this study several methodological issues in the field were encountered. None of the farmers who participated in the study were literate or spoke English. The use of written documents such as questionnaires could not therefore be used. The limited vocabulary in the local language prevented the use of discreet points on subjective scales being used, subjective feelings were described with more linguistic description than single words, hence the use of “yes/no” responses to discomfort on the body-maps rather than a severity scale.

Heart rate monitors were easy to use and unobtrusive however some women were reluctant to wear them against their skin. A signal from the heart rate transmitter was however received when it was worn over very light clothing that was moistened.

Finally, the benefits of using a participatory ergonomics approach were demonstrated in this study. It allowed for a rapid identification of the problems to be made by the users, and improvements to be developed with their co-operation, ensuring they perceived ownership of the technology.

Conclusions

This study has demonstrated how agricultural machinery developed for use in a developing country can be improved by employing a participative and iterative approach to design, paying closer attention to human factors. By incorporating ergonomics into the design process, drudgery associated with the machine was reduced and productivity, user comfort and satisfaction were increased. Improving the posture adopted to operate the machine resulted in a significant reduction in physical strain and incidence of body-part discomfort and can be expected to reduce the risk of musculoskeletal damage.

Acknowledgements

The authors are grateful to David O’Neill from Silsoe Research Institute and Prof. Ken Parsons from Loughborough University for their help during this study and to Seth Gogoe for his assistance and interpreting during data collection. This paper is an output from a project funded by the UK Department for International Development

(DFID) for the benefit of developing countries. The views expressed are not necessarily those of the DFID. [R6508:Crop Post-Harvest Research Programe].

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Table 1 Details of subjects who participated in the evaluation of cassava chipping machines

Subject	Sex	Age (Years)	Weight (kg)	Height (mm)	Resting Heart rate (bpm)	Experience (years)	Machine usually used
1	M	37	54.8	1680	68	1	Wooden
2	F	41	63.7	1645	65	1	Wooden
3	M	32	56.9	1651	72	1	Wooden
4	M	27	68.3	1715	57	1	Metal
5	M	34	63.2	1750	84	1	Metal
6	F	60	40.0	1532	89	1	Wooden
7	F	40	76.2	1681	70	0	-

Table 2 Anthropometric data from Brong Ahafo adults (mm)

	Men (n=13)				Women (n=22)					
Percentile:	**5^{th}**	**50^{th}**	**95^{th}**	**SD**	**5^{th}**	**50^{th}**	**95^{th}**	**SD**	**Min**	**Max**
Stature	1575	1697	1819	74	1360	1563	1767	124	1360	1819
Shoulder height	1285	1401	1518	71	1198	1306	1414	66	1198	1518
Elbow height	958	1053	1147	58	911	995	1078	51	911	1147
Knuckle height	599	696	792	59	597	668	739	43	597	792
Shoulder-fingertip length	678	753	828	46	645	708	770	38	645	828
Elbow - fingertip length	374	458	541	51	377	435	494	36	377	541
Biacromial breadth	362	403	444	25	316	382	448	40	316	444
Popliteal height	421	456	490	21	351	403	456	32	351	490
Thigh thickness	91	129	167	23	94	118	142	15	94	167
Knee height	451	515	580	40	447	501	554	33	447	580
Length of hand	172	190	209	11	161	177	193	10	161	209
Length of palm	98	108	118	6	93	100	107	4	93	118
Palm breadth[1]	88	94	101	4	75	84	93	5	75	101

[1]excluding thumb

Table 3 Summary of heart rate data, relative height of chipping machines and approximate angles of spinal flexion observed during chipping using the mini-chipper and prototype machines

	Heart rate (bpm)		% of effective heart rate range		Height of shaft centre as percentage of shoulder height (%)		Approximate angle of spinal flexion	
Subj.*	**Mini-chipper**	**Prototype**	**Mini-chipper**	**Prototype**	**Mini-chipper**	**Prototype**	**Mini-chipper**	**Prototype**
1 (*W*)	129	113	53	39	41	59	46°	31°
2 (*W*)	121	110	49	40	42	61	54°	25°
3 W)	145	118	64	40	42	61	41°	29°
4 (*M*)	123	108	49	37	29	59	76°	34°
5 (*M*)	140	117	56	39	28	57	42°	35°
6(W)	134	126	63	52	46	66	40°	20°
Mean			56	41	38	60	50°	29°

*(*W*) indicates that the farmer used a wooded mini-chipper and (*M*) indicates that a metal chippers was

Table 4 Work-rates of novice users using the mini-chipper and prototype machine calculated from the time taken to chip 20kg of fresh roots

	Work-rate (kg/hr)[1]		
Subject	mini-chipper	prototype	% improvement
7	32.3	43.2	75
8	46.1	60.5	76
9	38.0	39.3	63
10	79.6	137.9	58
11	65.5	88.9	74
12	50.2	78.0	64
Mean	52.0	74.6	68
sd	17.7	36.5	

[1]These work rates are presented to compare the mini-chipper and the prototype. They may not be sustainable over time or representative of machine-user productivity.

Table 5 Time spent working, work rate, and heart rate for farmer 5 using the mini-chipper and prototype machines

	Mini-chipper	Prototype
Total work time	174 min	204 min
Chipping time[1]	137 min	156 min
Harvesting roots[2]	37 min	48 min
Total chipped	276 kg	322 kg
Work rate	120kg/hr	124kg/hr
Heart rate[3]	140 bpm	131 bpm

[1]Chipping includes rest breaks. Removal of root ends and loading of chips into trays was undertaken by an assistant.

[2]The bulk of the roots were harvested before the trials.

[3]Mean heart rate whilst chipping.

Figure 1 Wooden framed cassava mini-chipper

Figure 2 Prototype mini-chipper