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Ergonomic modification and performance evaluation of a shoulder-strapped brush cutter

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ABSTRACT

Ergonomic studies were carried out on selected shoulder-strap brush cutters to evaluate some deficient ergonomic factors associated with their operations. These deficiencies were used as basis for modification. Contextual interview and field interactions were used to obtain ergonomic data that are descriptively analyzed. Results of ergonomic assessment shows that operators are subjected to pains around the neck, shoulders, upper arm and fingers which are largely traceable to shoulder-strap-long-time operation, exposures to prolonged mild vibrations, repetitive arm supination-pronation-swings during operation, exertion due to prolong suspension of the weight of the machine. Based on these outcomes, modifications were made on machine which include removing the machine weight from shoulder to a push-carrier that bear the machine weight, height adjustment mechanism to regulate the height of cut, reduction of the transmission assembly length from 1500mm to 300mm for effective maneuvering and orientation of the handle for ease of control. Performance evaluation shows that the modified machine was ergonomically acceptable and user friendly with excellent mowing quality.

Keywords: Ergonomic, brush cutter, anthropometry, injury, leaf damage.

1. INTRODUCTION

The aesthetic value of environment is as important as food and shelter to the modern man. As man evolved intellectually, brush cutting, mowing and cleaning of lawns and walkways have become a critical part of aesthetic design in building management, agricultural and horticultural operations for cutting grass along roadsides, lawns, parks and in other areas requiring weed control and have invariably developed into an art [1]. As technology advanced, grass cutting technology developed into better techniques of grass cutting on commercial scale, each suited to specific purposes such as shrub cutting, lawn mowing and hedge trimmings which are comparatively very much thicker than grass and other common weeds. Among the types available in market, is the one sold under the commercial name of brush cutter.

In operation, brush cutters navigate through weeds, heavy brush and overgrown vegetation with ease. The welded steel frame design and engine positioning provide excellent balance regardless of the terrain. Existing engine trimmers suffer from high initial cost, high levels of engine noise, high fuel consumption rate and high operator fatigue on the long run [2, 3, 4]. The brush cutter operation involves the use of a motorized (engine or electrical) powered cutters spinning at high speeds (up to 10,000 rpm) to cut grasses. Some of these machines are either mounted on the back (knapsack), or hanged around the neck or around the shoulder during operation. This equipment is highly efficient in its operation with high quality mowing ability, relative lightweights, convenient means of mobility, reduce the labour intensity, improved work efficiency and good quality of the work [5, 6, 7], However, the weight and speed of the engine often results in high levels of hand-arm vibration (HAV), high noise notes among its operators, especially the engine powered categories [8] noted that the present need for the use of agricultural mechanization requires a good knowledge and proper design of agricultural equipment with special consideration to efficiency, safety, and comfort of people using them. It is in this opinion that [9] maintained that ergonomics is the science of fitting work to the users; instead of forcing the users to fit the work and that a good match can be obtained if anthropometric data is used.

Anthropometry involves the systematic measurement of the physical properties of human body size and shape [10]. According to [11], anthropometric body dimensions play significant roles in human-machine interaction, industrial design, clothing design, ergonomics and architecture where statistical data about the distribution of body dimensions in the population are used to optimize products [12]. Anthropometric data have wide range of applications in the design of agricultural machinery among other physical equipment and facilities. It is needed in the design of products as it varies between individuals and nations [13]. The overall human efficiency of human-machine environment and resultant discomfort have severe impact while using farm equipment and/or machinery, and the anthropometric dimensions developed from one region may not be appropriate to be used when designing machines or tools for people in other ethnic origin [12].

Despite the various approaches to modern technology on agricultural machinery/equipment design, human drudgery has not been fully arrested in Nigeria agricultural and horticultural works. Some agricultural machines (e.g. held brush cutter) create discomfort and at times breakdown quickly due to various discrepancies in ergonomic factors peculiar to Nigeria agricultural workers using them. The advantages of the multifunction, and good quality of job delivery notwithstanding, brush cutters are constrained from the work task and the environment, such that the operator has to rely on the hand grip and neck strap during operation. The noise, vibration, and scraps made by brush cutter constitutes hazards and could lead to occupational safety problems such as hand–arm vibration (HAV) syndrome that is very common among workers operating power tools and performing similar work for extended periods. The risk of developing hand–arm vibration (HAV) syndrome has been reported to depend on the magnitude of vibration transmitted to the tool handle, on the mechanical coupling between the hand and the handle, on the duration of vibration exposure and on user sensitivity to HAV [14, 15, 16].

The functional performance characteristics of brush cutter is a justification for its growing and continuous utilization in agricultural and horticultural operations. However, standardization has placed a demand on all manufacturers to design a perfect product, its dimensions adapted to each population group that the product is sold to. Despite the standards, there are deviations from ideal situations often experienced from the use of such products. Hence the need for such equipment calibration and ergonomic studies. This study is aimed at determining what impact the product has on human body as well as to develop a system that can lead to less fatigue for the end user and higher experience of comfort after using the equipment. The existing shoulder strap and handle designs have been reported to cause HAV-related stress and neuro-muscular disorders due to bearing loads in operational load in operators.

2. MATERIALS AND METHODS

2.1. Materials - Experimental machine and specification

The experimental brush cutter used in the experiment is a Serene garden brush cutter manufactured in China. The machine consists of a gasoline power unit, a drive shaft with housing through which power is transmitted, rotary cutting head at the opposite extremity of the pole to the power unit, a handle for control, safety cover, hanging band or strap for operator. The two stroke petrol engine consists of fuel tank, starter knob, choke lever and air cleaner. The blade rotates through a long drive shaft operated by petrol engine. Salient specifications of the brush cutter are presented in Table 1.

Table 1: Features of the experimental machine

Features	Specifications
Engine type	2 stroke petrol (48 CC Max. power)
Engine weight	3.5kg
RPM	6800
Drive shaft length	1500mm
Blade diameter	400 mm
Cutting width	255 mm
Fuel tank capacity	0.8 L
Net weight/Gross weight	7.7/9.2 kg
Cost	N75, 500.00
Handle	Two handlebars on either side of the shaft

The machine in operation is hung on the shoulder with leather straps and a plastic pad to prevent direct contact with the body and also to reduce the amount of heat generated by the two stroke engine from reaching the body. While in operation, the cutter head is swung within the radius of full arm swing in both directions to cut grasses.

2.2. Methodology

Method of data collection

Two techniques were employed to obtain scientific data used in this study: contextual interview and field interactions. Contextual interviews and field interactions were conducted to gather operator information and impacts of machine effects on users. The contextual interview includes a number of questions that are considered indicators of operator-machine-dependent performances and ergonomic factors, many of which are unique and targeted at the evaluation of the possibility of modifying the machine. Where it was possible to get access to all forms of responses and ask follow-up questions, direct field interactions were employed. 6 groups of participants were engaged in the interview and field studies to discover their high priority problems in machine utilization. A quantitative analysis was used to ascertain that issues discovered in the contextual interviews reflected a typical user experience. After performing the standard tasks, participants were asked to answer questions about the user experience, to reflect on the effects of weight on hand units, vibrations, noise, areas of comfort, discomfort and soreness in the hand, wrist joint, and arm. Findings from both interviews, and field interactions was later compiled to form the basis for modification. The general sample information required include type of machine, length of operation, field experiences, effects of machine operations on health and safety.

Sample technique and method of data analysis

Random sampling technique was used to select 6 operators used in the study. The collated data from contextual interview and field interactions was analyzed using simple descriptive charts and the results used in making recommendations for modification.

3. RESULTS AND DISCUSSION

The following outcome represented the views of the operators and recommendations made for the purposes of modifications to contribute to knowledge in research and development.

Contextual interview and field interaction

The purpose of the contextual interview and field interaction was to gather information on product brands and determine the user friendliness of the machine as a guide to modifying and as well as improve the machine-operator performance. Six brush cutters were tested; 3 (50%) serene garden brand, 2 (33.33%) are Yak brand, and 1 (16.67%) Boch brand. None of these equipment are above three years old, and at the rate of 2 hours of operation per days in use, the machine functional efficiency is sure to reduce with age.

Figure 1 shows that 92% of the operators used their equipment for estimated 2 hours of continuous operation per day, which is a long enough time to cause significant stress and noise injuries.

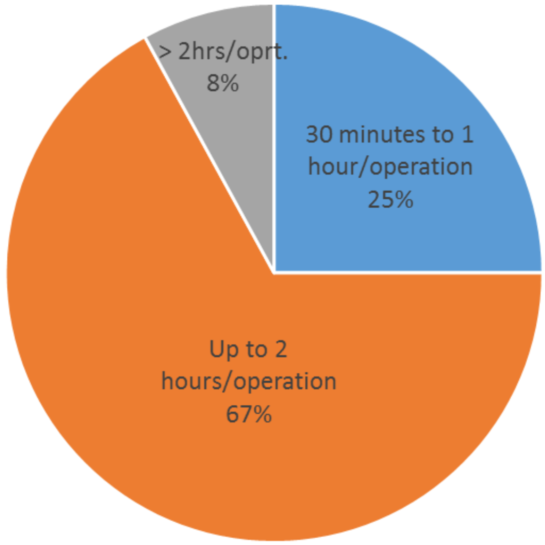

Figure 1: Time taken to operate the machine

Effect of vibration on operator

The study shows that 83.33 % of the operators experienced a mild vibration resulting from machine use, 50% experienced hand shaking during operation while other operators claimed no cognizant of it. However, investigating their body response to handling the machine for minimum 45 minutes, 67% of the operators reported numb sensation, nervousness and restlessness at the fingertips while 33% expresses slight shaking of the hand. This situation of continuous exposure to low vibrations for long time of use from the engine could result in repetitive stress injury.

Effect of noise on operator

There are reported cases of high level of exposure to noise (66.67%), due to the engine closeness to the body and the operators operating the machine without noise protective aids. The engine when snuggly suspended between 50-70cm behind the operator exposed them to high noise level that could lead to temporary hearing loss in most cases and permanent hearing loss in extreme cases.

Weight evaluation

The weight of the machine (6.8kg) constantly and snuggly hanged around the shoulder for considerable length of time constitutes a source of stress to the operator. From the weight distribution response, 83.33% of the operators agreed that the machine is moderate weight, 16.67% light weight, and in operation, 66.67% of the operators experienced pain around the neck while 33.33% reported they experienced pain around the shoulder.

Height of cut control

There are no height of cut adjuster in the brush cutter and as such, is not easily maintained except by as experienced or trained operator, which is a major disadvantage because most of the operators are not professionally competent to handle the machine.

Ergonomic observations

Drawing from the field observations from the experimental brush cutter, four distinctive control activities requiring simultaneous muscle movements are identified by the operator; directional movement, manipulation of the cutter blade as well as the height of cut control. Directional movement includes extension of the arm joints in continuous supination (outward) and pronation (inwards). This requires the swaying of the spinal and lumbar bones of the legs. The position of the machine in operation is such that the arms are constantly being contracted and extended due to the swinging of the machine to cut at extremities. This condition is attributed to reported cases of exertion and upper arm syndromes. These experiences are noticeable after days of constant operation.

Manipulation of the cutter head results from the rotation of the left wrist, elbow and shoulder joint. The wrist of the left hand is generally bent in palmar flexion. The ease of hand control of the equipment during operation is favorably high (83.33%) while the expression of difficulty on the control of the cutter head and height of cut simultaneously is unfavorably high (83.33%). The height of cut control is done by manipulation of the cutting plane by the wrist from ulnar to radial deviation. The index finger engagement in firing the clutch trigger in cutting is constantly engaged, subjecting it to stress due to constant engagement. Effect of machine on operator's posture reported no significant effects due to various adjustments that can be made.

Ergonomic studies on operators

The anthropometric parameters measured for six operators are shown in Table 2. The height of the operators is not linearly proportional to the width of swing and the weight of the operator. This indicates that the angle of swing is not a direct function of the operator's anthropometric parameters and consequently, this has no effect on the operator's or machine performances.

Table 2: Measured anthropometric parameters of the operators in mm

Operator height	Hand position above the ground	Width of swing
158	112	188
166	113	140
175	114	143
180	116	156
184	118	164
190	128	166

Machine modification results

From the contextual and field observations, it is obviously clear that the brush cutter poses some potential hazards and ergonomically unsafe for the operator with high level (66.67%) of non-acceptability. From the user studies and ergonomic evaluation, the following modifications were suggested:

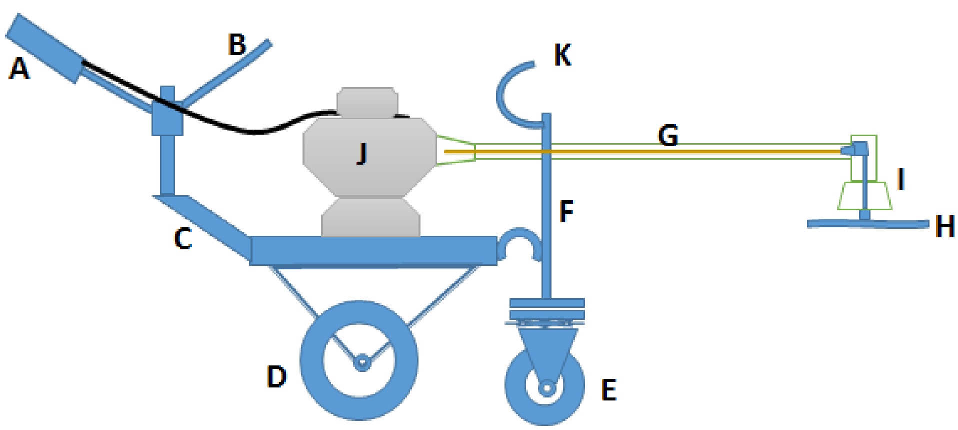

Figure 2: The schematic drawing of modified machine
A-Control lever, B-Adjustable handle, C-Carrier frame, D-Land wheel, E-Spinning roller, F-Screw shaft, G-Rod shaft assembly, H-Blade, I-Blade holder, J-Engine, K-Adjustable handle.

1. The shoulder strap for hanging that machine should be eliminated to relieve the operator of the weight hanging on the shoulder/neck.
2. The machine should be disengaged from the operator and moved away, ensuring a short distance between the center of mass and the operator to provide comfort for users and decrease the load on the wrist.

3.The handle position should be modified and made flexible to accommodate different height of operator. The height of cut control should be included. The handshake rule for optimal wrist position will be of advantage for the operational handle.
4.The existing machine was handheld, shoulder mounted. A carrier was developed with three rollers (2 directional rollers and 1 spinning roller) to mount the equipment.

The schematic drawing of the machine showing the component parts and mechanism is shown in Figure 2. The modified machine is shown in Figure 3.

The machine comprises of two major units: the machine and the carrier. The machine consists of a power unit, a control unit, the cutter head assembly and the guide. The carrier consists of two rear roller wheels and a 360° adjustable front roller assembly.

Figure 3: The modified experimental machine

The transmission shaft: The shaft length was adjusted from 1500mm to 300mm to accommodate the handle and handle frame.
The handle: The handle is the twin-arm type, with the shorter right handle being the operational hand, while the longer left handle, the steering handle. The position of the right handle is such that the torque load on wrist should not exceed tolerable limits of discomfort, therefore, it was made adjustable between 65 to 75 degrees angle in the forward direction to ensure adequate control of operation. The left handle was the steering handle adjusted lower, but convenient angle (15 to 25 degrees depending on the operator's height) for effective steering and propelling of the machine.
The steering handle frame: The frame supporting the handle is made of 1.8mm diameter pipe, 25mm long and 12mm high.
The carrier: the carrier is a 372mm by 82mm flat board made from hard wood fitly inserted into a rectangular iron frame constructed from ½ inch angle iron. The board is mounted on two wheels supported on a spindle with open end tread. The spindle is supported by two ball bearings. The wheel assembly is connected to the engine platform using two wheelbarrow supports.

Figure 4: Field tests (a) Shoulder mounted, (b) Modified machine

Height adjuster: The height of cut of the cutter head can be adjusted using the height adjuster. The adjuster comprises of a spinning roller capable of 360° turn, a full thread screw shaft 250mm length and 14mm diameter. The shaft is attached to the spinning wheel using a 70mm by 50mm 2mm thick plate.

Machine performance tests

The modified equipment was tested on the field with good performance and lot of stress relief from hanging the unit around the neck. The performance was compared with the shoulder strapped brush cutter to determine the level of acceptability. The Table 3 below shows the performance indicators and responses.

Table 3: Performance characteristics of existing and improved machines

Performance indicators	Existing machine	Modified machine	User acceptability	
			Existing machine	Modified machine
Steering ability	The operator stress the body to provide steering	The spinning roller provides effortless turning in operation	Strenuous	Easy
Height of cut control	The operator adjust the height of cut	The roller assembly attached to the frame provides height adjustment using a screw adjuster	Not easily controlled	Controllable
Aesthetics	Good	Better	Acceptable	Acceptable
Operational performance	Spent more time per unit operation	Less time required per operation	Good	Improved
Operability	Complex	Simple	Not user friendly	User friendly

From the table, comparing the use friendliness of the two machines, the modified machine has better performance and acceptability in terms of aesthetics, ergonomics and operateability.

Mowing quality

Samples of the grasses stalks cut were collected and the cut examined to know the level of acceptability of cut. Some sample of the leaf cut were selected as shown in Figure 5. Subjective mowing quality values was used to evaluate the machine based on the following [17, 18]:

1.Field quality with visual rating: (1 = poor; 9 = excellent), 6 considered acceptable.

2.Subjective mowing quality was assessed with visual rating: (1 = uneven cut edge of leaf; 9 = perfect cut edge of leaf); and

3.Leaf tip damage level (1 = excellent cut, no shredding at all; a greater value of leaf tip damage level indicates more leaf shredding).

Figure 5: Sample of neatly cut grass stalks mowed by machine and leaf damage level

The Table 4 shows the level of leave damage recorded from selected products cut from *Cida* acuta grasses on the field. A high leaf tip and stalk damage level corresponds to a lower subjective mowing quality while a low tip damage or smooth cut corresponds to a high quality mowing. However, leaf tip damage is totally independent from the person that does the assessment and gives more realistic information of the mowing machine performances. From the table, it is shown that the average level of leaf damage is 1.19 indicating excellent mowing quality.

Table 4: Percentage leaf damage level of plants

Leaf samples	LE	LI	% leaf damage
1	135.04	139.00	0.97
2	248.24	136.00	1.83
3	103.91	109.00	0.95
4	150.63	155.15	1.03
5	183.46	196.30	1.07
6	215.49	284.45	1.32
Average			**1.19**

4. CONCLUSION

An existing brush cutter machine has been ergonomically evaluated and modified based on observed shortcomings arising from the study. From the experiment, following conclusions are made.

1. The operators operate the equipment for a minimum of two hours per time. This is longer than the recommended length of operating time for brush cutters. The fatigues of long time working often caused frequent occupational injuries.
2. The operators experienced different levels of pains on the neck, shoulders, upper arm and fingers which are largely traceable to shoulder-strap-long-time operation, prolonged mild vibrations, arm supination-pronation-swings during operation, and exertion due to the prolong lifting of the weight of the machine.
3. Based on observed ergonomic conditions identified the following modifications are made to correct the defects; a carrier was developed to bear the machine, a height adjustment mechanism was introduced to regulate the height of cut, reduction of the transmission shaft length from 1500mm to 300mm to reduce the length of the equipment and adjustments in handle orientation to perform desired functions.

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Conflicts of Interest: The authors declare no conflict of interest.

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