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ASSESSMENT OF ERGONOMIC RISK IN DIFFERENT HAND TOOL DESIGNS IN NAPIER GRASS HARVESTING USING POSTURAL AND SURFACE ELECTROMYOGRAPHY SENSORS

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Abstract

This study focuses on the impact of different harvesting tool on musculoskeletal loads and work posture during Napier grass harvesting. Four harvesting hand tools are employed for this study and their muscle activities during Napier harvesting process is recorded using Surface Electromyography sensors (sEMG). This study examines the activation of three key muscle groups: the extensor carpi radialis, trapezius, and biceps brachii. RULA method is also employed to identify the postural risk during Napier grass harvesting while using each harvesting tool. Out of the three muscles being studied, the Extensor Carpi Radialis (ECR) muscle was the most active. When compared to traditional equipment, the ergonomic design of Model 1 produced a significantly lower ECR activation and lowest postural risk score, suggesting a superior ergonomic posture. As a result, Model 1's enhanced design presents a potential means of lowering the risk of MSDs, enhancing posture at work, and reducing muscular fatigue.

Keywords: Agricultural Workers; Harvesting Tools; Muscle Activity; Napier Grass; Work Posture

1. Introduction

Agriculture employs over half of the global workforce (1.3 billion workers). Despite the availability of many technology tools, manual harvesting has remained the most popular method in the agricultural sector since it is inexpensive and simple. Agriculture automation cannot be fully adopted since harvesting scenarios can frequently be untamed, outdoors, with uneven landscapes and varying crop heights and diameters. With these constraints and environmental factors, manual harvesting can be particularly challenging and necessitates a high level of adaptability [1]. Harvesters must monitor and modify their biomechanics, such as harvesting angle, pressure, and joint angles, to adapt to these environmental constraints and operate effectively. In the Poaceae family, Napier grass (Pennisetum purpureum), often known as elephant grass or Uganda grass, is one of the main perennial tropical forages. Despite its African origins, several tropical countries also farm it. The grass forms bamboo-like bunches and can reach a height of 12 feet. The majority of its uses are as feed crops [2]. The grass is often fed directly to cattle or turned into hay or silage. Because it can be harvested many times a year and generates a significant quantity of biomass, it is an appropriate source of nutrients for the manufacture of biofuel. Napier grass is planted on slopes and in marginal regions to reduce soil erosion and increase soil fertility [3]. It is the main resource used to produce paper in many places. Napier grass is frequently used as a pulling crop in integrated pest management tactics in areas that grow maize and sorghum [3, 4]. Agricultural work is inherently physically demanding and can have serious health consequences. According to Merino, et al. [5], musculoskeletal diseases (MSD) were the most common and severe conditions in agricultural production. This may have to do with the work environment, which involves a lot of awkward static postures when standing or sitting bending over for long periods, tilting the head and trunk forward, and stooping or lifting heavy objects, in addition to highly repetitive manual labor and vibration exposure [1, 6]. According to Dianat, et al. [7], musculoskeletal problems have a substantial negative cost impact on both individuals and society. The main implement used for harvesting is the sickle. When working with sickles, the upper limb is engaged. The force required to cut the stem causes the hands' muscles to get fatigued. In almost every nation, agricultural labor is regarded as one of the riskiest occupations due to the high frequency of accidents and deaths [8, 9].

Electromyography (EMG) signals are commonly used to assess muscle activity in certain muscles in order to investigate the biomechanics of manual harvesting operations [10]. To determine the muscles' rate of functioning capacity, electrical impulses collected from the muscles during an activity are utilized. By focusing on upper limb posture, the Rapid Upper Limb Assessment (RULA) is utilized to determine the rate of MSD risk and to pinpoint high-risk locations [11]. Risk can be represented by four distinct colors: green (score 1-2) denotes no risk, yellow (score 3-4) denotes mild hazard, orange (score 5-6) denotes considerable risk, and red (score 7+) denotes extreme risk. A modernized form of RULA is called Rapid Entire Body Assessment (REBA). The primary distinction in this case is that the entire body's position is taken into account when determining the danger [12, 13]. Despite the fact that hand harvesting accounts for a sizable portion of the agricultural industry as a whole, direct measurement-based research on the biomechanics and musculoskeletal diseases (MSDs) related to harvesting is lacking. However, research on tomato workers[14] used REBA to analyze the biomechanics of the workers, while research on coffee [15], banana

[5], and apple [16] harvesters used EMG to analyze worker productivity and workload. The primary distinction between the earlier and current studies is the inclusion of REBA and RULA tools, which produced far more precise and comprehensive results. The purpose of this study was to evaluate the possibility of muscular fatigue related to harvesting Napier grass in a field using a harvesting instrument. The creation of future ergonomic treatments targeted at lowering or eliminating dangers detected by substituting a new harvesting instrument would be made possible by this, as well as a deeper assessment of the risks associated with traditional tools. However, after analyzing tools made for various work postures, the most effective tools that reduced muscular tiredness was deemed the best.

2. Materials and Methods

2.1. Subjects

The study included ten male individuals who were 21 ± 2 years old, weighed an average of 70 ± 20 kg, were right-handed, and had no prior experience collecting Napier grass. The test subjects were all considered healthy since none of them reported having any musculoskeletal issues or injuries over the preceding 12 months. To investigate the differences in muscle activity across general users, subjects with no prior experience were selected. Each subject's exact anthropometric measures, including hand length (defined as the distance between the middle finger tip and the wrist end when the hand is held straight), were taken prior to the trial and are shown in Table 1.

Table 1 Anthropometric data of participants

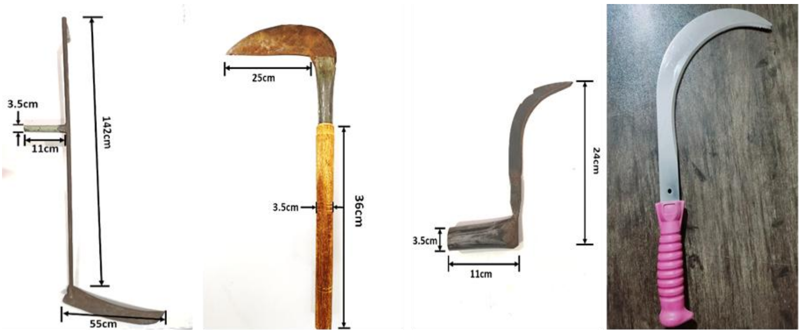
Parameters	**Mean**	**Range**
Age (years)	21.3	21-23
Height (cm)	172.4	170-175
Weight (kg)	62.5	55-80
Hand Length (mm)	168	166-170
Palm Length (mm)	181.3	179-184
Palm Width (mm)	88	85-91
Hand Thickness (mm)	17.8	15-21

2.2. Phases

The present experimental work has been divided into three phases. Phase1: Assessing the issue at hand instance, which includes labor and circumstances observations, interviews, and on-site study. Phase 2: On-site data collection: - information was acquired to determine the working conditions. Phase 3: Data analysis entailed organizing all of the collected data in a logical manner and analyzing it both qualitatively and quantitatively.

2.3. Tools design

Figure 1 illustrates the use of four distinct hand tools for grass harvesting, including one conventional model and three recently created versions. To provide a comprehensive approach to body involvement and risk assessment using these instruments, development attention was given to various labor postures during harvesting. Figure 1(a) displays Model 1, which is designed especially for standing harvesting. Its broad handle (142 cm) and curved cutting blade (55 cm) allow work to be done standing without bending. As seen in Figure 1(b), Model 2 is designed to be used in a bending posture. It is made for tight, forward-leaning harvesting tasks and features a shorter handle (36 cm) and curved blade (25 cm).



Model 1 Model 2 Model 3 Model 4

Figure 1 Comparison of Four Different Traditional Hand Tools with Measurements

Model 3, which is intended for sitting harvesting, is seen in Figure 1(c). With a handle length of 11 cm and an overall height of 24 cm, this model encourages a low working position that works the lower body. Another tool, the Model 4, is a conventional harvesting tool with a 24 cm height, a curved blade, and a comfortable handle for grip. These were carefully selected using the worker's anthropometric data as well as the specifications and dimensions of the tools [17] as presented in Table 2. These designs use several body components to maximize worker posture and accurately identify risk during harvesting.

Table 2 Characteristics of the tools

Design	**Weight (kg)**	**Length(mm)**	**Handle Material**
Model 1	1.5	1420	Steel
Model 2	0.7	360	Wood
Model 3	0.5	240	Steel
Model 4 (Traditional)	0.3	320	Plastic

2.4. Experimental setup

Data gathering was conducted in a Napier grass plantation in a nearby village, with one session having four trials for four tools for each subject. Expert advice of the traditional workers was considered and the subjects were provided with practice on harvesting for three days. Each trial will be of one minute with three minutes' gap to avoid tiredness and to improve result reliability. The plants selected were of same growth planted at a same period. As shown in Figure 2 the subjects perform harvesting with each tool for the given time of 1 minute until the grass is harvested.

Figure 2 Various postures for grass harvesting demonstration

The four postures utilized in grass harvesting and the actual use of various harvesting tools are depicted in Figure 2. Figure 2a shows a worker standing and plucking grass with Model 1. This position promotes upright body alignment and less bending strain. For jobs that require forward leaning, the worker in Figure 2b is using Model 2 in a hunched-over position. It gives you the chance to operate near the earth. In Figure 2c, the Model 3 is used in a squatting position. It burns the muscles in the upper body and lessens the strain on them. Figure 2d, for Model 4 displays the results of the traditional method of collecting grass, which used a hunched position quite similar to Figure 2b.

2.5. Muscle selection

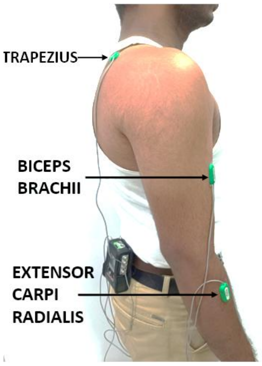


Figure 3 EMG Electrode Placement for Trapezius, Biceps, and Extensor Carpi Radialis

The primary investigation was undertaken to determine the muscles engaged in harvesting Napier grass. According to Stegeman and Hermens [10], the trapezius, biceps brachii, and extensor carpi radialis are the three muscles that contribute to the flexion and extension motions of the shoulder, arm, and forearm. Since the right hand is mostly used for this work, EMG sensors were positioned on the right side of the upper limb. Electrodes are positioned on critical muscles that are exposed during arm and shoulder movements to measure electromyography (EMG) recordings. EMG electrodes were placed on the three muscles to measure muscle activation during upper body-related tasks. Data was collected using an EMG device, which is usually worn around the waist for observing muscular tension and involvement throughout various postures or activities.

3. Results

The electromyography-monitored muscle activity during the task can be seen in Figure 4. The plot shows the amount of activation of various muscles as well as the variation in muscle activity over time and concerning various instruments. The difference in ECR muscle activity when utilizing four different kinds of instruments can be observed in Figure 4a. The pace of muscular exhaustion can be determined by the reduction in MPF; a sharp decrease in values indicate that the muscle was either overloaded or tends to get fatigued faster [18]. This serves as a gauge for the pace of muscle contraction over time. When utilizing Model 1, the rate of declination decreases from 45 Hz to 36 Hz, as shown in this plot. In a similar vein, the MPF drops from 85 Hz to 66 Hz when using Models 2 and 4, and from 70 Hz to 50 Hz when using Model 3. This suggests that utilizing Model 1 tends to reduce muscular fatigue.

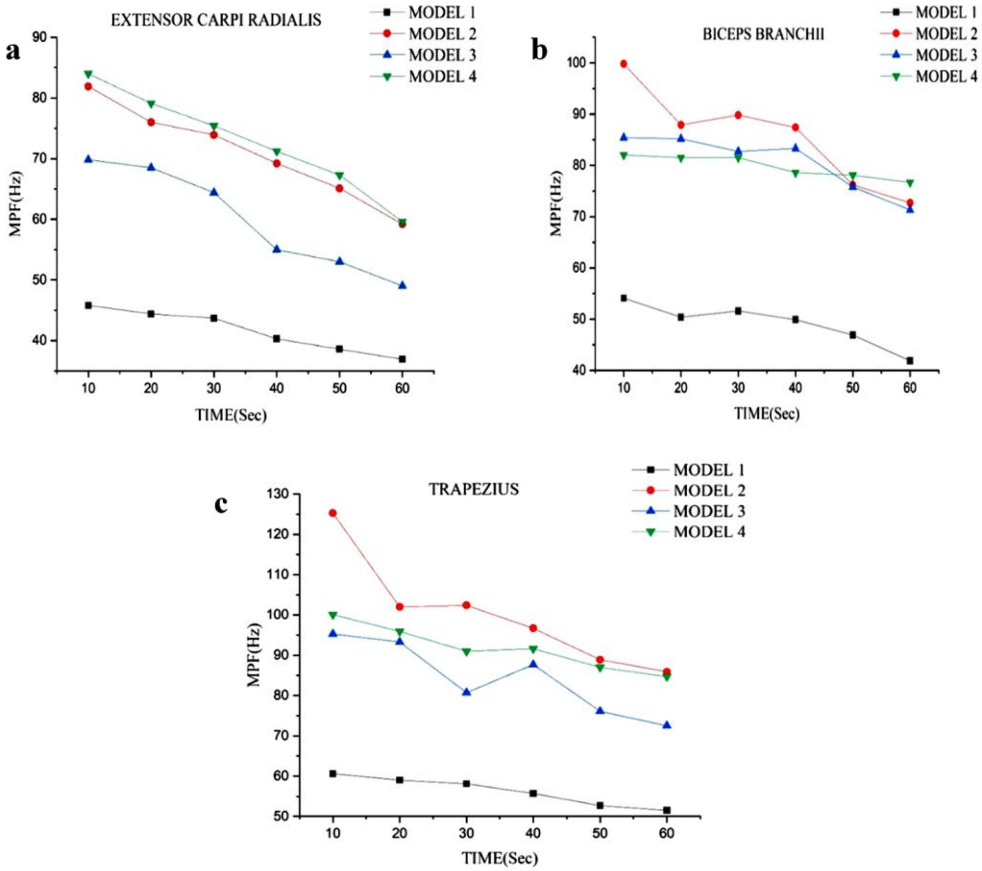


Figure 4 MPF vs TIME (a) Extensor carpi radialis (b) Biceps brachii (c) Trapezius

The Biceps Brachii muscle variation while utilizing various instruments was seen in Figure 4b. Here, the Model 4 fluctuates between 78 Hz and 84 Hz, causing the least amount of muscular stress. The Model 3, which has a frequency range of 95 to 85 Hz. Then, Model 3 has a frequency range of 55 to 40 Hz. The Model 2 showed a sharp drop, going from 100 Hz to 76 Hz. The fluctuation in electrical activity of the Trapezius muscle was seen in Figure. 4c. Here too, the Model 1 varies between 60 and 52 Hz, causing the least amount of weariness. The Model 2 has a significant variation, ranging from 125 to 90 Hz. All of the muscles had significant levels of activity during the work, and as time passes, the amount of oxygen that the muscles need declines.

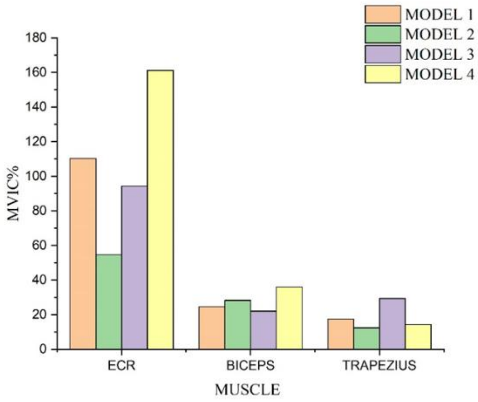


Figure 5 MVIC % for muscles

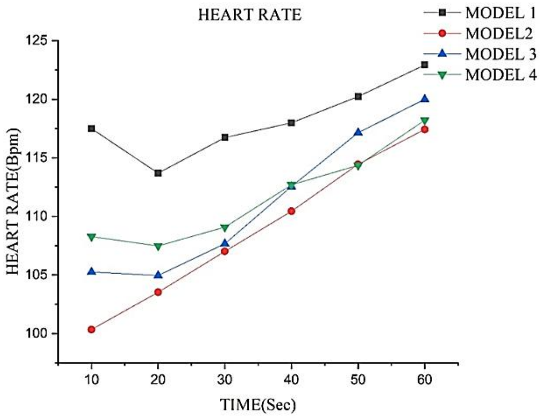


Figure 6 Heart Rate (Bpm) vs TIME (sec) for different tools

The maximum voluntary isometric contraction (MVIC)of the muscles used in this investigation is shown in Figure 5. It is evident that when utilizing the conventional Model 4, the ECR muscle was used at its highest rate. The Model 4 also activates the biceps more than any other instrument. However, when utilizing the Model 3, the trapezius was mostly engaged, with the muscle's activity during the work and its maximal contraction level. Figure 6 shows a heart rate with respect to time recorded using different tools. An increase in heart rate is a sign that the muscles require more oxygen [19]. Model 2 has a dramatic increase in heart rate from 100 to 118 bpm. Model 1 had the least amount of variability, ranging from 118 to 124 Bpm. It's important to remember that the beginning beats do not always indicate muscular tiredness; rather, the difference between the initial and final beats indicates the oxygen demand. Additionally, an RULA evaluation was conducted to determine the optimal harvesting equipment. Python code taken from GITHUB for biomechanics utilizing visual code was used for the assessment. The algorithm produces output for RULA after 480P video recordings of the subject's posture were uploaded. To determine the outcomes, the scores were put into an RULA sheet. RULA scores for the four tools. RULA assigns comments based on four sorts of outcomes (no risk, low risk, medium risk, and high risk)[19]. A score of three for Model 1 denotes little danger but need research. With a score of 5, Model 2 is considered medium risk and should be replaced as soon as possible. The scores for Models 3 and 4 were 5, indicating medium danger and the need to switch tools as soon as possible, which cannot be advised.

4. Discussions

The study intends to assess into how harvesting tools affect heart rate, musculoskeletal disorders, bad posture at work, and muscular fatigue. The difference in muscle activity during hand harvesting with different implements is determined by work posture and the quantity of labor load caused. The newly created model 1 exhibits less muscular fatigue than any other design employed, according to the MPF graph data previously indicated. Over time, muscular exhaustion appears by the drop in the MPF[18]. The primary distinction between the Model 1 and other tools is that it is made to be used with both hands. In contrast, models 2, 3, and 4 need the use of a single hand. Model 1 has the primary benefit over the others in that the workload is split equally between the two upper limbs [20]. In contrast to previous models that incorporate stooping, model 1 also has a work posture that consists only of standing. According to [21], the Model 1's handle was designed to decrease wrist acceleration by horizontally using the wrist. This suggests that the amount of strain placed on the spine will be significantly lessened. Because harvesting by hand is a repetitive operation that is done regularly, bad posture can result in MSDs. This finding suggests that an ergonomically constructed instrument avoids MSD and lessens muscular fatigue. The ECR was somewhat more muscularly active than the biceps and trapezius (Figure. 5). When utilizing any tool when the forearm is not supported, the trapezius muscle gets tired [22]. Kuthe, et al. [18] suggested that a handle with a larger palm contact area may considerably lessen the activity of the Biceps Brachii muscles. The ECR muscle has a relatively high percentage MVIC in comparison to other muscles. In many cases, manual harvesting tasks involve holding, lifting, and moving tools to cut through plants. The wrist must be flexed backward in repeating wrist extension motions in order to control the instruments and deliver power effectively. The ECR muscle is crucial for stabilizing and regulating wrist extension motions because it is the primary muscle responsible for this function. Compared to the Biceps Brachii muscles, which are employed for elbow flexion, the wrist muscles are more strongly activated during gripping activities [18]. A larger contact area for gripping handles basically improves comfort through constant load distribution, which lowers wrist muscle activity since the gripping duty engages the Biceps Brachii.

The main intention of this research work is to enhance the farmers' work posture. The traditional tool was utilized when bending or crouching. Long-term maintenance of this position will cause chronic muscular fatigue, which can lead to sprains and tension in the spinal area (Dianat et al., 2020). Because RULA results also showed that conventional tool Model 4 got a score of 5. The score suggests that the tool should be changed soon. According to Kee [12], the RULA score is higher when the bending and shoulder inclination are high. The identical situation is present in Models 2, and 3. Given that the instrument may be used while standing, the shoulder and bending angles are both very small, as indicated by the score of 3. This suggests that, in comparison to the current tools, the ergonomically designed tool's work position is safer. The individuals' heart rates were also tracked in order to provide further clarity, and the data were displayed in Figure 6. There is a clear correlation between heart rate and muscle activity. Oxygen is essential for muscles to function. According to Dewi and Komatsuzaki [19], the oxygen requirement for muscles rises in tandem with an increase in muscle activity and heart rate. The fact that the activity was carried out in an open field contributed to the results' high initial heart rate. Figure 5 makes it evident that, in comparison to other tools, the heart rate increases at a significantly slower pace while utilizing Model 1. This is because the swing power needed to handle Model 1 makes cutting the lawn simple. In addition, the blade area is rather large in relation to other instruments. Consequently, Model 1's heart rate and muscular activity are both quite modest.

5. **Conclusions**

Harvesters were found to have MSDs as a result of their extreme work posture and inappropriate tool use. Using EMG data, it was also possible to identify repetitive tasks performed during harvesting that resulted in muscle fatigue. In this work, three new instruments were designed and manufactured using farmer anthropometric data and ergonomic circumstances. Farmers assessment indicators including heart rate, RULA scores, and muscular activity were used to evaluate these instruments in a variety of ways. The modified tools' outcomes were contrasted with those of the original tool. Three muscles such as ECR, Biceps Brachii, and Trapezius muscles were selected to be examined. It was evident from the evaluation findings that, in comparison to the other three tools, Model 1 significantly increased the subjects' performance and efficiency. Additionally, the long-term usage of the traditional instrument results in comparatively lower performance and efficiency. However, this study only looked at three muscles in the right upper body. On the other hand, a larger sample size might reveal new patterns of harvesters' muscular synergy.

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