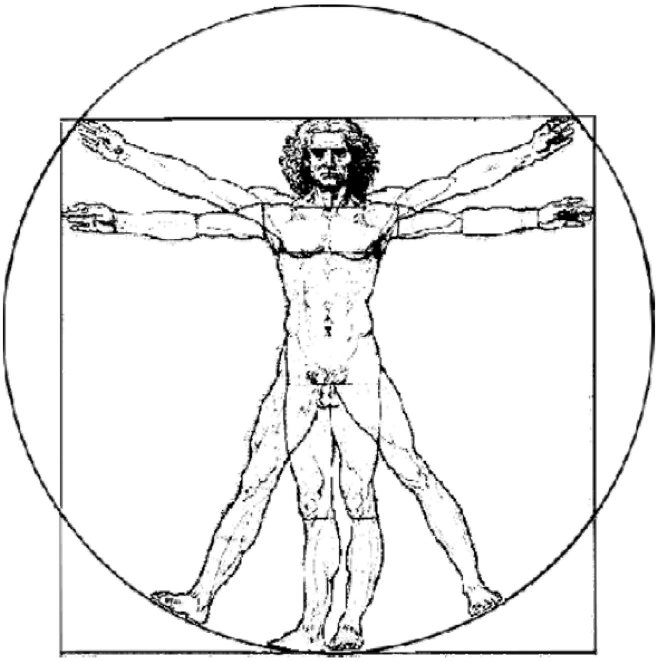
DEPARTMENT OF
HUMAN KINETICS AND ERGONOMICS



Ergonomic Survey

Ennepetaler Schneid - und Mähtechnik

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Content

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1 Objective

The main objective of the investigation was to investigate the new *CaneThumper® METHOD* of cutting sugar cane in the Oribi and Harding regions of Kwazulul Natal. A further objective was to compare the responses to a previous project which investigated the manual method of cutting sugar cane.

2 Task description

The nature of the task was to have a 'team' of workers consisting of a driver and 5-8 sorters, with the goal of cutting and sorting sugar cane. The driver was responsible for manoeuvring the *CaneThumper®* to cut the sugar cane at the base (Figure 1). Evident in Figure 1 is that the sorters were required to manually bundle sugar cane and pull it toward them (to prevent contact with the blade of the *CaneThumper®)* so that bundles of sugar cane could then be cut by the driver and placed on the adjacent ground by the sorter. The workers then kept rotating as the driver moved forward on each line.

Figure 1: The driver and sorter while harvesting cane with the *CaneThumper®*.

Two areas were investigated – the one area required that the team work-to-task while the other area was not based on task performance, but rather the team was remunerated for the amount of work completed. With the first area, the team was required to cut 73 tons of cane. With the second area the team cut 64 tons of cane. The workers had a set rest period of 30 minutes for breakfast from 8.00 am to 8.30 am and 30 minutes for lunch from 1.00 pm to 1.30 pm. Although work patterns were generally governed by the driver of the *CaneThumper®*, work intensity was affected by potential 'hold ups' experienced when equipment malfunctioned. This was the case at the second area, as the workers were required to stop twice for the equipment to be repaired.

Four workers were assessed each day (one driver and three sorters) in each of the regions. In the first area all the workers were male while in the second area only the driver was male and the other workers were female.

3 Occupational risk factors

Although a mechanical device is used to cut the sugar cane, the main tasks being performed are manual and repetitive in nature – this is particularly noteworthy with the sorters. The tasks are dependent on the speed of the work process. In light of this, three main occupational risk factors have to be taken into consideration:

<u>Musculoskeletal disorders:</u>

This refers to the potential overload of muscles and joints due to awkward body postures and/or high exerted forces or repetitive movements as was observed in this investigation. In order to exert forces and to stabilise body posture, very high internal forces may be required which in turn increase the risk of muscle fatigue, muscle ruptures and damage to the spine in the lumbar region (particularly rupturing of the inter-vertebral disks). The latter factor is particularly important, because overloading of the inter-vertebral discs may not be felt by the individual (in contrast to muscular and cardiovascular fatigue). Furthermore damage to the spinal column has long term effects that are not reversible. Risk of injuries depends on a number of factors including body posture, load, distance from torso, as well as duration and frequency of operation.

<u>Cardiovascular strain:</u>

The cardiovascular system may be over strained if the total metabolic activity associated with the task exceeds the cardiovascular capacity of the worker. Risk of exhaustion depends on total energy cost associated with the overall job of the worker and is affected by individual factors such as the physical capacity of the worker as well as health and nutritional status, to name a few. The environment can also impact on cardiovascular strain.

<u>Thermoregulatory strain:</u>

Manual work combined with warm environmental conditions and/or personal protective equipment increases the strain placed on the worker. Work performed in hotter and/or more humid environments, increases the physical demands of the work which negatively impacts on the performance of the worker, which is of concern in this investigation.

4 Evaluation

4.1 Worker characteristics

Eight workers (5 males and 3 females) were assessed over a period of two days. The characteristics of the workers tested are shown in Table 1.

Table 1: Basic mean anthropometric and demographic characteristics of the eight workers assessed.

	Male workers (n=5)	**Female workers (n=3)**
Age (yrs)	28	36
Stature (mm)	1680	1600
Mass (kg)	64.80	64.33
BMI ($kg.m^2$)	23.06	25.17
Sum of skinfolds (mm)	65.30	121.90
Body fat (%)	8.99	24.29
Waist to hip ratio	0.92	0.78
Blood pressure (mmHg)	144/83	144/92

BMI refers to Body Mass Index (mass/stature^2)

The BMI values for the male and female workers can be classified as normal and slightly overweight, respectively. Both male and female workers are within the normal range for body fat percentages. A 'normal' resting blood pressure is 120/80 mmHg. Both male and female participants have an elevated blood pressure, however, this may be attributed to anxiety and the recent physical activity that they were engaged in prior to testing.

4.2 General environment

The harvesting of sugar cane is performed outdoors and therefore environmental factors play an important role. Ambient temperatures were close to 30 degrees centigrade even at the completion of the work shift. Shade is also sparse as no trees were present and the cane being cut did not provide any shade. Therefore, workers were exposed to high temperatures throughout the work shift and were only able to find shade during rest periods. The environment was also dusty as little rain had fallen. Smoke and soot were also present in the air due to the burning of cane which sometimes occurs relatively close to where workers are cutting cane. Noise and vibration were also produced by the *CaneThumper®* which mostly affected workers in close proximity to the machine. The driver of the *CaneThumper®* also experienced vibration in the hands and arms throughout the work shift. The cane was harvested on an uneven terrain which at times was also on a slope. Harvested cane was occasionally placed in areas where workers needed to walk in order to complete the work cycle which added to the effects of the uneven walking surface.

4.3 Spinal Kinematics

Spinal kinematics of both tasks was assessed using the lumbar motion monitor (LMM) which is an exoskeleton attached to the subjects back (Figure 2). The data reported highlight the risk areas of the tasks in terms of load placed on the spine.

Figure 2: Tester fitted with the Lumbar Motion Monitor in order to assess spinal kinematics of the sorting task.

Velocity

From Table 2 it can be seen that the velocity of movement is a greater concern for the sorter when compared to the driver. For the sorter, high risk velocities were found in the mean velocity in the sagittal and twisting planes. Peak velocity in the twisting plane was also found to be in the high risk category. Mean lateral and peak sagittal velocity were found to be a medium risk. The twisting plane is of greatest concern for the sorter and driver as both mean and peak velocities were classified as having a high risk of injury. Comparing this data to those of Christie *et al.* (unpublished) which investigated manual sugar cane cutters, it is evident that there has been a substantial reduction in the demands placed on the lower back. For example, average lateral velocity for the driver has reduced from a mean of 18.00, during manual cutting, to a mean of 6.63 degrees per second with the new *CaneThumper® METHOD* of cutting cane. Mean saggital velocity has also reduced from 11.0 to 6.7 degrees per second.

Table 2: High, medium and low risk accelerations for a driver and sorter

	SORTER			**DRIVER**		
PLANE	VELOCITY		ACCELERATION	VELOCITY		ACCELERATION
	Mean	Peak	Peak	Mean	Peak	Peak
Lateral	9.87	36.59	303.01	6.63	32.59	219.29
Sagittal	12.21	45.48	342.72	6.7	33.75	203.42
Twisting	23.22	81.79	547.97	18.02	65.66	389.72

-------- High risk ------- Medium risk ------- Low risk

Accelerations

For the sorter, accelerations in all planes can be classified as being high risk. This may be due to the pace of work which may cause high accelerations for the sorters. With regard to the driver, acceleration in the twisting plane could be classified as being high risk. This may have been due to shifting the machine into appropriate positions for harvesting.

Table 3: High, medium and low risk displacements for the driver and sorter.

	SORTER	**DRIVER**
Maximum left bend	-0.09	-7.35
Maximum right bend	11.34	8.5
Maximum lateral range	11.43	15.84
Maximum flexion	23.66	28.59
Maximum extension	7	2.45
Maximum sagittal range	16.65	26.15
Maximum left twist	-32.92	-11.92
Maximum right twist	46.15	22.35

-------- High risk ------- Medium risk ------- Low risk

From Table 3 it can be seen that maximum flexion and maximum right twist for both the driver and sorter were considered as high risk. All of the other variables can be considered to be of low risk.

4.4 Cardiovascular responses

The eight workers were fitted with a Polar ® heart rate monitor, which recorded the heart rates of the workers every minute for the duration of the shift. The use of heart rate monitors is extensive throughout ergonomics research and practice and is accepted as a means of inferring the level of physiological strain being experienced. Manual work contributes to an increase in heart rate while the thermal strain experienced by workers further increases heart rate responses. It is has been suggested that over an 8 hour shift, an average heart rate of 110 bt.min^{-1} should not be exceeded.

In this section manual cutting will be compared to mechanical cutting and sorting. The responses to topping, which is a task performed by one worker, is also included from the previous investigation for comparison. All manual data is sourced from Christie *et al.* (unpublished). The *CaneThumper® METHOD* of cutting cane shows a mean heart rate of 108 bt.min^{-1} and 110 bt.min^{-1} for the driver and sorters respectively. This is compared to 122 bt.min^{-1} (Table 4) which was the mean working heart rate when cutting cane manually. During topping, mean heart rate responses were 117 bt.min^{-1}. Therefore, whereas the manual cutters and toppers average heart rate exceeds the recommended limit of 110 bt.min^{-1} for an 8-hour shift, those of the workers using the new *CaneThumper® METHOD* are within the recommended ergonomics limits for heart rate.

Table 4: Mean heart rate responses (bt.min^{-1}) comparing the manual method of cutting cane and the *CaneThumper® METHOD*.

	MANUAL		***CaneThumper®***	
	CUTTING	**TOPPING**	**DRIVER**	**SORTERS**
Day one			105.3	107.9
Day two			111.9	112.57
Mean	**122 (15)**	**117 (14)**	**108.61 (5.92)**	**110.24**

Shaded areas = data not obtained on two days therefore only mean data relevant

4.5 Energy expenditure responses

The eight workers were required to perform a step test after the completion of their work shift whilst wearing a portable K4b^2 which weighs 0.8 kg and is attached to the workers back (Figure 3). The worker is required to wear a face mask for the analysis of the breathing data - specifically oxygen consumption and carbon dioxide production. Energy expenditure for the duration of the work shift can then be inferred from these measurements, and the working heart rate responses, using a calculated regression equation based on each worker's individualised heart rate-oxygen uptake relationship. Energy expenditure is key in assessing the physical demands of any given task. It is has been suggested that over an 8 hour shift, energy expenditure should not exceed 20.98kJ.min^{-1}.

Figure 3: Subject performing the step test post work shift in order to determine energy expenditure.

Table 5: Energy expenditure (kJ.min^{-1}) responses comparing the manual method of cutting sugar cane and the new *CaneThumper® METHOD*.

	ENERGY EXPENDITURE (kJ.min^{-1})			
	MANUAL		***CaneThumper®***	
	CUTTING	**TOPPING**	**DRIVER**	**SORTERS**
Day one			22.29	21.45
Day two			14.50	20.66
Mean	**26.83**	**25.59**	**18.37**	**21.05**

Shaded areas = data not obtained on two days therefore only mean data relevant

As can be seen in Table 5 manual cutting and topping (mean energy cost of 26.83 kJ.min^{-1} and 25.59 kJ.min^{-1} respectively) exceeds the recommended energy expenditure

(20.98kJ.min^{-1}) for an 8-h shift. Even though they worked for less than 5 hours in the investigation which looked at manual cutting and topping, the accumulation of this excessive demand will be extremely large if they worked for an 8 hour shift. Mechanical cutting does not surpass this recommended limit (18.37 kJ.min^{-1} and 21.05 kJ.min^{-1} for the driver and sorters respectively) and therefore does not pose any immediate threat to the workers. With respect to the energy expended per shift (Table 6), the mean cost of the team of workers (driver and sorters) was 8806 kJ.shift^{-1} which was 27% less than the manual method of cutting which is performed by one worker. Topping requires less energy with a mean energy expenditure of 5470 kJ.shift^{-1}.

Table 6: Energy expenditure (kJ.shift^{-1}) responses comparing the manual method of cutting sugar cane and the new *CaneThumper® METHOD*.

	ENERGY EXPENDITURE (kJ.shift^{-1})			
	MANUAL		***CaneThumper®***	
	CUTTING	**TOPPING**	**DRIVER**	**SORTERS**
Day one			9336.39	9009.89
Day two			6961.6	9916.20
Mean	**12071.25**	**5740.00**	**8149**	**9463.05**

Shaded areas = data not obtained on two days therefore only mean data relevant

Table 7: Energy expenditure (kJ.ton^{-1}) responses comparing the manual method of cutting sugar cane and the new *CaneThumper® METHOD*.

	ENERGY EXPENDITURE (kJ.ton^{-1})			
	MANUAL		***CaneThumper®***	
	CUTTING	**TOPPING**	**DRIVER**	**SORTERS**
Day one			767.34	740.52
Day two			870.24	1239.52
Mean	**1157**	**406**	**818.79**	**990.02**

Shaded areas = data not obtained on two days therefore only mean data relevant

Manual cutters expend 1157kJ in order to get one ton of sugar cane off the land, while mechanical operators only expend 904.01 kJ (mean of 818.79 kJ.ton^{-1} and 990.02 kJ.ton^{-1}

expended by the driver and sorters respectively) in order to remove the same amount of cane. Therefore the energy cost per worker per ton, is reduced by 22%. Although the toppers expend only 385 $kJ.ton^{-1}$, it must be noted that this is for only one worker.

4.6 Changes in body mass and hydration levels

As seen in Table 8, the first team was found to lose a mean of 1.5 kg over the work shift. This team was observed to work consistently throughout the work day, with only the allocated work breaks. This loss in body mass could be attributed to the combination of high levels of physical exertion and the high temperatures. Furthermore, the workers did not consume any food or liquid during the work shift, other than during the allocated breaks. It was observed that the second team gained a mean of 2.25 kg in body mass which is unusual. However, this could be due to the fact that the workers not only took the allocated breaks, but also rested during the times that the equipment malfunctioned. Therefore, these workers sat in the shade, and consumed enough food and water that their body mass did not decrease despite the heat, and the physical exertion.

Table 8: Mean changes in body mass, and resulting dehydration during the work shift comparing the manual method of cutting sugar cane to that of the *CaneThumper®* (only including the first team's values).

MANUAL CUTTING		***CaneThumper®***	
Pre-body mass (kg)	63.69	Pre-body mass (kg)	64.5
Post-body mass (kg	61.77	Post-body mass (kg	63
Mean loss (kg)	1.92	Mean loss (kg)	1.5
Mean loss/dehydration (%)	3.01	Mean loss/dehydration (%)	2.33

These losses in body mass are due to an increased sweat loss which is not matched by fluid replaced.

Levels of dehydration (% body mass) were calculated as follows:

Dehydration = post activity body mass (kg) / pre exercise body mass (kg) x 100

As seen in Table 8, the mean loss in body mass, and resulting dehydration was much less for the mechanical cutting workers, than for the manual cutting workers. This is an important finding, as loss of body mass and high levels of dehydration will be detrimental to workers' health and well-being. The workers which use the *CaneThumper®* are less at risk of developing dehydration which has both physical and cognitive performance effects.

5 Perceptual responses

As well as assessing the spinal kinematics and physiological strain experienced by the workers, ratings of perceived effort and body discomfort were also assessed periodically during the work shift (Tables 9 and 10). Although there were language barriers, the scales had been translated to Zulu (refer to Appendix I) and when necessary, an interpreter was used. Ratings of perceived exertion and body discomfort were taken at approximately half hour intervals and at the end of the work shift.

Table 9: Mean central ratings of perceived exertion of the workers.

	DRIVER	**SORTERS**
Day one	13	12
Day two	12	10
Mean	**12.5**	**11**

The mean RPE for the drivers and sorters on both days can be classified as being 'light'. This indicates that workers did not perceive excessive strain due to the work they were required to perform. It should, however, be noted that workers may not have wanted to express how hard the work was due to the workers not fully understanding the purpose of testing and also not wanting to appear to be "weak" by co-workers as well as experimenters and employers. The concept of RPE may also not have been fully understood which may have lead to inaccurate ratings.

Table 10: Areas of body discomfort noted by the workers due to the demands of the tasks.

	DRIVERS	**SORTERS**
Day one	Upper back, right and left shoulder	Latissimus dorsi, right and left shoulder
Day two	Right and left hand, upper back	Right and left bicep, shoulders, wrists

Only mild body discomfort was expressed on both days of the investigation. The workers are, however work hardened and therefore used to the repetitive strains placed on them during a work day. The workers may also not have fully understood the concept of body discomfort and how to accurately rate the discomfort experienced. Therefore these results may not accurately reflect true levels of discomfort. The most discomfort experienced by the drivers was the hands and arms as well as the upper back. The discomfort of the sorters was mostly to the upper and lower back region, the arms, shoulders and wrists.

5 Conclusions

Overall it is evident that the new *CaneThumper® METHOD* of cutting cane is superior to manual sugar cane cutting – this was biomechanically, physiologically and perceptually. Likewise, even though not directly operating the machinery themselves, the sorters experienced substantially less biomechanical, physiological and perceptual strain than the manual stacking of sugar cane.

6 Recommendations

Following the assessment carried out, the following recommendation should be considered:

- In order to make conclusive statements about the new *CaneThumper® METHOD* of cutting sugar cane, a more detailed ergonomics assessment should be conducted on a **larger sample** of workers and over several work shifts.

Other recommendations would be to:

- Provide regular, cool water and EDUCATE workers about the importance of regular fluid intake.
- Train more workers with the *CaneThumper®* so as to encourage task rotation

APPENDIX:

RATING OF PERCEIVED EXERTION

(ISIKALI ESITSHENGISA UKUTHI USEBENZA KANGAKANANI)

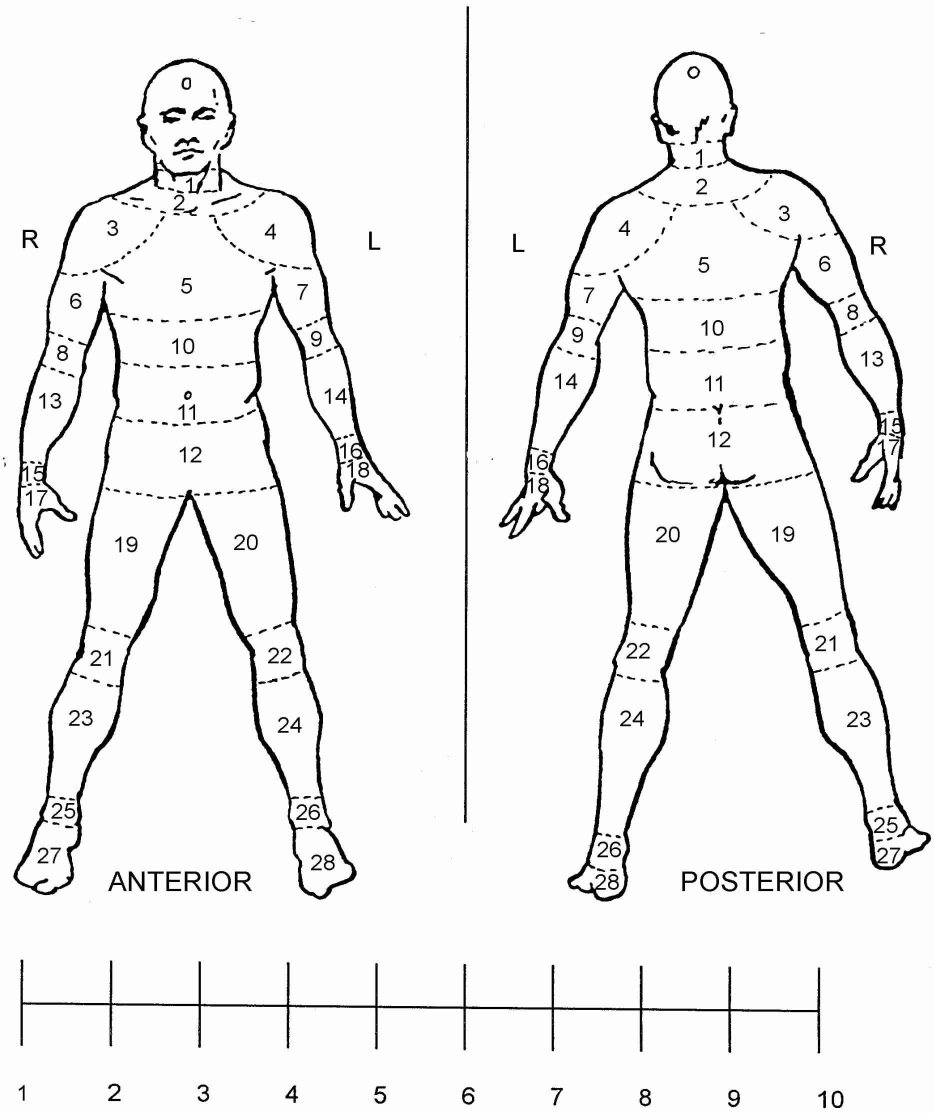
NUMERICAL	VERBAL
6	
7	KULULA KAKHULU
8	
9	KULULA
10	
11	KULULA KANCANE / KULULANA
12	
13	KUNZIMA KANCANE / KULIKHUNYANA
14	
15	KUNZIMA / KULIKHUNI
16	
17	KUNZIMA KAKHULU / KULIKHUNI KAKHULU
18	
19	KUNZIMA NGOKUSEZIGENI ELIPHEZULU / KULIKHUNI NGOKUSEZINGENI ELIPHAKEME

EXPLANATION OF RPE IN ZULU

Ngalesikhathi usebenza kufuneka ukuthi ucabange ukuthi uzizwa ukuthi usebenza kanzima kangakanani: ngolusemandleni akho ucabanga ukuthi usebenza kangakanani. Kuzodingeka ukuthi ukhombe inamba lapha esikalini, ngalenamba uzobe uchaza ukuthi uzizwa kanjani. Okokuqala uzobe uchaza ukuthi inhliziyo yakho namaphaphu akho asebenza kangakanani, lena ibizwa ngokuthi I "Central RPE" okwesibili uzobe ubuzwa ukuthi amamasela(njengemilenze, izingalo noma iqolo) akho asebenza kangakanani. Lena ibizwa ngokuthi I "Local RPE". Izimpendulo zakho zizobe zisitshela izinga osebenza ngalo, lokhu kuchaza ukuthi zizobe zehlukile kunezabanye abantu osebenza nabo.

Kubalulekile ukuthi uphendule ngokuseqinisweni, ungasho ngaphansi noma ngaphezulu kwezinga okuyilona osebenza ngalo. Kuzodingeka ukuthi njalo emuva kwemizuzu elushumi nanhlanu usinike lezizimpendulo kuze kuphele isikhathi sakho sokusebenza. Uma impendulo yakho ingu (6), kuchaza ukuthi uzobe uzizwa ngalendlela ozizwa ngayo njengamanje uhlezi ungenzi lutho. Impendulo engu (20), ichaza ukuthi usebenza kanzima kangangokuthi awusakwazi ukuqhubeka, sekufanele ume.

BODY DISCOMFORT MAP AND RATING SCALE



Minimum Intensity Maximum Intensity

(Adapted from: Corlett EN and Bishop RP (1976). A technique for assessing postural discomfort. **Ergonomics,** 19 (2): 175-182).

EXPLANATION OF BODY DISCOMFORT IN ZULU

Njalo emuva kwehora kuzodingeka ukuthi ukhombe indawo lapho lapho uzizwe uhlukumezeka khona emzimbeni wakho ngalesikhathi usebenza ngalelohora. Kunephepha elinezitho zomzimba ezihlukile lapho ungakhomba khona ukuthi ubuhlukumezeke kuphi. Lezitho zinikezwe izinombolo kusukela ku 0 kuya ku 27. uma usuzikhombile izitho zomzimba ozwe ubuhlungu noma ukuhlukumezeka kuzo kuzodingeka ukuthi ukhombe ukuthi ubuhlukumuzeke kangakanani kulezozitho. Isikali esisho ukuthi ubuhlukumezeke kangakanani si gcina ku 10. uma uthi 1 uchaza ukuthi ukhululekile ungaqhubeka usebenze kanje isikhathi eside. Uma uthi 10 uchaza ukuthi kubuhlungu kakhulu. Kubalulekile futhi ukuthi uphendule indlela ozizwa ngayo. Ungakali ngaphansi noma ngaphezulu kwezinga lobuhlungu obuzwayo.