Ergonomics SA, 2008, 20 (2)
ISSN Number : 1010-2728

A preliminary investigation of spinal kinematics during sugar cane harvesting

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Abstract

The sugar cane industry forms a significant portion of the South African economy, and unlike many other countries the harvesting of sugar cane in South Africa remains manual in nature. The focus of the present study was therefore on the assessment of spinal kinematics (range of motion, velocities and accelerations in all three cardinal planes) during the harvesting process. Eight workers were recruited from the Illovo Esperanza farm in Kwa-zulu Natal as subjects for the study. The experimental protocol was conducted in situ and required subjects to cut the sugar cane using specially modified knives as they would under normal harvesting conditions. The motion performance was quantified using the lumbar motion monitor (LMM), a triaxial electrogoniometer.

Results indicate that the harvesting of sugar cane places excessive demands on the spine. During cutting, subjects were required to maintain the spine in a high degree of flexion throughout the task which also demonstrated significant twisting and lateral bending. Of particular concern were the high lateral velocities (ranging between 50 and 90 $m.s^{-1}$), as this is a key risk factor in the development of lower back pain. It is evident from these results that new techniques of harvesting sugar cane are essential to reduce the rate of injury within this industry.

Keywords: Sugarcane harvesting, lower back, spinal kinematics.

1 Introduction

The sugar cane industry in South Africa plays an important economic role, with an annual direct income generation of R 6 billion (R 2 billion for the country's foreign exchange earnings). This translates into the employment of approximately 85 000 people, with an estimated one million people being dependant on the sugar industry (South African Sugar Association, 2007). On average approximately 22 million tonnes of sugarcane are harvested in South Africa each year (this makes South Africa the 12th largest producer of sugarcane in the world). Internationally sugar cane is usually harvested using mechanical devices, however in South Africa, partly due to financial reasons but primarily due to the terrain (the slope) that the cane is grown on a significant proportion of these yields are harvested manually. Although no injury statistics are available in the public domain, the continual search for an alternative mechanized harvesting system, which still remain more expensive than manual labor in South African sugar cane industry (Langton et al., 2007) is indicative of the problems associated with this task. Thus an understanding of the physical demands placed on the manual sugarcane harvesters is imperative in improving the efficiency of this important industry within the South African context.

Traditionally the assessment of the biomechanical demands placed on the worker, regardless of what task they are performing, has been achieved using static, two-dimensional evaluations of trunk loading (Marras et al., 1992). Primarily these models have focused on predicting the compression and shear forces experienced at the lower back, and more specifically at L5/S1. However, over the last decade the importance of trunk motion has become increasingly evident (Allread et al., 2000; Davis and Marras, 2000). Static analysis of dynamic task demands typically underestimates the task demands as it ignores the inertial forces associated with the acceleration of the load and body parts involved in the movement. Furthermore, there is epidemiological evidence to suggest that dynamic tasks such as sugar cane harvesting greatly increase the risk of injury when compared to static tasks. Detailed assessment of the dynamic trunk characteristics during workplace tasks revealed that the combination of external moment, frequency, sagittal flexion, lateral velocity and twisting velocity best predicted the risk of injury (Marras et al., 1993). Davis and Marras (2000) argued that trunk motion was of particular importance when it occurred in multiple planes simultaneously (for example combination of high lateral and twisting velocities).

The technique used to harvest sugar cane on the steep slopes characteristic of the industry in South Africa has been previously described by Lambert et al. (1994). This method divided the task into cutting (which included topping) and stacking, however this was not the case on the plantation under investigation in the current research as the individual workers performed both tasks. Furthermore the workers typically ‘work-to-task’ beginning their shift at day break to prevent working in the midday heat. They therefore govern their own pace and get paid based on how much they cut and stack. The task is done manually with a bush knife which the worker uses to cut the cane at the base. The sugar cane is then topped (the top leafy section of the cane it cut off while it is lying on the ground) and then stacked into bundles for mechanical removal from the area. Although previous studies (Lambert et al., 1994; Smit et al., 2001) have investigated the physiological strain associated with the manual harvesting of sugar cane in South Africa, to the author’s knowledge no studies have investigated the biomechanical strain experienced by the workers.

It is therefore evident that an understanding of spinal motion during the manual harvesting of sugar cane will provide important information regarding the risks of lower back injury in this significant South African industry. The purpose of the current research was thus to undertake a preliminary investigation of the spinal kinematic responses to the manual task of sugar cane harvesting.

2 Methods

2.1 Subjects

Eight workers were recruited from the Illovo Esperanza Farm on the South Coast of Kwazulu-Natal approximately 60 km south of Durban, South Africa. The protocol was approved by the Ethics Committee of Rhodes University, Grahamstown, South Africa and workers consented to participate. Basic demographic data such as age and work experience were obtained the day before the experimentation. During this session, the main purpose of the study was explained in detail to the workers and supervisors with the assistance of a Zulu interpreter. Body mass of each worker was assessed using a portable Seca scale while stature was measured using a tape measure secured to a wall. Stature was measured from the floor to the vertex in the mid-sagittal plane.

2.2 Measurement procedure

Measurement procedures for this research project occurred *in situ* allowing workers to perform their tasks in a realistic environment. Before the workers started their shift at day break, body mass was measured and recorded in their full working gear at the work site. The subjects were then fitted with the Lumbar Motion Monitor (LMM) and asked to perform their tasks as they would under normal conditions. Before any data were collected subjects were given a chance to familiarize themselves with the cutting of sugar cane while wearing the LMM, and only once it was deemed that the subjects had been sufficiently habitualized to the equipment did experimentation commence.

Figure 1. Example of a worker cutting the sugar cane at its base

During experimentation subjects were required to cut sugar cane using the technique that they would usually use during which the trunk motion data were recorded using the LMM and then sent to a laptop computer and saved for later analysis. The subjects were required to continue cutting sugar cane for a period that was long enough to ensure that at least three separate recordings of trunk motion (of at least one minute each) were obtained and were deemed to be a representative sample of the task performed.

2.3 Apparatus

Trunk motion data were collected using the LMM, which is essentially a tri-axial electrogoniometer that acts as an exoskeleton for the lumbar spine (Marras et al., 1992), which has been previously validated in several papers (Marras et al., 1993; Marras et al., 1995; Marras et al., 1999). The LMM attaches to the subject in line with their spines with the use of two harnesses (one at the pelvis and the other at the thorax). From the LMM the instantaneous position, velocity and acceleration of the trunk are measured. Due to the fact that the LMM is light weight and the design of the harnesses, the wearing of the apparatus did not have a significant impact on the trunk motions of the subjects during the performance of their task. The instantaneous trunk motion data are sent directly via telemetry to a laptop computer were the individual responses are recorded and stored for later analysis.

2.4 Data Analysis

The LMM provides comprehensive trunk motion data at a rate of sixty data points per second. Once the raw data has been transmitted to and stored on a laptop computer it is transferred to Microsoft Excel© for further analysis. In this software package the mean and standard deviation for all three planes can be determined (this includes the distinction between left and right for lateral bending and twisting).

3 Results

In order to assess the trunk motion responses to manual harvesting of sugar cane the responses have been separated into the three cardinal planes, namely the sagittal, lateral and transverse planes.

3.1 Sagittal plane responses

The degree of sagittal flexion has been shown to play an important role in determining the risks associated with any task (Marras, 2000). In the present study subjects were required to cut sugar cane at the base of the stem using a hand held bush knife, due to the short length of these knives workers are often required to spend a significant portion of the workshift with the back bent in the sagittal plane (see Figure 2).

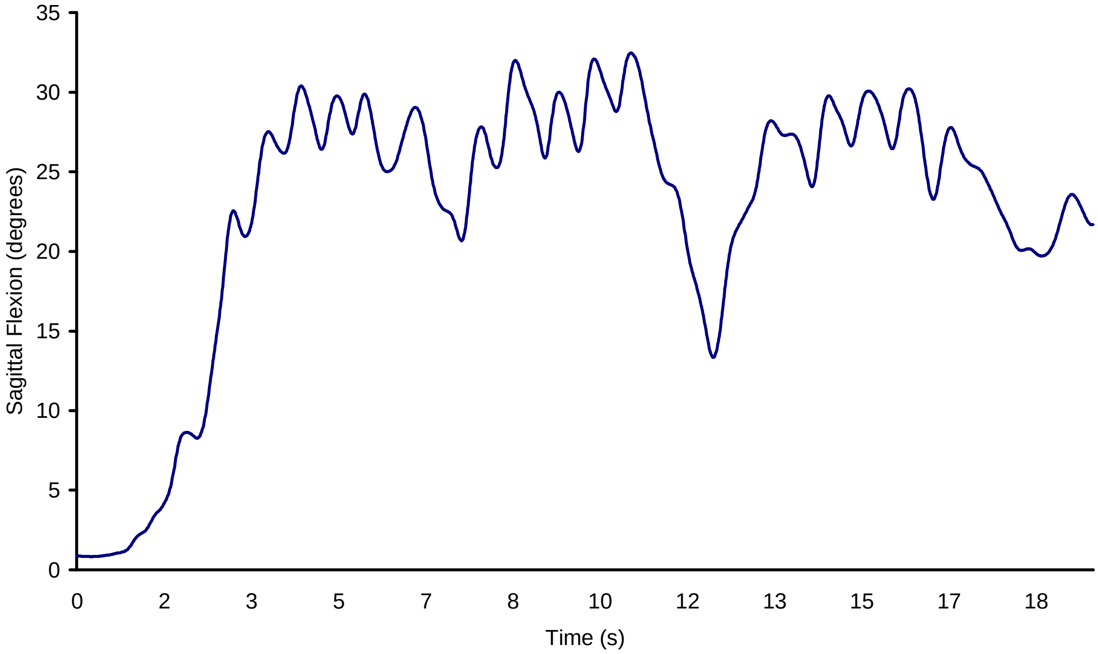

Figure 2. Typical sagittal flexion during cutting sub-task (From one subject)

The average angle for maximum sagittal flexion of 27.2 (±11.76)°, will have a significant impact on the task demands. It has long been accepted that the forces used to support the head, arms and trunk in sagittal flexion may contribute significantly to the compression forces experienced at L_5/S_1, and as such could be considered to be a risk factor. Furthermore it is evident that subjects are required to maintain this sagittal flexion position for extended periods of time with the average angle for sagittal flexion of 19.13° over the data collection period for all subjects.

Table 1. Summary of sagittal plane trunk motion responses (with standard deviation in brackets)

	Maximum	**Average**
Position (°)	27.2 (11.76)	19.13 (10)
Velocity ($°.s^{-1}$)	44.21 (21.72)	9.76 (5.2)
Acceleration ($°.s^{-2}$)	347 (162)	

MacKinnon and Lee (1998) have previously argued that rapid jerking motions significantly increase the individual’s risk of injury. The average sagittal plane velocities were only 9.76 (±5.2) $°.s^{-1}$, which could be considered not to be excessive (Marras **et al.**, 1992); however of greater concern where the maximum velocities achieved which had a mean value of 44.21 $°.s^{-1}$, which according to values suggested by Marras **et al.** (1992) would be classified as medium risk. Although there are high standard deviation values associated with the position, velocity and acceleration responses, the intra-subject variability was low, suggesting that each individual ‘cutter’ employed a unique technique to harvest the sugar cane.

3.2 Lateral plane responses

The LMM provides data for lateral bending for position (both left and right), maximum range, average and maximum velocity and maximum acceleration.

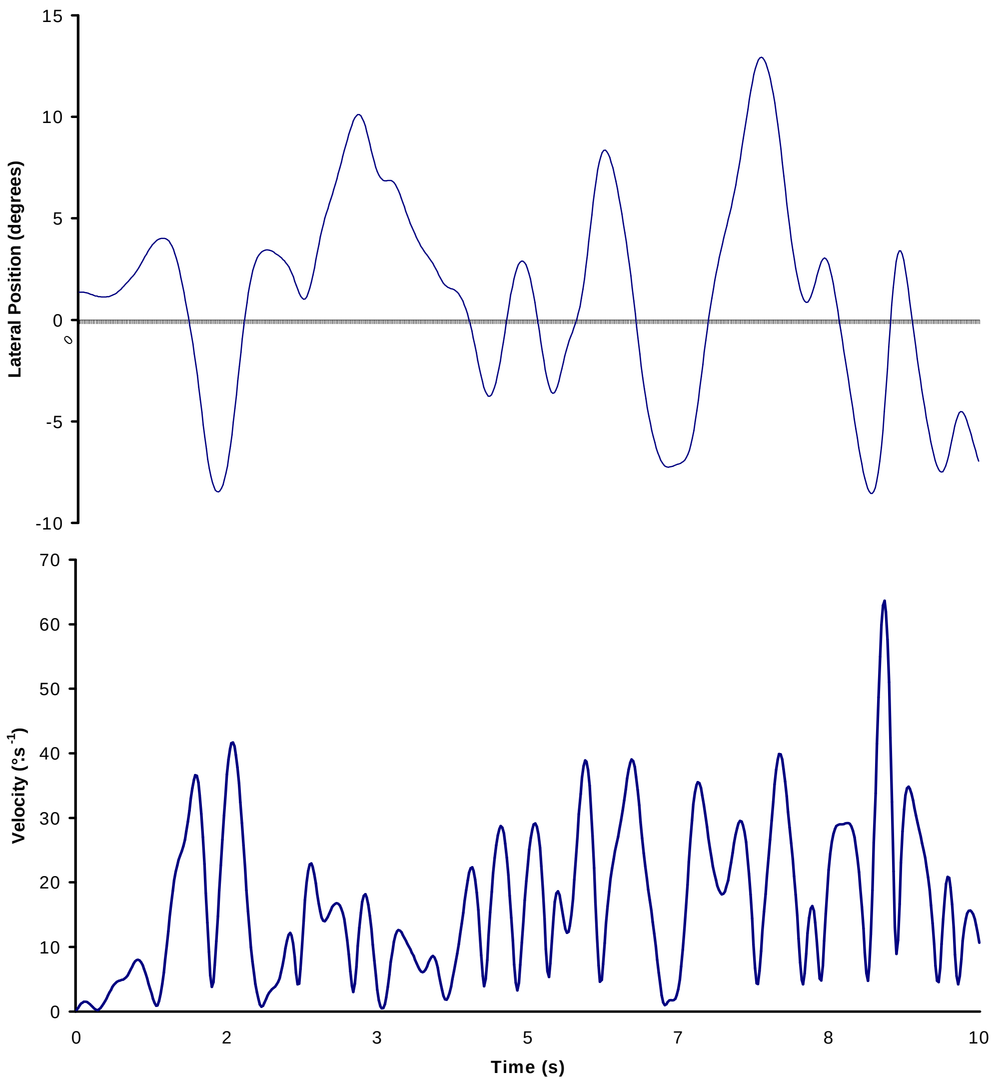

Figure 3. Lateral bending position and velocity

It is evident from figure 3 that the subjects were continually cycling between lateral bending to the right and left as they attempted to generate the force required to cut the sugar cane. Subjects bent laterally to the left in the backswing of the cutting action and then to the right in the follow through as illustrated in Figure 3. However the average position was only marginally to the right (see Table 2). The result of these lateral trunk motions are high lateral bending velocities and accelerations, with peak values averaging 55.96 $°.s^{-1}$ and 439 $°.s^{-2}$ respectively, increasing the forces the lower back is exposed to and hence increasing the risk of injury.

Table 2. Summary of lateral plane trunk motion responses (with standard deviation in brackets)

	Maximum	Average
Position Left (°)	-10.36 (6.5)	2.1 (7.08)
Position right (°)	14.0 (7.4)	
Velocity ($°.s^{-1}$)	55.96 (24.9)	13.76 (5.72)
Acceleration ($°.s^{-2}$)	439 (197)	100 (95)

It is further apparent from the results that not only are the lateral trunk motions characterized by high velocities and accelerations, but that these values are also rapidly changing over time. The rapid cycling of trunk motions are of concern as they are a precursor for injury.

3.3 Transverse plane

As with the results for the lateral plane, there was a significant amount of twisting associated with the process of cutting cane. The average range of motion for twisting was 19.00 (±7.4) °, with this being evenly split between twisting to the left and right (See Table 3).

Table 3. Summary of transverse plane trunk motion responses (with standard deviation in brackets)

	Maximum	Average
Position Left (°)	-10.03 (5.15)	19.00 (7.4)
Position right (°)	8.97 (4.08)	
Velocity ($°.s^{-1}$)	63.53 (24.24)	14.97 (6.9)
Acceleration ($°.s^{-2}$)	502.18 (190)	

Although the twisting range of motion is not excessive, of importance in determining the risks associated with twisting is the velocity of the movement. The average maximum velocity achieved by the subjects was 63.53 (±24.24) $°.s^{-1}$ with an average velocity overall of 14.97 (±6.9) $°.s^{-1}$. Of particular concern with regard to the velocities is the continual cycling from left to right (thus there is a continual shift from positive to negative velocities) which has been shown to be a risk factor in the development of lower back disorders.

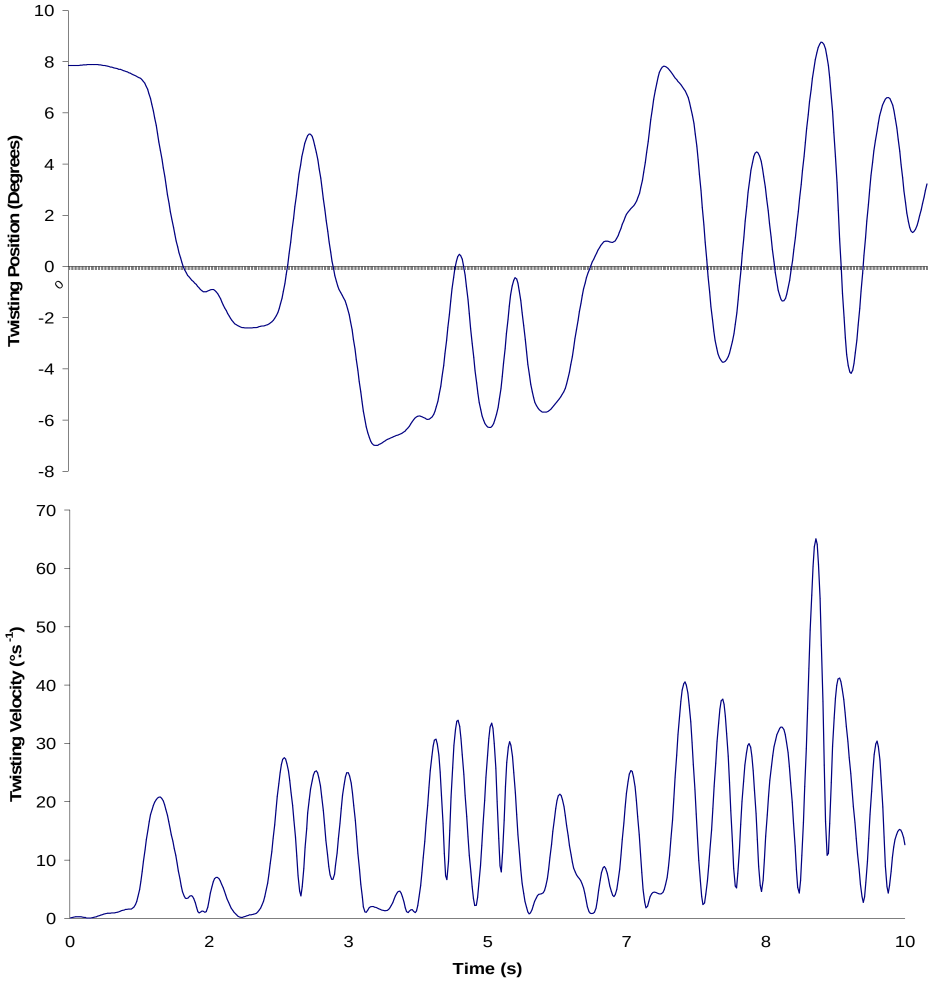

Figure 4. Twisting position and velocity for sugar cane cutting

When the results are compared to the risk classification described by Marras and colleagues (1992) it is evident from the results that there are prominent risk factors associated with all three planes of movement. In the sagittal plane subjects are required to spend a significant proportion of the workshift with the trunk in a high angle of flexion, while both the lateral bending and twisting velocities are of concern.

4 Discussion

Although several papers have investigated the physiological demands associated with sugar cane harvesting in South Africa, there has been little focus on the biomechanical responses to this demanding task. It is evident from the findings above that it is important to take the biomechanical demands of the task into consideration. Flexion of the trunk increases the internal forces that are required to counteract the external moment, increasing the forces on the anatomical structures of the lower back, ultimately reducing the load limit of the spine (Marras, 2000). The significant trunk flexion during the current research project places the workers at risk of developing lower back problems. Both lateral and torsional position changes during sugar cane harvesting were significant, the impact of which is increased due to the sagittal loading of the spine.

Another important determinant of risk is the velocities of trunk motion, as fast-paced movements are likely to increase both the shear and compression forces in the lower back (Marras et al., 1995). Peak velocities in all three planes were high, consequently increasing the forces in the spine and reducing the strength of the trunk. Furthermore, Marras (2000) argued that there is a correlation between trunk velocities and the risk of injury for workers performing an eight hour workshift, although the South African work force is significantly different to those reported on by Marras the is still a concern for the development of musculoskeletal disorders. As such further research into the prevalence musculoskeletal disorders amongst sugar cane harvesters in South Africa is needed. The accelerations associated with trunk motion are also an important indicator of task risk, as high accelerations are typically linked to 'jerking' actions on the back and consequently with severe tissue trauma. Once again there were high peak accelerations (Marras et al**.**, 1992) in all three planes evident in the current project significantly increasing the risk of injury.

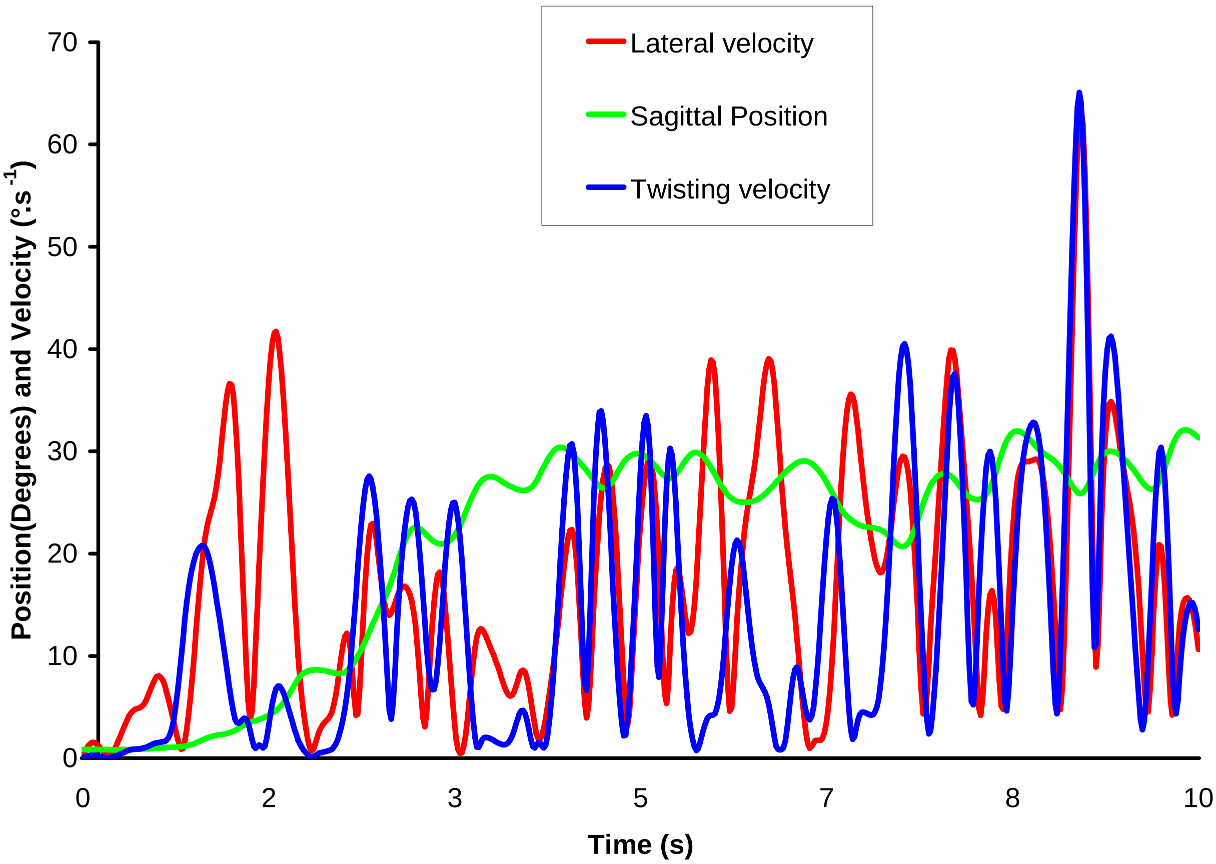

Figure 5. Combination of sagittal position and lateral and twisting velocities

As workers are required to 'work-to-task' the amount of sugar cane harvested varies significantly from worker to worker from approximately 4 to 8 tons. Regardless of the amount harvested the task is highly repetitive, with Smit et al. (2001) reporting harvesters to make as many as 34 strokes per minute for burnt sugar cane as in the current study. The highly repetitive nature of the task has a significant impact on the trunk motion responses as it is evident in the lateral bending and twisting position responses which are characterized by a significant amount of cycling from side to side.

McGill (1997) and Marras (2000) have both stressed how even low loads that are repetitive in nature reduce the load tolerance limit of the spine and ultimately are likely to result in injury. Furthermore variable loading that often occurs in repetitive tasks (as is illustrated by the variable nature of the trunk motion velocities) has also been shown to be a significant risk factor.

In order to determine the overall risk associated with any task it is important to take all three planes into consideration simultaneously. As Davis and Marras (2000) argued the simultaneous movement of the trunk in more than one plane places the spine under greater strain and the incident of injury is likely to be significantly increased. It is clearly evident from the diagram above that there was significant sagittal flexion as well as high lateral and twisting velocities all occurring simultaneously. It is therefore suggested that the risks of injury associated with the manual harvesting of sugar cane are high and that intervention strategies to reduce the demands placed on the lower back of the workers are essential.

5 Conclusions

It is evident that the technique that is currently used to harvest sugar cane in a significant proportion of the South African sugar cane plantations (especially considering that there are a growing number (approximately 15% of total production) of communally owned plantations) (Maloa, 2001) may be placing them at risk of developing lower back disorders. The task is characterized by high lateral and twisting velocities as well as sagittal flexion, all three of which have been shown to be important determinants of task demands. Furthermore the highly repetitive nature of the task heightens these already stressful demands that are placed on the worker. It is therefore evident that further more detailed research is required into the biomechanical demands associated with the manual harvesting of sugar cane and that ergonomic interventions strategies are paramount in alleviating the demands that are currently being placed on the worker.

6 Acknowledgements

The author would like to thank Mr. C. Pfotenhauer, Mr. B. Thompson, Mr. J. Bowley and Mr. D. Rein, Illovo Sugar, Sezela, for overseeing, facilitating finance of the project and for organising the labourers. I would also like to thank Prof. P.W.L. Lyne from the South African Sugarcane Research Institute (SASRI), for also organizing funding and supporting the project. The author would also like to thank the co-workers in the data collection and problem identification phase of this research.

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