July 30, 2003

Harvesting Ground Level Crops: A Biomechanical Assessment and Ergonomic Intervention

Gary A. Mirka, *North Carolina State University*
Gwanseob Shin, *North Carolina State University*
Yu Shu, *North Carolina State University*
Zheng Li, *North Carolina State University*
Zongliang Jiang, *North Carolina State University*, et al.

This is not a peer-reviewed article.

Paper Number: 038021
An ASAE Meeting Presentation

Harvesting Ground-Level Crops: A Biomechanical Assessment and Ergonomic Intervention

Gary A. Mirka, PhD

The Ergonomics Laboratory, Department of Industrial Engineering, North Carolina State University, Raleigh, NC 27695-7906, mirka@eos.ncsu.edu

Gwanseob Shin

The Ergonomics Laboratory, North Carolina State University, Raleigh, NC 27695

Yu Shu

The Ergonomics Laboratory, North Carolina State University, Raleigh, NC 27695

Zheng Li

The Ergonomics Laboratory, North Carolina State University, Raleigh, NC 27695

Zongliang Jiang

The Ergonomics Laboratory, North Carolina State University, Raleigh, NC 27695

Theresa Costello

The Ergonomics Laboratory, North Carolina State University, Raleigh, NC 27695

Written for presentation at the
2003 ASAE Annual International Meeting
Sponsored by ASAE
Riviera Hotel and Convention Center
Las Vegas, Nevada, USA
27- 30 July 2003

Abstract. *Observation of standard work practices for the harvesting of small ground crops such as sweet potatoes and cucumbers reveal long-term static, full flexion of the torso. The implications of these postures of the torso in relation to fatigue and spinal stability are being more closely considered in the biomechanics literature. Specifically, there are concerns with regard to the changes in the properties of the viscoelastic structures that support the spinal column (longitudinal ligaments, interspinous ligaments and the intervertebral discs. The focus of the current project was in*

the biomechanical assessment of these work postures as well as some preliminary work in the development of ergonomic interventions aimed at reducing these loads. The results of the biomechanical assessment component of these work postures showed interesting inter-relationships between back angle and knee angle under loaded conditions wherein the knee angle had little effect on the back muscle activation levels in more upright postures but had a significant impact on these activation levels when the subject assumed the fully flexed postures. These results led to the development of two ergonomic interventions aimed at reducing the moment about the L5/S1 intervertebral joint during ground harvesting activities. The results of the analysis of these two first level prototypes showed mixed results relative to their ergonomic impact and impact on productivity.

Keywords. agriculture, harvesting, ground crops, ergonomics, back injury

Introduction

Observation of the standard work practice for the harvesting of small ground crops such as sweet potatoes and cucumbers revealed long-terms static, full flexion (>90 degrees) of the torso. This is an extremely fast-paced incentive work environment. The system currently being employed requires that the workers repetitively move buckets filled with produce as they move along the rows. This involves repetitive lifting in extreme awkward postures.

In more traditional industrial environments workers are often told to "lift with the legs and not the back" in an effort to reduce the loads on the spine. This is not a particularly practical approach in the farmwork setting because of the amount of fatigue that develops throughout the workday. As the fatigue develops from the near continuous exertions and heat, farmworkers will adopt the working technique that requires the least amount of energy expenditure and in the present case a stooped trunk posture. Observation of the farmworkers has, however, revealed considerable variance in the technique employed with varied knee and back angle being two important biomechanical characteristics that are varied. A review of the literature in the area of the interaction between knee and back angle revealed several studies that have focused on the flexion-relaxation response of the low back musculature (Floyd and Silver, 1955; Schultz et al., 1985; Sihvonen, 1997). Briefly, this response results from the interplay between the muscular and ligamentous forces as a function of trunk angle. Because there are multiple muscles that span not only the joints in the hip/lumbar region but also the knee joint, consideration should be given to the impact of the knee angle on the flexion-relaxation response of the musculature of the lumbar regions.

The impact that this flexion-relaxation response has on the health of the lumbar spine has been the focus of a number of studies concerned with the changes in the viscoelastic tissues of supporting the lumbar spine. Specifically, there has been some concern raised with regard to the impact of visocelastic elongation of the ligamentous tissues of the spine on their stabilizing capacities. The spinal ligaments play an important structural role in mechanically stabilizing the spine and an important sensory role in providing stretch reflex kinds of information that can be used to activate the spine stabilizing musculature (Solomonow, 2003). This model notes that as a worker maintains a stooped work posture for extended periods of time the ligaments become stretched and when the worker returns to the upright position there is a period were the tissue remains in the lax state. Further, the stretch receptors that reside in the tissue become desensitized to the stretch and when the person returns to the upright position they remain desensitized to for a period of time. During this time the spine is at an increased risk of injury during lifting tasks.

Another important characteristic of the biomechanical configuration during a stooped lift is the multiple joint muscle effect. There are a number of extensor and flexor muscle groups that span multiple joints in the spine, and others that span both the hip and knee joints. These multiple joint muscles can have an impact on the loading characteristics in the spine as well as the previously described flexion-relaxation response.

The main objectives of this study were to consider the basic biomechanics of the stooped postures assumed by farmworkers during harvesting of ground crops. Specifically we were interested in quantifying the impact of varied knee angles on the activation levels of the trunk

extensor musculature. Based on these results prototype solutions for the reduction of low back loads were developed and some preliminary results with regard to their effectiveness are presented.

Methods

Subjects

Eight male subjects with a mean age of 27 years were recruited from the university community and participated voluntarily. All subjects were free from chronic and current back problems and subjects' flexibility levels were assessed by fingertip to floor distance with straight knees (three subjects categorized as high-flexible, three subjects categorized as moderately flexible and two subjects categorized as low-flexible). Basic anthropometric characteristics of the subjects were gathered.

Apparatus

Eight pairs of surface electrodes were used to collect the muscle activity from the right multifidus, longissimus, iliocostalis, vastus lateralis, rectus femoris, vastus medialis, biceps femoris, and gastronemius. A lumbar dynamometer was used to provide the necessary resistance for the collection of maximum trunk extension exertions, and a stationary chair with a strap was for the collection of maximum knee extension/flexion exertions.

Independent variables

Independent variables of this study included four back flexion angles (30°, 50°, 70°, and 90°), three knee flexion angles (0°, 20°, and 40°), and subject flexibility level (low moderate, high). Two levels of trunk extension moment were considered in this study (50% of angle specific maximum and zero external load) but only the 50% loading is considered in the current report. The angle between a vertical reference line and the line from shoulder (acromion) to hip joint (greater trochanter) was defined as back flexion angle, and the angle between the line from hip to knee (lateral collateral ligament at the height of the joint cleft) and the line from knee to ankle (lateral malleolus) was defined as knee flexion angle.

Dependent variables

Dependent variables were the normalized integrated EMG (NIEMG) from back extensors (multifidus, iliocostalis, and longissimus), knee extensors (rectus femoris, vastus lateralis, and vastus medialis) and knee flexors (gastrocnemius-soleus and biceps femoris). As all tasks performed were sagittally symmetric, muscle activity data were collected on right side only. A 10 Hz high pass, 500 Hz low pass and 60Hz notch filter were applied to each of these signals to remove artifacts. Normalization of the task EMG was accomplished by dividing the task IEMG by the angle-specific EMG elicited during the maximum voluntary contractions.

Experimental procedures

After the electrodes were placed and the signals verified, a maximum voluntary back extension exertion was performed at each of the four different back flexion angles (30°, 50°, 70°, and 90°).

The maximum EMG of knee extensors and flexors were collected at 0° (knees locked), 20°, and 40° knee flexion angles on a stationary chair while pulling against the harness system.

Following collection of all MVC exertions subjects performed a randomized sequence of static, weight-holding tasks at the different combinations of knee and trunk angle. The weight of the barbell held by the subjects was computed to produce an angle-specific 50% MVC exertion. Subjects performed a total of 48 trials (two repetitions of each combination of four back flexion angles (30, 50, 70, and 90 degrees), three knee flexion angles (0, 20, and 40 degrees), and two load conditions (no external load, and 50% of maximum voluntary contraction force). At each trial, subjects bent their back forward and flexed both knees and hold a weight barbell by both hands. They were asked to maintain a stable posture and keep their heels in contact with floor. As soon as the posture was stable, their muscle activities were collected by EMG system for three seconds. There was 20-second rest break between consecutive trials.

ANOVA procedures were used to identify significant effects of trunk and knee angle on muscle activity. The first analysis used subject as a blocking variable while the second analysis considered the independent variable "flexibility".

RESULTS

The results of the first ANOVA (Table 1) show the relationships between the trunk angle, knee angle and the EMG of the lumbar musculature, while Table 2 shows the same analysis with the addition of a simple estimate of subject flexibility.

Table 1. ANOVA Results without Flexibility as an Independent Variable (** p<.001, *p<.05).

	Multifidus	Longissimus	Iliocostalis
Trunk Angle	**	**	**
Knee Angle	NS	NS	*
Trunk*Knee	NS	NS	*

Table 2. ANOVA Results with Flexibility as an Independent Variable (** p<.001, *p<.05).

	Multifidus	Longissimus	Iliocostalis
Trunk Angle	**	**	**
Knee Angle	NS	NS	NS
Flexibility	**	**	**
Trunk*Knee	NS	NS	NS
Trunk*Flex	NS	NS	NS
Knee*Flex	NS	NS	NS

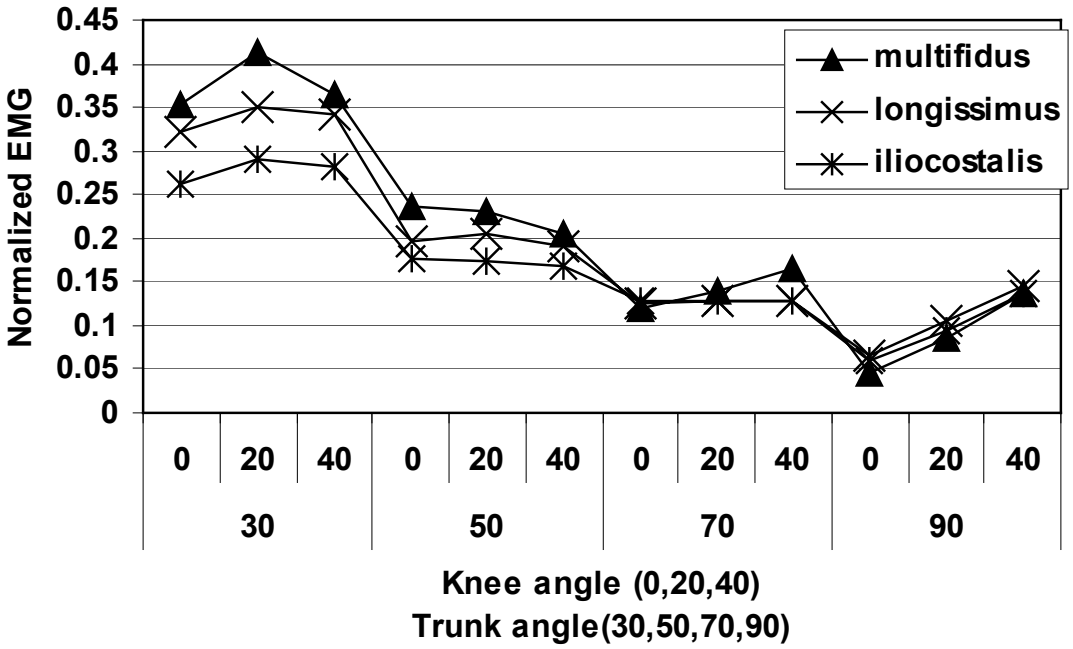

Figure 1. Response of Lumbar Musculature to Changes in Knee Angle and Trunk Angle.

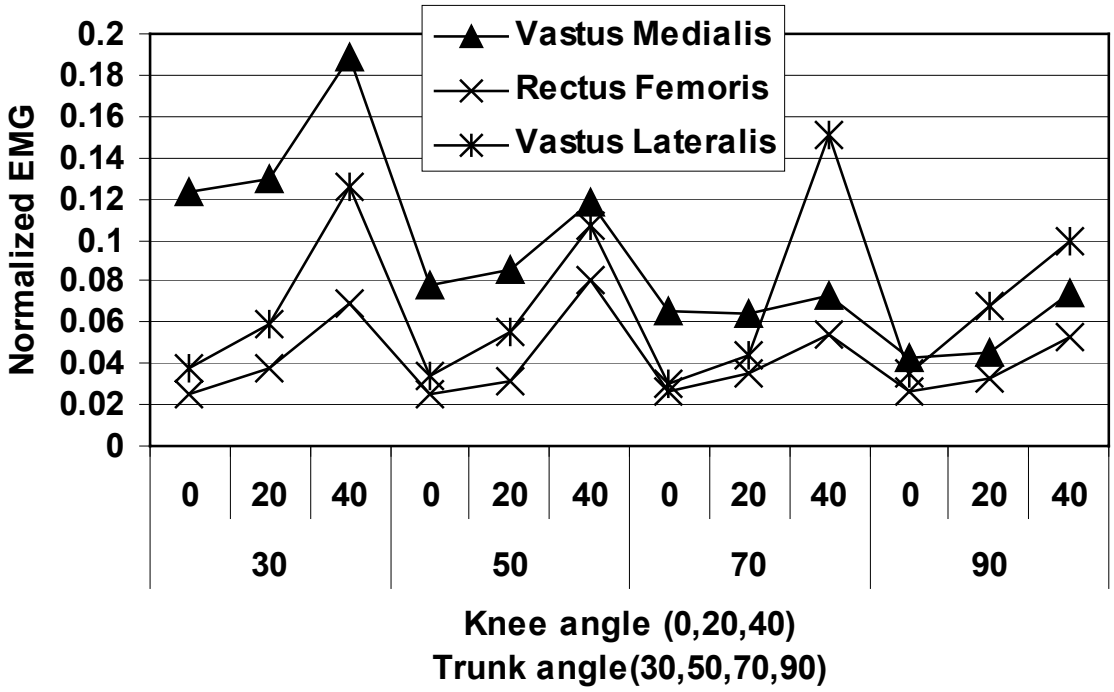

Figure 2. Response of Knee Extensor Musculature to Changes in Knee Angle and Trunk Angle.

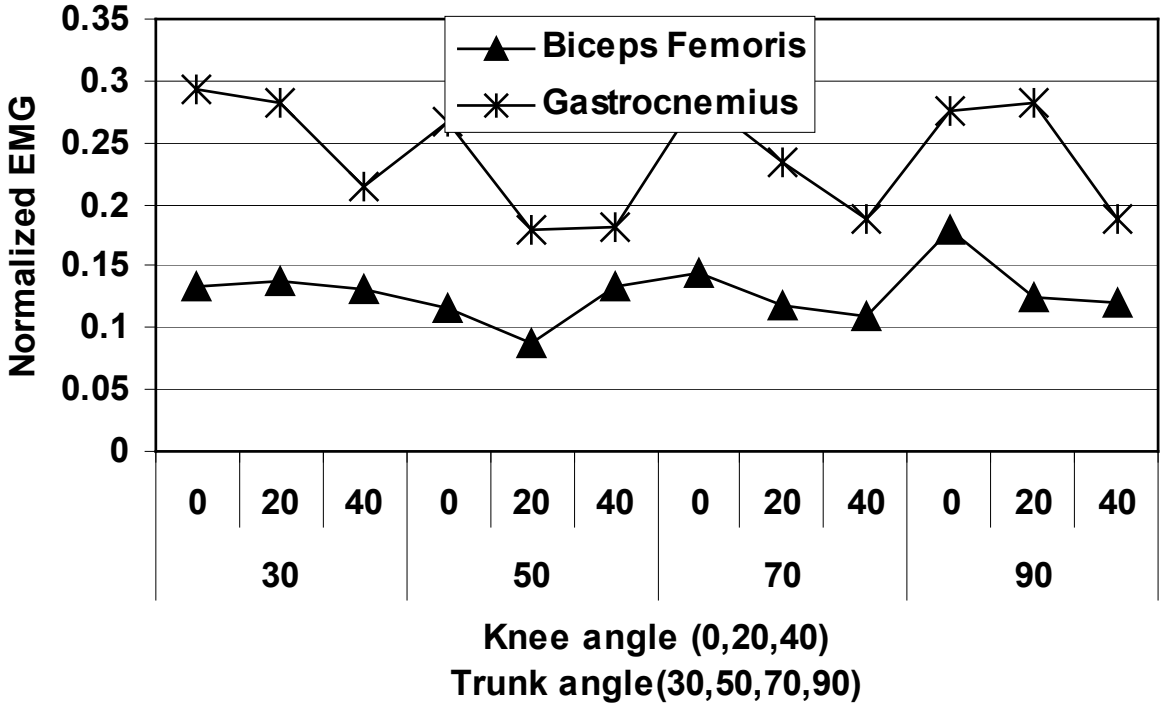

Figure 3. Response of Knee Flexor Musculature to Changes in Knee Angle and Trunk Angle.

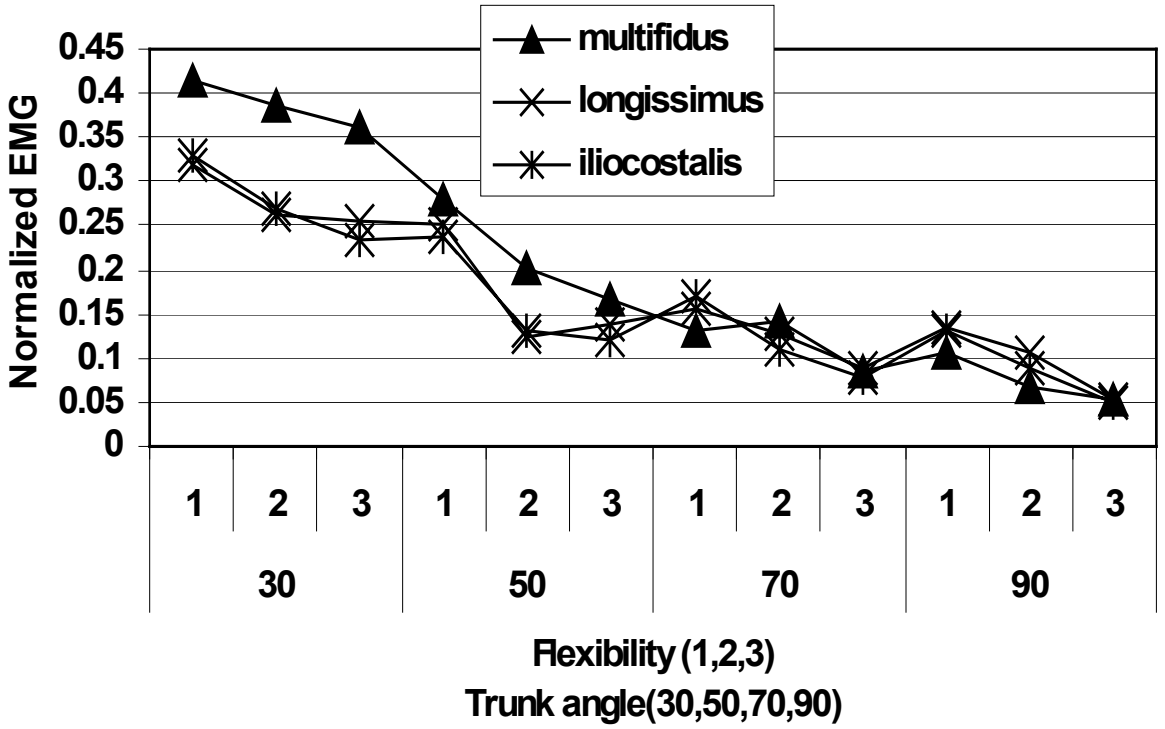

Figure 4. Response of Lumbar Musculature to Changes in Trunk Angle and Subject Flexibility (1 - most flexible, 3 - least flexible.)

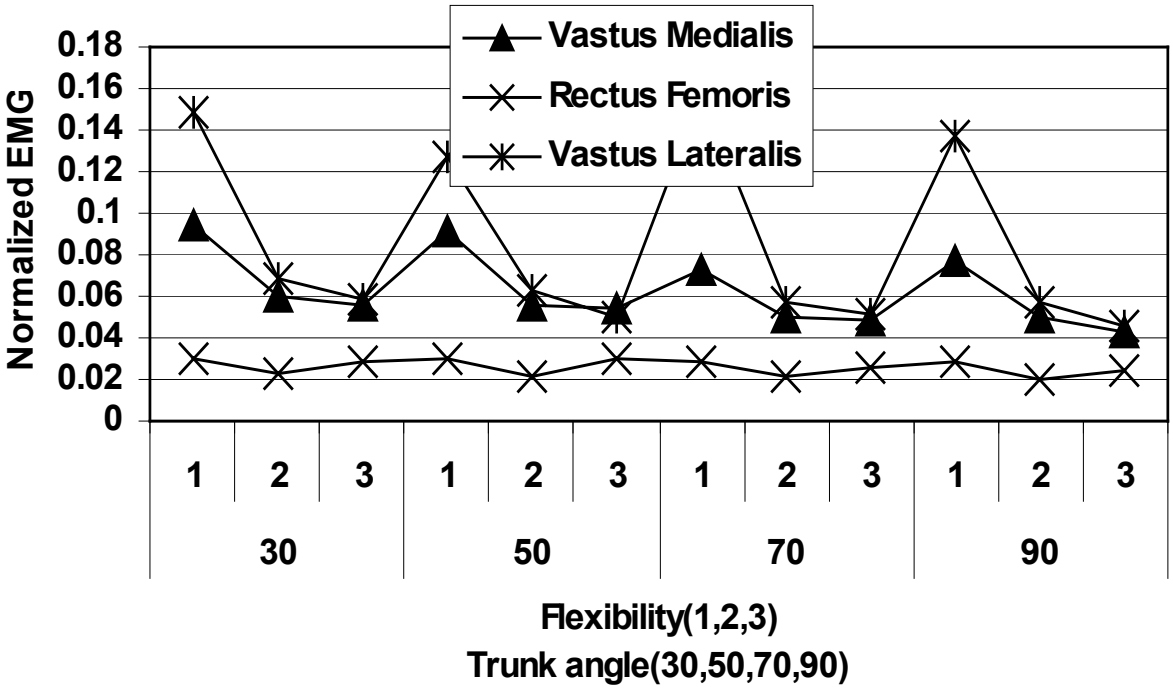

Figure 5. Response of Knee Extensor Musculature to Changes in Subject Flexibility and Trunk Angle.

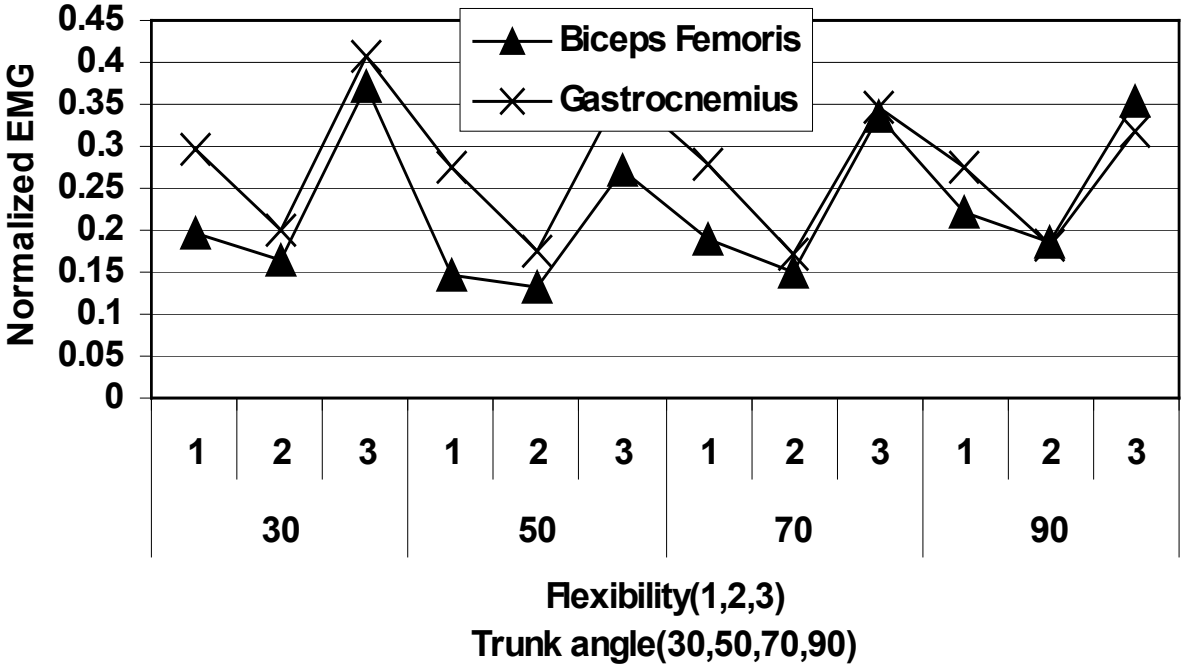

Figure 6. Response of Knee Flexor Musculature to Changes in Subject Flexibility and Trunk Angle.

INTERVENTION DEVELOPMENT

The results of the EMG-based study illustrated that the flexion-relaxation response was evident in the kinds of postures that farmworkers assume during the harvest of ground crops. Recognizing that this flexion-relaxation response may have deleterious effects on the visco-elastic structures of the spine (ligaments and intervertebral discs) the research team embarked on an ergonomic intervention effort to reduce the loads on the lumbar spine. There were two basic ideas prototyped. The first (Figure 7a) was a harness-based system that transmitted the weight of the vegetables being harvested through a cable system that generated a trunk extension moment. The second (Figure 7b) was a dual-bucket system that allowed the workers to lift the weight of the vegetables in a more upright posture.

(a) (b)

Figure 7. Two protoype interventions for the reduction of low back loads during harvesting of ground crops.

A biomechanical model of the impact of the harness-based system was developed and showed an overall reduction of moment about the L5/S1 intervertebral joint of approximately 60Nm when the bucket is full. The reaction force at the fulcrum (pelvis) is approximately 400N.

Preliminary data with regard to the impact of these two interventions on muscle activity of persons performing this type of work has been gathered. Three subjects performed a simulated sweet potato harvesting activity. The sweet potatoes were placed in clusters based on observations of sweet potato harvesters in the field. Each of the three conditions (conventional bucket approach, harness-based system and dual bucket system) was experienced by each subject two times. As they performed these activities the electromyographic activity of the multifidus, rectus abdominis, vastus lateralis and biceps femoris was collected using surface electrodes. Productivity was established by the time it took the subject to harvest all of the sweet potatoes. The task was to "harvest" one load (~20 kg) of sweet potatoes from the specific locations along a path in the laboratory. The results from this preliminary assessment of the ergonomic interventions do not immediately look promising (Figure 8).

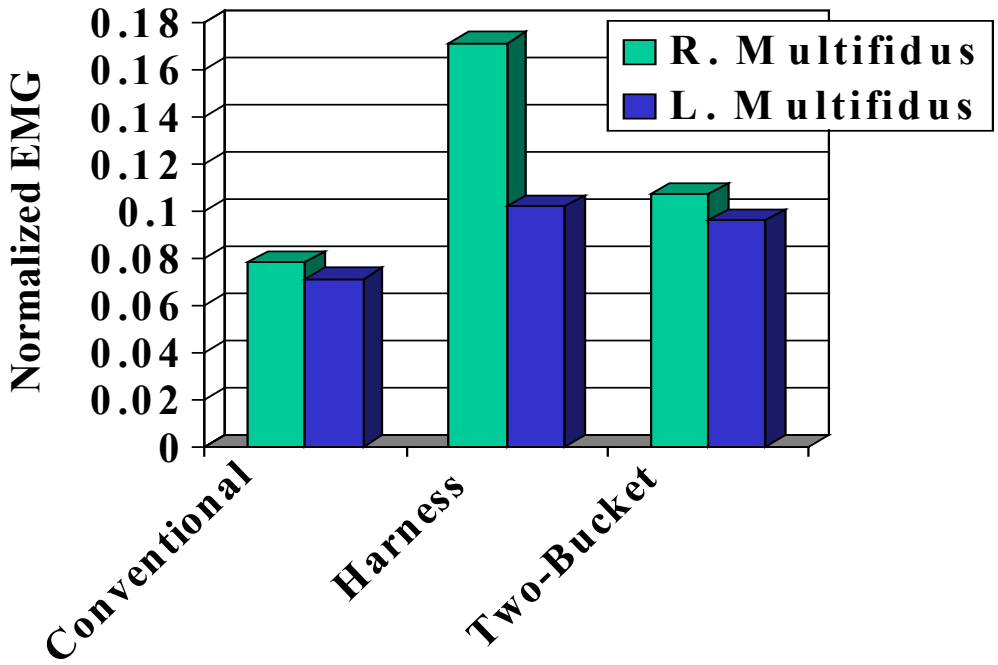

Figure 8. Effect of the prototype solutions on the response of the right and left multifidus muscles.

It is important, however, to remember that the effect of the intervention in these extreme flexed postures may not be adequately described by looking at the active component (EMG) of the moment producing system. Subjective assessments by the subjects did tend to show a reduced sense of moment and therefore some optimism is warranted. Likewise, the dual bucket system also received positive subjective assessments from the participants. Ongoing research is focused on refining these prototypes and assessing their effectiveness in the field.

Conclusion

Harvesting ground-level crops forces the farmworker to assume a static awkward trunk posture and these postures can led to long term chronic back problems. The results of this research have shown that there is an impact of the knee angle on the muscle activation strategies of the lumbar musculature. Preliminary results with regard to the ergonomic interventions designed to reduce the loads on the lumbar spine are shown to have minimal impact on the muscle activity levels.

Acknowledgements

This work was supported by Grant No. U50 OH07551-01 from the National Institute for Occupational Safety and Health (NIOSH). The contents are solely the responsibility of the authors and do not necessarily reflect the views of NIOSH.

References

Floyd, W. and Silver, P. 1955. The Function Of The Erectores Spinae Muscles In Certain Movements And Postures In Man. *Journal Of Physiology-London.* 129 (1): 184-203.

Schultz, A.B., Haderspeck-Grib, K., Sinkora, G., Warwick, D.N. 1985. Quantitative studies of the flexion-relaxation phenomenon in the back muscles. *Journal of Orthopaedic Research*. 3:189-197.

Sihvonen, T. 1997. Flexion relaxation of the hamstring muscles during lumbar-pelvic rhythm. *Archives of Physical Medicine and Rehabilitation*. 78(5):486-490.

Solomonow M., Baratta R.V., Banks A., Freudenberger C., Zhou B.H. 2003. Flexion-relaxation response to static lumbar flexion in males and females. *Clinical Biomechanics* 18 (4): 273-279.


OHIBITED