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Methods for Ergonomics Assessment of Agricultural Work with Hand Tools

BY

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A project report submitted in partial fulfilment of the requirements for the Master of Science degree in Ergonomics

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ABSTRACT

Methods for Ergonomics Assessment of Agricultural Work with Hand Tools

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The objective of the study was to develop methods for ergonomics assessment of agricultural work with hand tools in the laboratory and thereafter adapted in the field.
A total of eight male graduate students (mean age, height and weight were 29.4 years, 176.8 cm and 81.0 kg respectively) participated in a digging task using a hand hoe. The digging task was performed within three minutes in a 2 m * 1.5 m metal box full of moist sand.
3 video cameras were installed to record the working posture. At the last minute, during interval of 15 seconds, heart rates (HR) along with rate of perceived exertion (RPE) 6-20 were measured to assess the physical load.
Awkward postures while the hoe lifted up as well as stroke the soil were frozen and different joint angles were measured to provide input for 3-dimesional static strength prediction programme (3D SSPP).
The data analyses included linear regression for HR as a function of RPE; 3D SSPP software calculated the percentage of population capable of performing the task and low-back compressive forces. Compression force on L5/S1 was plotted as a function of HR and RPE.
The results revealed that the correlation coefficient (r) for HR and RPE ($p<0.05$) was 0.59; the measured and perceived physical load range from light to heavy. The output obtained from the software showed that low-back compressive forces were below the NIOSH recommended safe limit (3400 N) when the hoe lifted up. However, when the hoe stroke the soil, compression force on L5/S1 for 25% from the subjects exceeded the NIOSH safe limit and therefore they were at high risk of back injury. When the force on L5/S1 plotted as a function of HR and RPE, the results showed that there was no linear relationship between these variables.
In conclusion, HR a long with RPE proved to be used in the laboratory as well as in the field. 3D SSPP could be used in the laboratory, nevertheless, in the field, one video camera would be appropriate.

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1. INTRODUCTION

1.1 Background

Throughout the history, agriculture was described as a manual-labour intensive, life-shortening industry (Bobick and Myers, 1994). As time went on, the technology of agricultural engineering, in general, and farm mechanisation, in particular, have undergone profound change (Sims, 1996). In the industrialised countries, land consolidation and the enhancement of labour productivity through investment in machinery constitute current agricultural trends (Sims, 1996). However, in horticulture for instance, landscaping operations, cleaning, digging and lifting are still carried out manually with handled shaft tools (Degani *et al.*, 1993; Öberg and Gebresenbet, 1998). In addition, Kumar (1995) pointed out that gardening and landscaping do not warrant the use of motor-driven device.

In many developing countries, the situation is reversed (Sims, 1996). Although engine power is employed, the most important sources of farm power are draft animals and humans (Tewari *et al.*, 1991; Sims, 1996; Jafry and O'Neill, 2000). The farmers tend to mechanise high power requirement tasks first, preferring to retain precision control for human intervention (Sims, 1996). In this way, ploughing and secondary cultivation are allocated to tractor or animal power whilst seeding, weeding, digging and harvesting are carried out manually (Gite, 1991; Tewari *et al.*, 1991).

In small-scale farms, the socio-economics factors limit the choice of agricultural activities techniques (Jafry and O'Neill, 2000). Therefore, animal traction and human are the most likely the sources of power.

Given this situation, it is evident to say that despite increased agricultural mechanisation, there still a need for muscular power (Freivalds, 1986a; Freivalds and Kim, 1990; Kroemer and Grandjean, 1997). In other words, hand tools such as shovels; rakes and hoes require considerable muscle forces and stressful working postures (Öberg and Gebresenbet, 1998).

These tools comprise a metal blade and a wooden handle (rarely metallic) (Bassi, 1992). A metal blade is the action points for digging, cutting, scooping and lifting whereas the handle serves as the linkage between the power source (human) and the blade (Bassi, 1992).

With reference to relevant literature, it can be said that over the history, the discussion of ergonomics principles in agricultural hand tools design has been generally omitted (Freivalds 1986a, b). Therefore, working with these tools, may result in acute and chronic injuries due to the excessive force demanded by the task (Capodaglio *et al.*, 1997) or may lead to a stressful working posture and high load (Mital *et al.*, 1993). Further, the tools are physically demanding through their energy and postural requirements (Rogan and O'Neill, 1993) and a source of drudgery (Hall and Milner, 1997).

In short-term, this will cause muscle fatigue which reduce capacity for work whereas in long-term, the consequences may be cumulative and result in musculoskeletal trauma disorders and chronic muscle pain (Mital *et al.*, 1993).

Having presenting an overview of manual work with hand tools, various methods for ergonomics assessment of work load have become available and each serves a slightly different purpose (O'Neill, 1997).

In general, these methods can be categorised into the following: checklist, task analysis, observations, interviews, diaries, questionnaires and direct measurements.

The ergonomics checklist developed for manual material handling, for instance, described as a tool that can be used both in reactive and proactive modes. That is to say the checklist could be used to identify the worker's exposure(s) or to evaluate a job for the presence of musculoskeletal disorders (MSD) risk factors in an effort to reduce the likelihood of injury occurrence (Sommerich *et al.*, 1996-1997).

Task analysis deals with the study of the requirements of a human operator in a system, in order to compare the demands of the system with the characteristics and capabilities of the operator (System Approach, 200). This type of study may uncover mismatches between system demands and operator capabilities and so the results usually take the form of recommendations for design and modifications.

The use of questionnaires, diaries and interviews techniques provides an opportunity to study cumulative exposure over time, an important parameter that is not usually available with direct measurements or when even there is no equipment to measure the work load.

In addition, questionnaires can be used in a very broad series of applications. They can be used for evaluating specific features or issues of a system, and they can also be used in order to investigate different opinions, knowledge or attitude towards this system (Capodaglio *et al.*, 1997). However, the relatively low reliability and validity of the subjective assessment make the use of questionnaires separately becoming debatable (Wiktorin *et al.*, 1993).

In relation to agriculture, it has been reported that an intervention method such as participatory ergonomics can significantly reduce the injuries of work-related problems (Christiani, 1982; Partanen *et al.*, 1991). This is particularly true in industrially developing countries where an increasing number of examples demonstrating the effectiveness of participatory approach, both in ergonomics (Kogi and Sen, 1987; O'Neill and Haslegrave, 1990) and in research to improve subsistence agriculture (Appleton, 1994).

Furthermore, O'Neill (1997) stated that the use of participatory approach is now advocated and recently established form of research and the recommended techniques are being continually developed and refined as shown in table 1. In this context, the plan was to identify the best options for farmers in field trials and thereafter find out through laboratory tests, the scientific reasons behind the farmers' preferences. However, this in contrast to the normal approach whereby test of various options take place in the laboratory and then evaluate the most promising in the field (O'Neill, 1997).

Another issues that could be concluded from table 1, all the mentioned participatory techniques revolve around interviews and likewise which were already discussed earlier.

Table 1. Participatory techniques selected for the hand tools project (McCracken *et al.*, 1988).

Technique	Comments
Secondary data review	Examination of relevant information already existing
Direct observation	This may provide a good alternative to direct questions and may be awkward (e.g. size and contents of a dwelling will reflect income/health).
Semi-structured interviews	Do not administer questionnaires and make as few notes as possible. Do not have "official looking" documents and try not to work from prepared sheets. Be prepared to shift on interesting points Make full use of "key informants" e.g. village leaders, teachers, etc.
Analytical games	Asking farmers to rank or rate aspects of their work or life.
Stories and portraits	Discuss or describe difficult or delicate situations by creating stories.
Diagrams	Produce, with members of the village, diagram in space (i.e. maps) and time (i.e. calendars, work routines). A picture can save 1000 words and illustrate emphases in perception. And this is to say a part of interviews.
Workshops	Aim to involve all stakeholders in discussion of problems and situations; particularly try to avoid marginalisation of weaker groups.

As for direct measurement, it includes but not limited to anthopometry, work physiology and biomechanics. These methods are quantitative and relatively accurate (Capodaglio *et al.*, 1997) and could be employed in parallel with subjective methods.

Anthopometry is a branch of ergonomics which deals with measurements of the physical characteristics of human being, in particular, size and shapes (Pheasant, 1990). Traditionally, little attention has been paid to the efficiency, comfort and safety of the operators, but designers are now developing an ergonomics consciousness and if the anthropometric data are available they may wish to use them in the design process (Yadav *et al.*, 1995).

Work physiology, refers to the study of physiological functions subjected to the stress of work (Rodahl, 1989). Accordingly, the methods available to assess the work stress or demand are immense (Eastman Kodak Company, 1986). Of these, heart rate, blood pressure, oxygen consumption, minute ventilation (volume of air exchanged per minute), estimation of oxygen consumption at submaximal test and surface electromyography (muscle signals).

Obviously, numerous as these indices are, most are rarely used due to the problems of instrumentation, repeatability, and precision in practical situation (Bassi, 1992).

Heart rate along with oxygen consumption (direct measurement) was used to assess shovelling activities. For example, the energy expenditure of the operator using different shovels (Freidvals, 1986b). In another study Freidvals (1986a) describes the effect of shovel design on parameters such as shaft angle, size, and shape of the blade and the hollow on energy expenditure and subjective ratings.

However, carrying monitoring device can hinder the worker and hereby influence work methods (Capodaglio *et al.*, 1997). Having said that, heart rate (beats per minute) followed by psychophysical measures such as rating of perceived exertion (RPE), are the best universal measures of job demands (Eastman Kodak Company, 1986). Moreover, heart rate is the most convenient physiological measure of job stress and used to estimate accurate changes in cardiac output even in the lighter work loads (Eastman Kodak Company, 1986).

As for biomechancics methods, Chaffin *et al.* (1999) pointed out that occupational biomechanics, in both research and application is highly empirical. Furthermore, data acquisition can require elaborate measurement device such as dynamometers, motion analysis and electromyography (Davis and Marras, 200).

In relation to hand tools, a modified shovel design with two perpendicular shafts was studied by Degani *et al.* (1993). The results indicate a significant reduction in EMG values of the lumbar paraspinal muscles and a consistent reduction in rating of perceived exertions, when using the modified tool.

Öberg (1993) who reports the results of a simplified biomechanical analysis showing very significant values for the compression and shear force on the spine studied a similar tool.

Working postures and biomechanical analysis of shoulder load and lower-back compression when using shovels, push hoes and rakes was studied with advanced methods and optoelectronic measurements (Hansson and Öberg, 1996). The results show that certain parameters in tool design are affecting the work load. In addition, the determination of working posture itself gives a strong relation to the ergonomic load at different stage of work task (Öberg and Gebresenbet, 1998).

With reference to the literature on raking or rakes, Kumar and Cheng have carried out few studies. For instance, spinal stress in raking with different rake handles (Kumar and Cheng, 1990). Biomechanical analysis of raking and comparison of two rakes (Kumar and Cheng, 1990). In addition, Kumar (1995) studied the electromyography of spinal and abdominal muscles during garden raking with two rakes and rake handles. As a result, ergonomics designed of rakes were made which in turn, reduced the energy expenditure and low back problems.

In contrast, agricultural work with hand hoe has been neglected (Bassi, 1992). Having said that, it is important to have sophisticated measurements to gain an in-depth understanding, however, simpler measurement will allow the ergonomics assessment take place in the actual workplace (Davis and Marras, 200). In this regard, several methods of acquiring biomechanical data are available to evaluate the human kinematics and kinetics in occupational activities (Chaffin *et al*, 1999).

For kinematics, the method concerns with the study of motions without the forces that cause them. In this context, methods of observation such as, OWAS (Ovako Working Posture Analysis System) and WOPALAS (Working Posture Analysis System) are relevant examples. Both OWAS and WOPALAS are used for rapid assessment of inadequate postures that may be hazardous (Pinzke, 1994). They described as suitable methods for analysing postural load at agricultural work (Pinzke, 1994). However, they give no detailed information regarding the load on different joints (Pinzke, 1994; Nevala-Puranen, 1995).

As for kinetics, the method concerns with the study of forces that cause the motion, in that respect, kinetics study takes an advantage on the descriptive nature of kinematics.

Since the required measurements concern with the forces exerted, studies have shown that, measure of 2-D and 3-D movement, including; displacements, angles, velocities and acceleration for every part of the body, may strike a balance between the cost of direct measurements and the low validity, and subjectively of questionnaires, diaries and interviews (Capodaglio *et al.*, 1997).

To this effect, for estimated biomechanical parameters, the measurement systems should meet at least the following biomechanical criteria (Chaffin, 1982; Brand and Crowninshield, 1981):

(a) Measurements should accurately estimate a specific, definable human motor function-that is; they should provide well-correlated and unbiased estimates of the function of interest.

(b) Results should be repeatable under prescribed conditions.

(c) Measurement should reflect specific population.

(d) The measurement should not alter the function being estimated.

(e) The measurement system should be practical – easy to set up and use, insensitive to outside influences and inexpensive (attention should be paid to the applicability under different conditions, skills required and cost with compare to direct measurement).

1.2 Aim of the project

The aim of this project is to develop methods under laboratory conditions that could be adapted in the field for ergonomics assessments of agricultural work with hand hoes. Bearing in mind that these methods should be appropriate to be used in both developing and industrially developed countries.

1.3 Definition of terms

Ergonomics is the discipline concerned with the fundamental understanding of interactions among human and other elements of a system. It continues "ergonomics contribute to the design of tasks, jobs, products and environments in order to make them compatible with the needs, abilities and limitations of people".

Assessment may be defined as a process by which one produces a value judgement of an object. The value judgement is used to accept or reject the object, or to choose the relatively best object from several alternatives (Kirchner, 1997).

Agriculture: The science, or occupation of cultivating the soil, producing crops, and forestry, harvesting any agricultural or horticultural commodity, raising livestock, dairing, poultry and etc. (State of Connecticut, 2000).

Hand tools: is a generic term that can be used to refer to many different types of equipment. For the purpose of this study, hand tools powered and controlled entirely by human effort (muscles) and which have no moving parts (Rogan and O'Neill, 1993).

Small-scale: The FAO's definition is "those who are socially, economically or cultural marginal". They constitute groups with limited or no access to productive resources and technology or to credit and with little and no bargaining power in the market (Singh, 1990).

Socio-economic: is a combination form of society, sociology and economics. Which means the scientific study of the nature and development of society and social behaviour in terms of culture, birth and mortality rate, income, education, and etc.

2. REVIEW OF LITERATURE

This chapter integrates and summaries related literature which presents what is so far known about the objective and problems under consideration, and thus providing the setting theories of the proposed study. Thus, the focus of this chapter is on heart rate a long with RPE and three-dimensional static strength analysis.

2.1 Heart rate and RPE

Hence estimation of the physical work load, and its physiological and psychophysical consequences, are essential activities in ergonomics, relatively simple and inexpensive intervention method such as measuring the heart rate and RPE can significantly reduce the risk of work with hand hoe (O'Neill, 1997).

Measuring the heart rate (taking the pulse) is one the most useful ways of assessing work load (Kroemer and Granjean, 1997). One can easily feel the pulses (the blood pressure in waves) at the radial artery in the wrist or at the carotid artery at the neck as depicted in figure 1. The measures take place by counting the number of beats per minute (e.g. beats in 10 seconds*6, or beats in 30 secods*2) and that is to say the estimated HR. However, to do this while a person is working with hand hoe is an intrusion that may disturb his or her work, thereby producing a false result (Kroemer and Granjean, 1997). So, an alternative cheapest and easiest way to measure HR in laboratory as well in the field is by mounting a portable Polar/Sports Meter on the chest and transmitter watch on the wrist and thereafter reading the pulse base on the time setting.

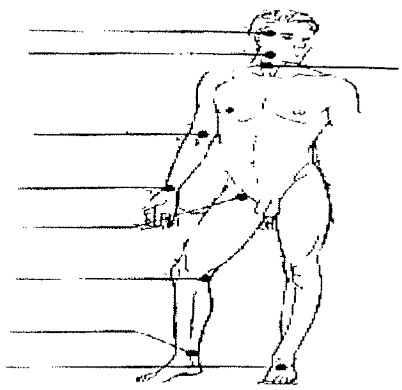


Figure 1. Body site where the pulse is most easily palpable (Marieb, 1991).

As for RPE, Borg (1998) stated that it can be used in both laboratory and field studies of short-term work task for which valid physiological measurements are difficult to obtain. The perceived exertion, difficulty and fatigue that a person experiences in a certain work situation is, as a rule, an important sign of a real or objective load. Measurement of the physical load is not sufficient since it does not take into consideration the particular difficulty of the performance or the capacity of the individual. It is often difficult from technical and biomechanical analyses to understand the seriousness of difficulty that a person experiences. Physiological determinations give important information, but they may be insufficient due to technical problems in obtaining relevant but simple measurements for short-term activities or activities involving special movement patterns. Therefore, perceptual estimations give important information because the severity of a task's depends on the individual doing the work (Borg, 1998).

Further, RPE scale offers an important way to compare the exertion and difficulty when using different tools, and one main advantage is that the given ratings grow linearly with exercise intensity, HR, VO2. Given ratings are then easy to compare with common measurements of exercise intensity. By developing reliable scaling methods with precise instructions, the quantification of subjective symptoms is found to be well justified. The validity of the scaling methods can be proven using physiological correlates with subsequent prediction of behaviour and physical performances.

In relation to hand hoe, Tewari *et al.* (1991) studied the physiological demands of Indian hand hoes in conjunction with some consideration of productivity. By recording the work pulse rate (HR) and oxygen uptake of subjects during a weeding task, together with a number of work assessment measures (e.g., the length of time taken to weed a given area), the authors determined the physiological demands and efficiencies of the tools for weeding.

On the other hand, Bassi (1992) in a study about improvements to the design of the hand hoe for Nigerian farmers included different methods for assessing the existing design. Of these, heart rate measurements and video recording of the working posture. The results revealed that the heart rate of the subject vary from 109.0 to 144.0 beats per minute. This is similar to the range of heart rate values of 109 to 129 beats/minute (Nwuba and Kaul, 1986), and 108.0 to 138.0 beats/minute (Dibbits *et al.*, 1978).

Sen and Sahu (1996) employed heart rate measurement along with subjective ratings of perceived exertion (RPE) of the shoulder, arms and low back for ergonomics evaluation of a multipurpose shovel-cum-hoe during manual material handling. Correspondingly, an ergonomics designed prototype was made and accepted by the users.

Further, the ergonomics techniques and methodologies selected by O'Neill (1997) depicted in table 2 was being described as the most appropriate for developing countries and the most likely to yield meaningful results.

Table 2. Ergonomics technique selected for the hand tools project

Technique	Comments
Subjective assessment	Rating, ranking, interviews, questionnaire.
Body maps (e.g. for discomfort, fatigue)	Simply indicate areas. Rank areas (worst, etc.) Rate areas on a pre-determined scale (e.g. 0-5).
Postural evaluation	Diagrams, photographs, video (stress selection). Anthopometric measurements.
Workload	Rating of perceived exertion (Borg scale) Heart rate, for work stress/ heat stress fatigue / recovery (Oxygen uptake).
Work study	How tasks are performed The organisation of the tasks

2.2 Three-dimensional static strength analysis (3D SSPP)

Broadly speaking, manual material handling that require awkward posture and exertions of high magnitude are classified as ones have a high worker strength demand (Chaffin, 1997). It is believed that these types of exertion still account of a serious risk factor for discomfort, reduced efficiency and musculoskeletal disorders.

In 1989 Chaffin and associates at the University of Michigan developed a static three-dimensional kinematic model of the musculoskeletal system that can be used to evaluate biomechanical responses to whole-body exertions such as lifting, pushing and pulling (Chaffin and Baker, 1970; Garg and Chaffin, 1975; Chaffin and Anderson, 1991). The model is applicable to worker motions in three-dimensional space (The University of Michigan, 1999).

3D SSPP has generally been used for two purposes: to compare strength demands of a task to the strength capabilities of the workforce to estimate the the percentage of adult males and females are capable of performing the task, and to predict compressive forces acting at the L5/S1 spinal disc during static exertions.

Moreover, the model has been used extensively to evaluate whole-body tasks that are performed at normal movement speeds on an infrequent basis. Because the model does not consider the effects of fatigue, it is generally not appropriate for highly repetitive tasks or highly dynamic motions (Chaffin and Baker, 1970; Garg and Chaffin, 1975; Chaffin and Anderson, 1991).

Despite these limitations, the model has been used to predict biomechanical resposes to strenous exertions associated with common manual handling tasks.

Another issue, the model helps to evaluate proposed workplace designs and redesign prior to the actual construction or reconstruction of the workplace or task (The University of Michigan, 1999).

However, the 3D SSPP should not be used as the sole determinant of worker strength performance or job designs based on that performance. Other criteria and professional judgement are required to properly design safe and productive jobs (University of the Michigan, 1999).

2.2.1 Overview of biomechanical strength prediction modelling

In general, much attention has been paid to the solution of the spinal joint load distribution problem (Cheng and Kumar, 1991). And that is to say, an operational estimate of loading may be obtained by biomechanical modelling (Chaffin *et al.*, 1999). Biomechanical models, describing the human body as a mechanical system of links connected by various types of joints, use body posture data and information about external forces applies to calculate joint forces and moments (Chaffin *et al.*, 1999). In other words, biomechanics provides calculations of compressive forces based on the observations of joint position, external forces and anthopometry of the subject (Capodaglio *et al.*, 1995). In this way, figure 2 shows a general logic used to predict population static strength in various jobs by means of biomechanical model.

Specific joints data and spinal vertebrae data are used as the limiting values for reactive moments at various body joints when a person of a designated stature and body weight attempts an exertion (e.g. lifts, pushes, or pulls in specific direction with one or both hands, while maintaining a known posture) (Chaffin, 1997).

To use the Michigan model (figure 2), it is necessary to describe the worker's anthopometry (height, body weight), working posture (angles at the ankles, hip, trunk, shoulders and elbows), and the vector (magnitude and direction) of the external load acting on the hands, the model use information to compute the strength required at ankles, knees, hip, trunk, shoulders, and elbows to maintain the system in static equilibrium. For this reason, strength is characterised as the ability to create mechanical moment (Chaffin and Baker, 1970; Garg and Chaffin, 1975; Chaffin and Anderson, 1991; Chaffin, 1997). To maintain equilibrium, each joint must exert an equal opposite reactive moment. Moreover,, indivual and task parameters such as body weight, posture and hand force create resultant forces and mechanical moments at each joint.

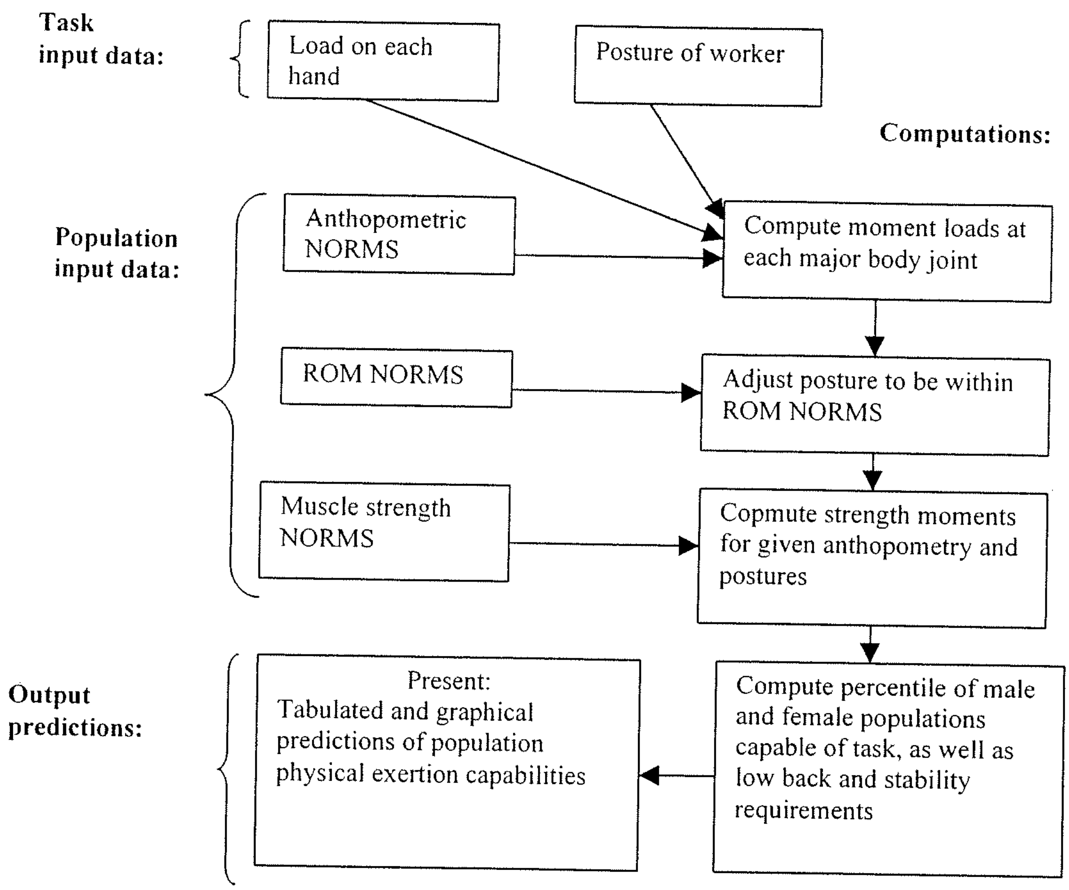


Figure 2. Biomechanical logic used to predict whole-body static exertion capabilities for given postures, hand force directions, and anthopometric groups (Chaffin, 1997).

3. Material and Methods

The methodology employed is meant to serve the objective of the study as defined earlier. Thus, this chapter will cover equipment; procedures; data collection and data analysis.

3.1 Equipment

The main equipment used in this experiment were as follows:

3.1.1 Location of the study

The study was conducted in the ergonomics laboratory at the Swedish Institute and Environmental Engineering (JTI). The laboratory is utilised by both JTI and the Department of Agricultural Engineering at Swedish of (SLU) Agricultural Science University.

The physical environment during the experiment; dry and wet temperatures was 20 and 14°C respectively. The relative humidity read from Screen Mansons Hygrometer was 50%.

3.1.2 Subjects

Eight male graduate students (3 Masters and 5 Ph.D.) from Department of Agricultural Engineering and Rural Development, SLU volunteered for the study. A statement from the subject was taken as the proof of their health in connection with cardiovascular and musculoskeletal problems. And a summary of the subjects' characteristics is presented in table 3.

Table 3. Subjects' characteristics

	Age (years)	Weight (Kg)	Height (cm)	Arm length (cm)
Mean	29.4	81.0	176.8	74.10
SD	8.2	10.5	5.9	5.0
Median	27.0	83.0	176.0	76.0
Max.	51.0	97.0	187.0	80.0
Min.	24.0	61.0	169.0	67.0
Range	27.0	36.0	18.0	13.0

SD = standard deviation, Max = maximum, Min = minimum

3.1.3 Task

The subjects were asked to hold a hand hoe and dig in metal box full of wet sand.

3.1.4 Hand hoe

A hand hoe is a tool for ground clearing, soil cultivation, planting, weeding, irrigation canal making, diverting irrigation water onto plots and harvesting (Bassi, 1992).

The weight of the representative hoe (figure 3) was 2.5 kg with a wooden handle has a length of 1090.0 mm and blade angle of 65°.

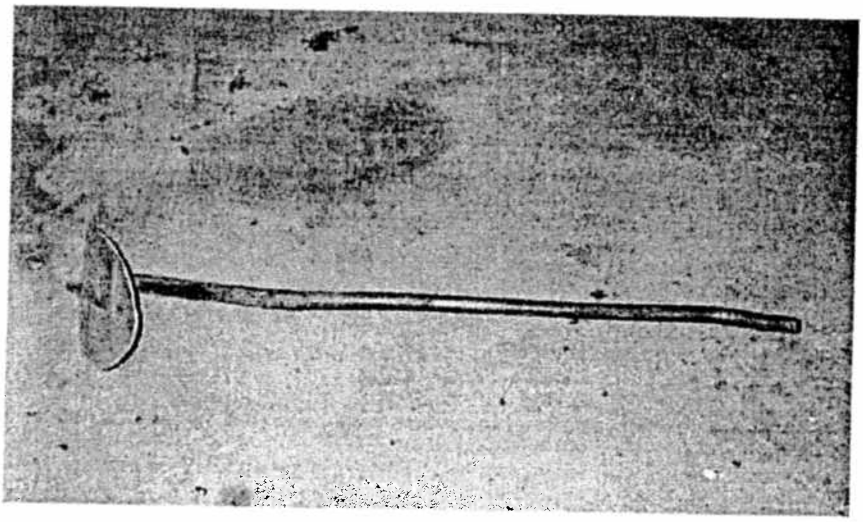


Figure 3. The hoe used during the experiment

3.1.5 Soil box (bin)

A metal box with a length of 2m and width of 1.5 m (figure 4) was used as an experimental media.

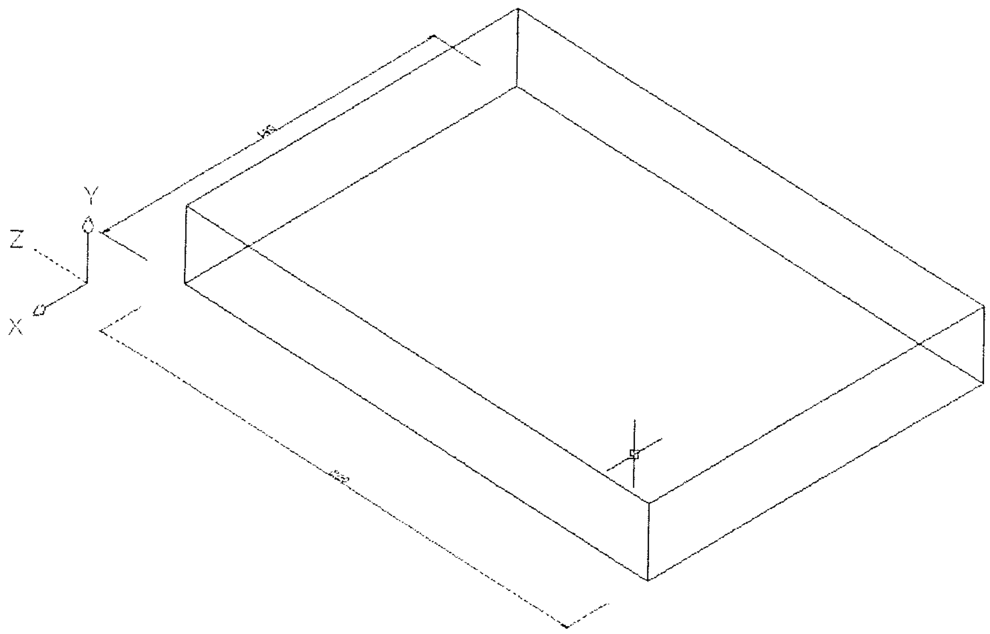


Figure 4. Sketch for the soil box

3.1.6 Whirling and Mansons Hygrometer

Whirling Hygrometer was used to measure dry and wet temperature and thereafter the relative humidity was read from Mansons Hygrometer.

3.1.7 Cameras

The following video cameras were used to record the working postures:

- Panasonic VHS-C Model NV-R10E.
- Panasonic S-VHSC Model NV-S7E.
- Panasonic Digital Video Camera, Model No. NV-DS99EG

3.1.8 Monacor (The video quad processors)

A Monacor (TVSP-420, No 19.2260) unit (made in Germany) was used to synchronise the pictures. This unit has been designed for monitoring and alarm system applications. With this unit up to four cameras pictures can be displayed in real time on one monitor. The cameras were connected to the input buttons while the monitor and video recorder was connected to the live jack. The unit is protected against humidity and heat (permissible operating temperature range 0-40 ° C.

3.1.9 Video recorder and TV

The Panasonic VCR was used to record the pictures from the cameras in one tape while the monitor displaying the pictures.

3.1.10 Weighing machine (Scale)

An electric scale was used to measure the subjects' weight as input for the 3D SSPP.

3.1.11 Polar Meter and Transmitter Watch

This consists of two electrodes mounted on the chest belt which pick up the pulse rate, and the belt transmits the pulse picked up to the a receiver watch that display the pulse rate.

3.1.12 Markers

Mefix: self-adhesive fabric (white colour) was used to mark the following body joints: shoulder; elbow; wrist; hip; knee and ankle.

3.1.13 Borg Scale

The RPE scale (6-20) is based upon asking the subject immediately at the end of hoeing task about how intense the level of exertion. On this scale, very light exertion is under 10 points and very heavy is over 15. All the odd numbers are anchored with the aid of verbal expression as shown in Appendix A.

3.1.14 Metronome: Seiko Quartz uses a battery as a power source was used to adjust the digging task at steady rate of 60 rev/min.

3.1.15 Protractor: It was used for measuring joint angles.

3.1.16 Hardware requirements for 3D SSPP

Due to the complexity of the interactions between the 3D SSPP programme and the Windows environment as well as the computations that are performed by the posture prediction, inverse kinematics, human modelling graphs, and 3D back optimisation routines, the minimum hardware configuration recommended (The University of Michigan, 1999) to run the programme consists of the following:

- IBM PC or compatible with an Intel 486SX, 486DX, or Pentium processor running at 33 MHz or greater.
- 8 MB RAM minimum recommended 16 MB.
- 2 MB of available hard disk space.
- VGA monitor and graphics card, 256 colours minimum.

Regardless of the platform used to run the 3D SSPP, a math coprocessor must be used a part of the hardware configuration for the programme to run. In computers with an 80486DX or Pentium processor, a math coprocessor is integrated into the main processor; systems without one of these processors will need to have a math coprocessor installed.

3.1.16.1 Software requirements

In order to run 3D SSPP, A Microsoft Windows 95, 98 or Windows NT operating system is required.

3.2 Procedures

3.2.1 Installation of the cameras:

The aforementioned cameras were installed as follows:

- Camera on the ceiling: to view the movement in the horizontal plane
- Camera on the front: to view the movement on the frontal plane
- Camera on the lateral side: to view movement on the sagittal plane.

3.2.2 Instruction

The subjects were briefed about the aim of the study, and Borg scale was verbally explained and presented in Swedish language (Appendix A). In that respect, Borg pointed out that RPE could give a better result if the scale translated into the local language.

3.2.3 Placement of the markers

Markers were placed on the earlier mentioned joints at the sagittal plane.

3.2.4 Setting

The Polar meter was mounted on the chest whereas, the transmitter watch worn on the writs.

3.3 Data collection

The subjects were rested on a chair for 5 minutes and HR was recorded at 3rd and 4th minute durining interval of 15 seconds.

Thereafter, the subjects were asked to dig in the experimental media for 3 min. and HR was recorded at the last minute during interval of 15 seconds. The performed task followed by rest for 5 min and HR was recorded at the last two minutes (3rd & 4th) during interval of 15 seconds.

The digging task was repeated and the HR was recorded as mentioned during digging task. Thereafter, average of recorded resting and working HR was taken as final readings. RPE was shown to the subject at the end of each digging task to mark the level of exertion on the scale 6-20 (Appendix A). Simultaneously, the video cameras were adjusted to record the working posture. Using the snapshot, pictures were frozen at two postures. First, when the hoe lifted up whereas the second, when the subject digging in the box at assumed awkward posture as illustrated in figure 5.

From the frozen pictures, 6 frames (drawings) were made for each subject on transparencies. These frames taken for the top; lateral and frontal view (Appendix B) while the hoe lifted up as well as stroke the soil at assumed awkward posture. Then, various joint angles were measure and input in the 3D SSPP software through task input. The task input includes body segment angles, subject's anthopometry (gender, weight and height), hand location and hand force (load) magnitude and direction. The hand force direction can be illustrated in figure 5 and 6 and analysed and calculated by the followed equations.

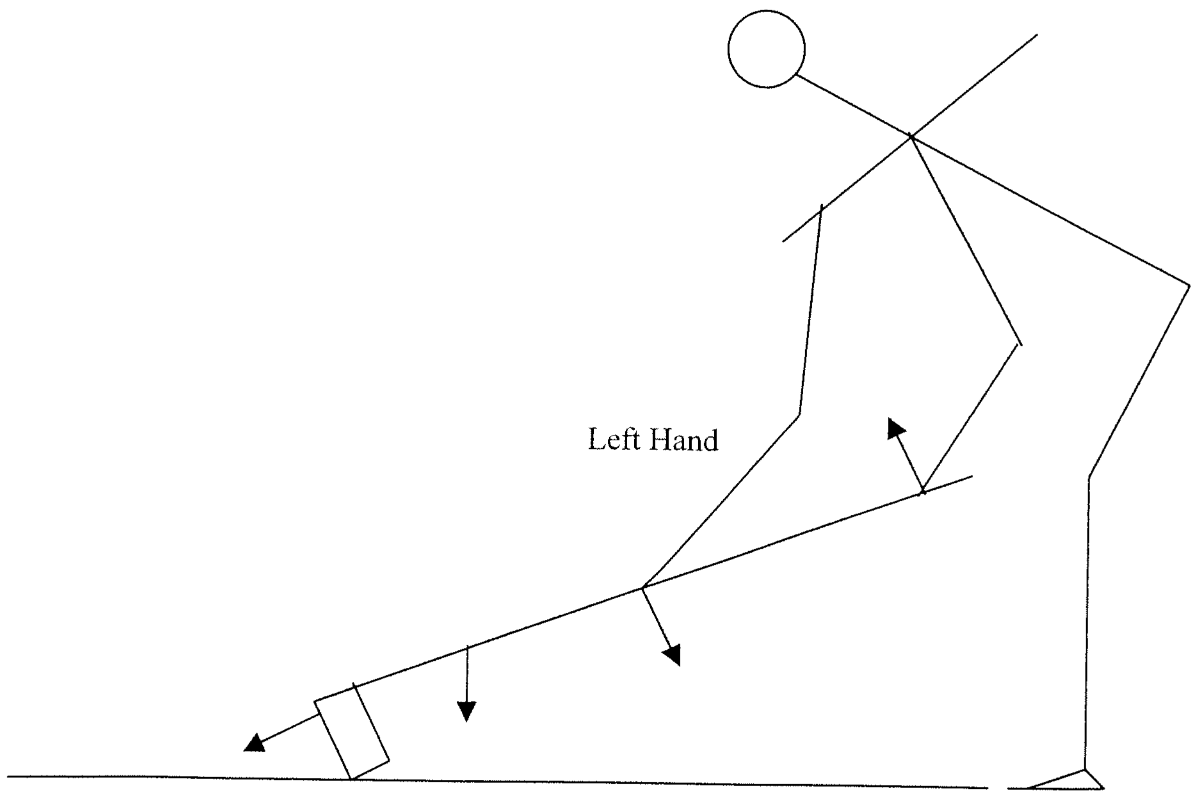


Figure 5. A subject at assumed awkward posture

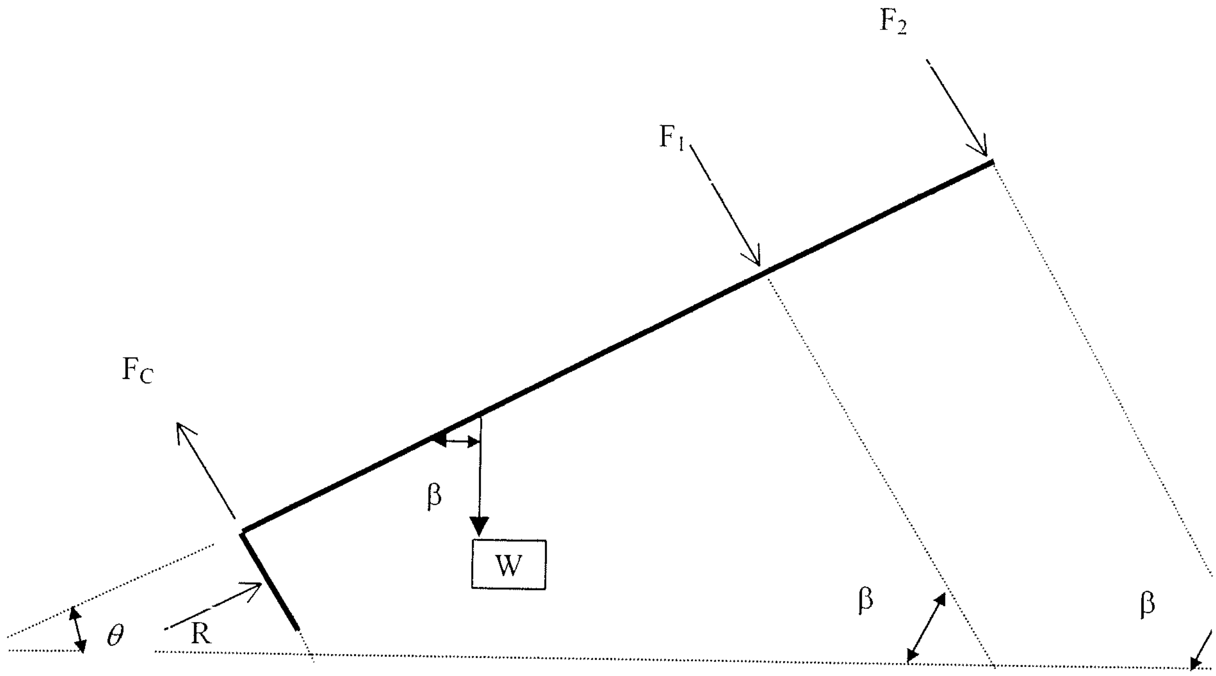


Figure 6. Analysis of hand force

Equations for analysing the vectors and calculating the force:

F1 = Force applied to the left hand.
F2 = Force applied to the right hand.

F_C = Friction Force between the head of the blade and the ground
R = The reaction force, from the ground on the blade
θ & β = The angles

$F_c = \mu R$ ... (1)

A: Resolve the forces perpendicular to the handle:

$\mathbf{F_1 + F_2 + W \sin\beta - F_C = m * a}$ ... (2)

(a: is the acceleration of the handle and equation (2) was derived from Newton third Low F- F_C = m a where m is the mass of the handle and it is equal to the W divided by g)

$\mathbf{F_1 + F_2 + W \cos\theta - \mu R = m * a}$ ... (3)

(Substitute $F_C = \mu R$ and $\sin \beta = \sin (90- \theta) = \cos \theta$),

B: Resolve the forces parallel to the handle:

$\mathbf{R = W \cos \beta}$ ... (4)
$\mathbf{R = W \sin \theta}$ ... (5)

By substituting equation (5) into equation (3) the followings were obtained:

$\mathbf{F_1 + F_2 + W \cos \theta - \mu W \sin \theta = m * a}$ ... (6)

($a = dv/dt = dx/dt * dv/dx = v\, dv/dx$, where v is the velocity of the handle, t is the time and x is the height of the handle from the ground)

$\mathbf{F_1 + F_2 + W \cos \theta - \mu W \sin \theta = m * v\, dv/dx}$ ... (7)

The forces F_1 and F_2 depend on the height **X**, and the relation is that, F_1 and F_2 are directly proportion to the height **X**, that is to say, if **X increases**, the value of the force will increase.
Therefore:

$\mathbf{F_1 = K_1 X}$
$\mathbf{F_2 = K_2} X$

By substituting the value of F_1 and F_2 in equation (7) gives

$\mathbf{K_1 X + K_2 X + W \cos \theta - \mu W \sin \theta = m * v\, dv/dx}$

$\mathbf{(K_1 + K_2) X + W \cos \theta - \mu W \sin \theta = m * v\, dv/dx}$ ... (8)

$\mathbf{(K_1 + K_2) X + W (\cos \theta - \mu \sin \theta) = m * v\, dv/dx}$

$\mathbf{\int (K_1 + K_2) X + W (\cos \theta - \mu \sin \theta)\, dx = \int m * v\, dv}$ ... (9)

Integration of both sides gives:

$\mathbf{\frac{1}{2} (K_1 + K_2) X^2 + W (\cos \theta - \mu \sin \theta) X = \frac{1}{2} m * v^2}$ ... (10)

($\mathbf{(K_1 + K_2) X^2 = (K_1 X + K_2 X) X}$, which is equal to:
$\mathbf{(F_1 + F_2) X}$ and substitute in equation (10))

$\mathbf{\frac{1}{2} (F_1 + F_2) X + W (\cos \theta - \mu \sin \theta) X = \frac{1}{2} m * v^2}$

$\mathbf{(F_1 + F_2) X = m * v^2 - 2W (\cos \theta - \mu \sin \theta) X}$

$\mathbf{(F_1 + F_2) = \frac{m * v^2}{X} - 2W (\cos \theta - \mu \sin \theta)}$ ... (11)

$\mathbf{v^2 = (F_1 + F_2) X + 2W (\cos \theta - \mu \sin \theta) X}$ .... (12)

Equation (11) shows that the value of force **(F_1 + F2)** increases with the increase in the velocity **v.**
Equation (12) shows that the value of **v** increases with the increase of force **(F_1 + F2).**
So, for a large force the velocity of the handle should be increased.

$\mathbf{R} \cos\theta + \mu\, \mathbf{R} \sin\theta = \mathbf{F_1} \sin\theta + \mathbf{F_2} \sin\theta,$
(Substitution of $F_C = \mu\, \mathbf{R}$ and $\cos\beta = \cos(90-\theta) = \sin\theta$),
$\mathbf{R}(\cos\theta + \mu \sin\theta) = \sin\theta\, (\mathbf{F_1} + \mathbf{F_2}) \ldots (2)$

3.4 Data analysis

3.4.1 3D SSPP

3D SSPP software was utilised to perform various transformations and calculation for the input data. The Report menu in the software analysed force and moment vectors, strength capabilities, and low back compression forces and the muscle action in the torso.

3.4.2 Microsoft XL

XL was used to perform linear regression analysis between HR and RPE at level of significance $p < 0.05$. In addition, the software was employed to plot the force on L5/S1 as a function of HR and RPE.

4. RESULTS

This chapter presents the results of the study, which cover the HR along with RPE; Analysis Summary obtained from 3D SSPP software while the hand hoe lifted up as well as stroke the soil and the forces on L5/S1 as a function of HR and RPE when the hoe strokes the soil.

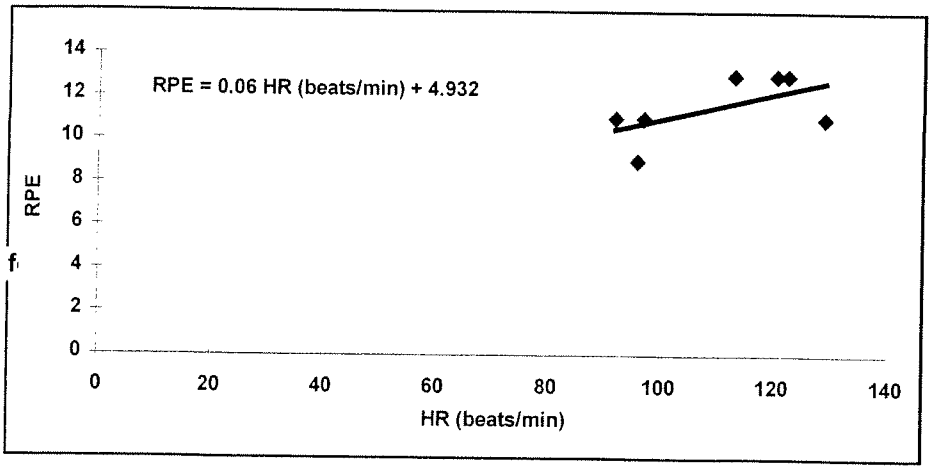
4.1 HR and RPE

A maximum HR for each subject was estimated from the equation 220-age and the mean of resting and working HR along with RPE is presented in table 4.

Table 4. Summary of HR and RPE for different age group

Sub. No.	Age	HR.rest	HR.hoe	HR.max	RPE.
1	24	55.5	97	196	13
2	26	73	122.5	194	15
3	29	55	96	191	15
4	26	62	92	194	11
5	29	65	120.5	191	13
6	51	69.5	113	169	13
7	27	53.5	105	193	11
8	27	57.5	129	193	15

The plot of HR as a function of RPE is presented with a regression line as shown in figure 7.



Coefficient correlation (r) = 0.59; p<0.05

Figure 7. Linear regression analysis between HR and RPE when the hoe stroke the soil.

4.2 The output from 3D SSPP

The output obtained from the 3D SSPP is numerous and therefore the results presented here include only the Analysis Summary while the hoe lifted up as well as stroke the soil. The 3D Lowback Analysis (force on L4/L5) while the hoe stroke the soil is presented in Appendix C.

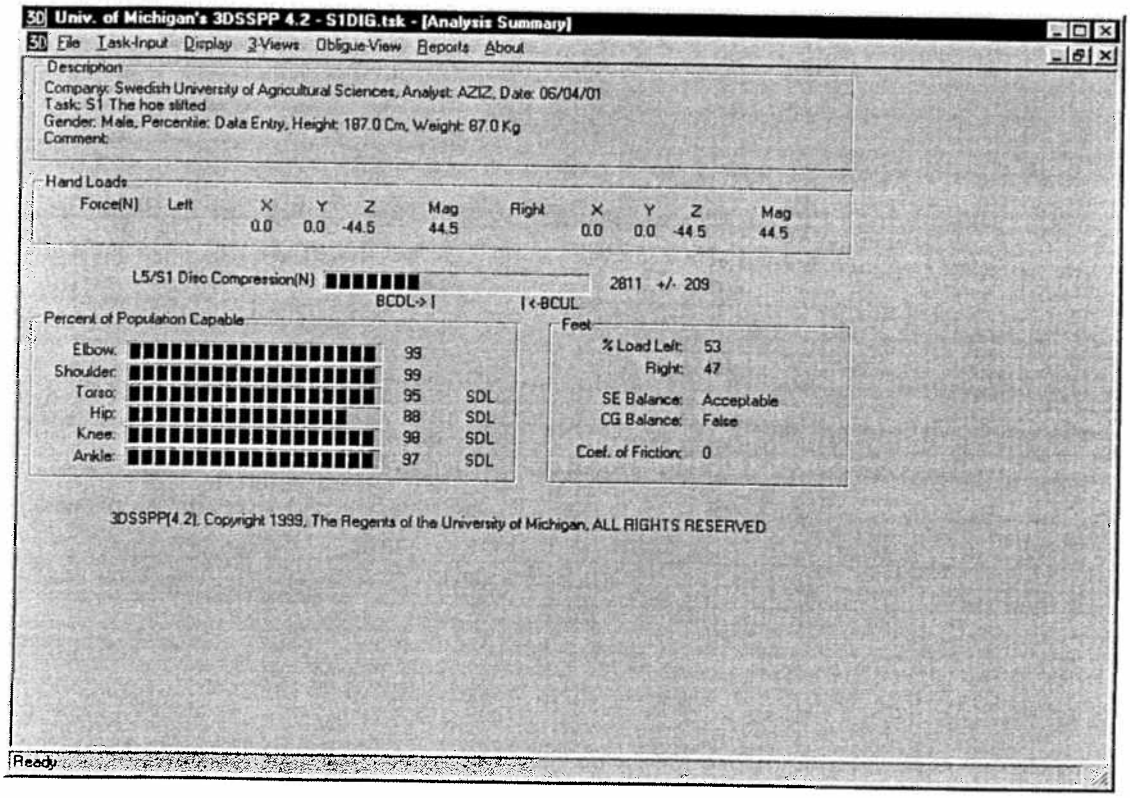


Figure 8. Analysis Summary for S1 while the hoe lifted up.

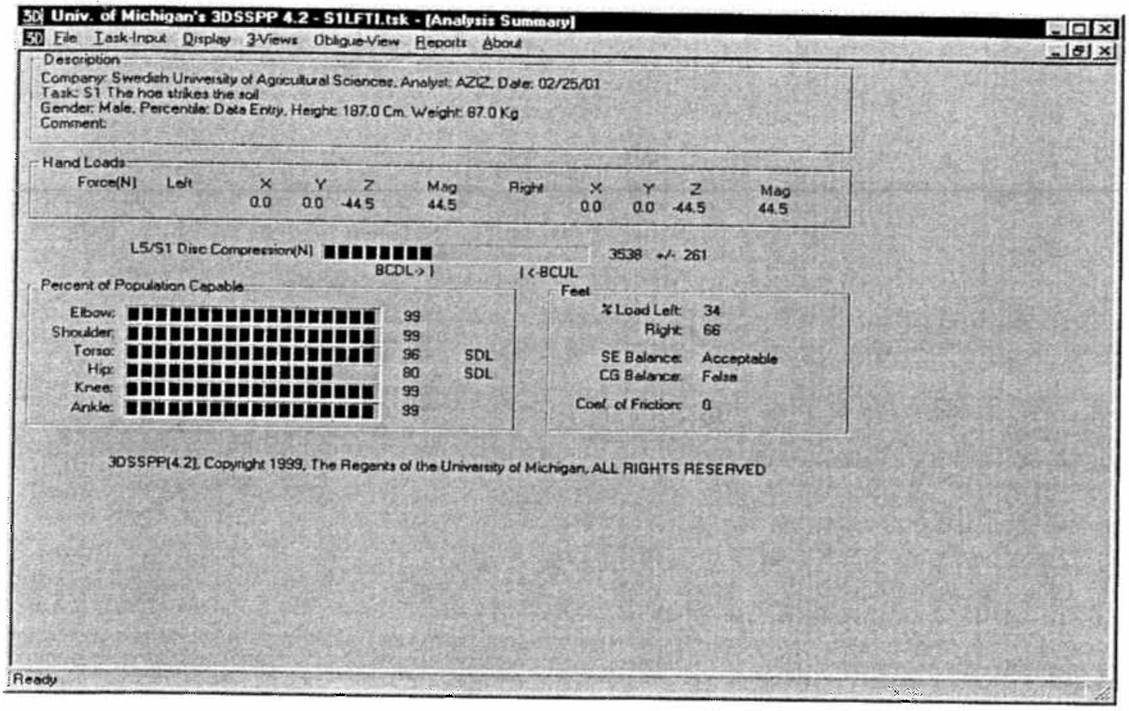


Figure 9. Analysis Summary for S1 while the hoe stroke the soil.

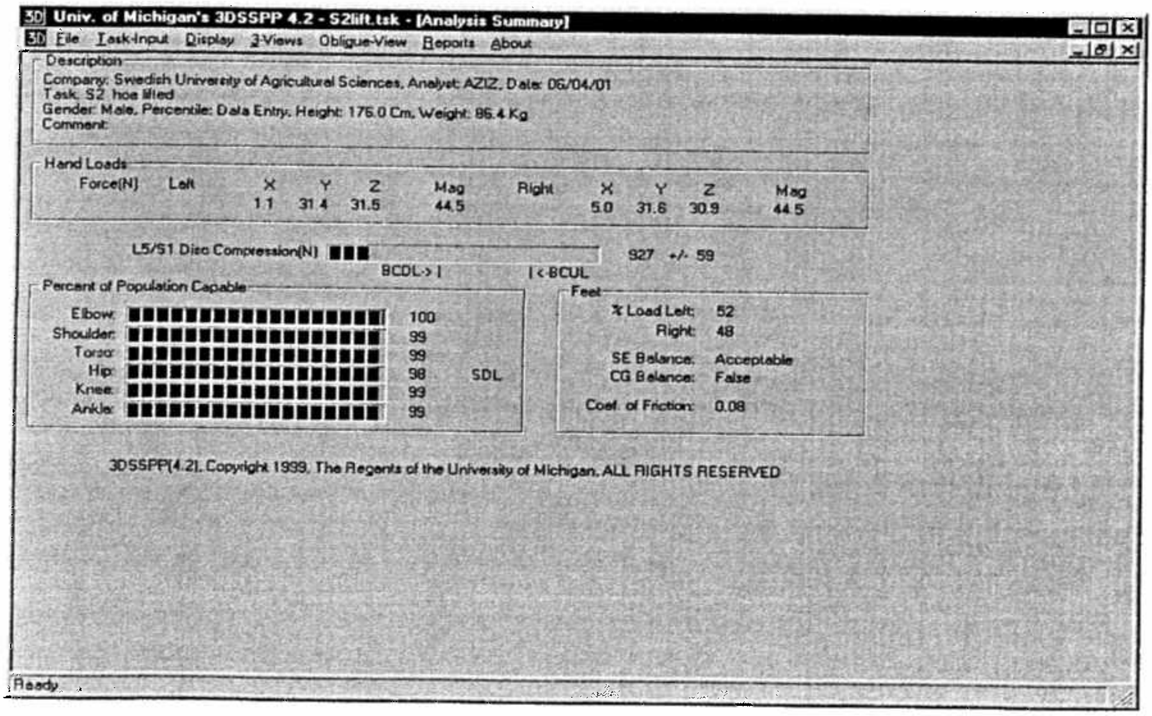


Figure 10. Analysis Summary for S2 while the hoe lifted up.

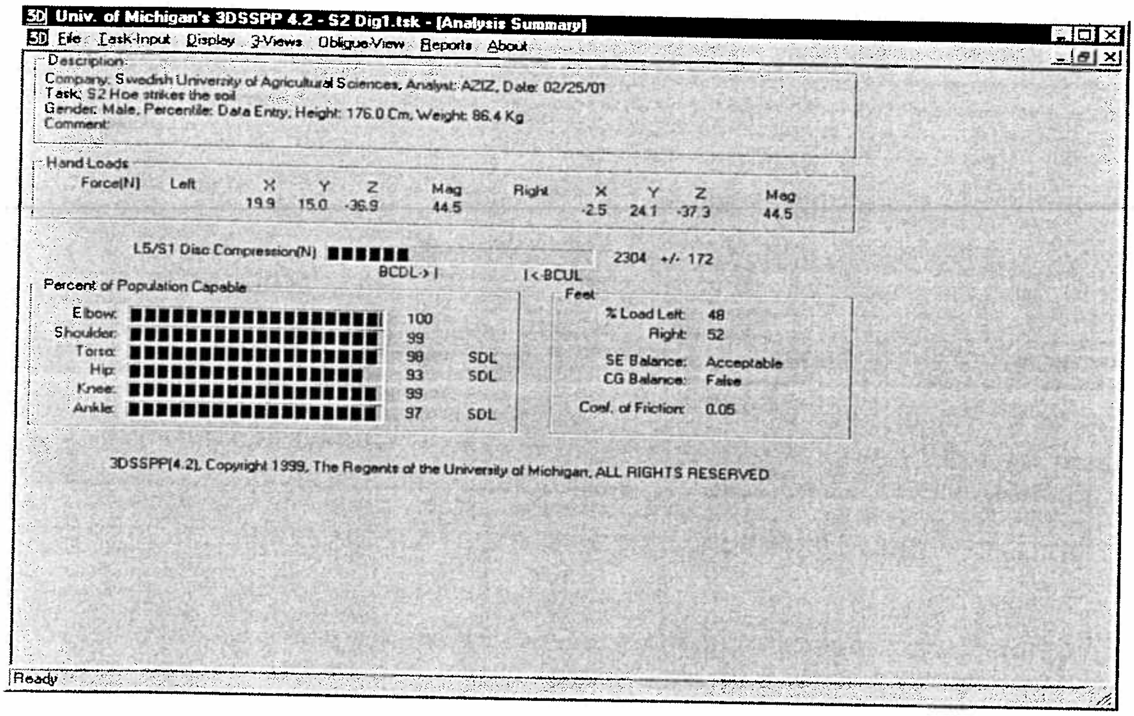


Figure 11. Analysis Summary for S2 while the hoe stroke the soil.

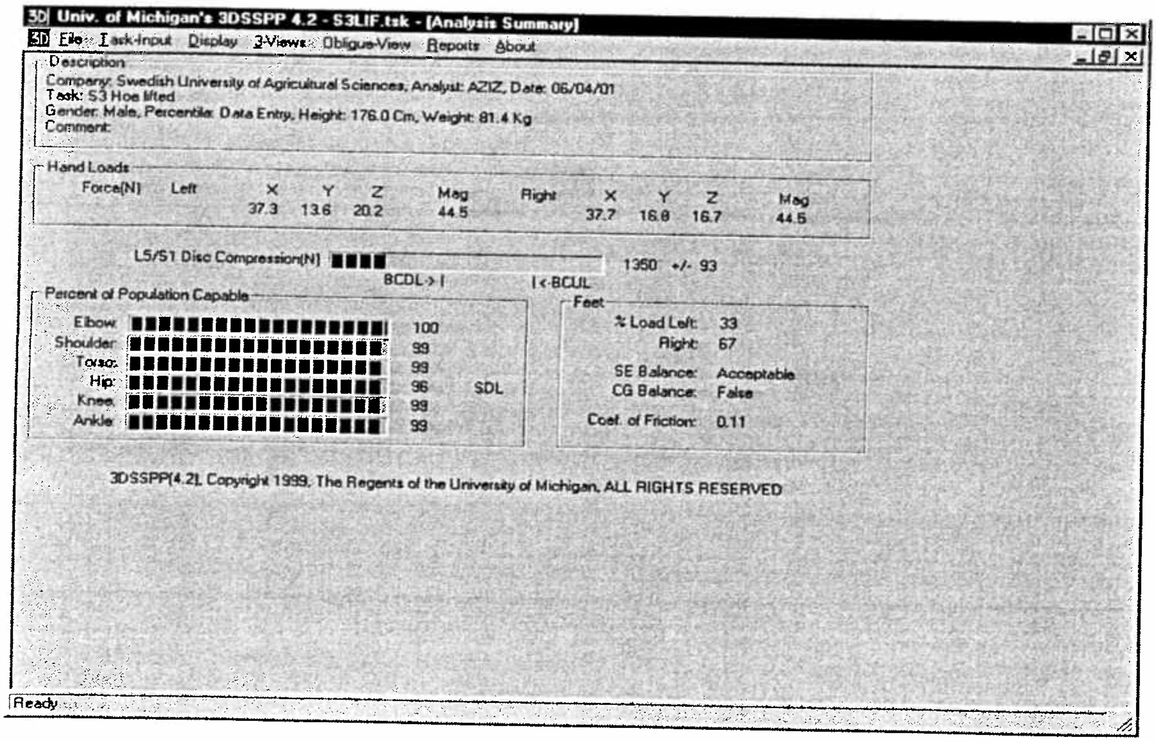


Figure 12. Analysis Summary for S3 while the hoe lifted up.

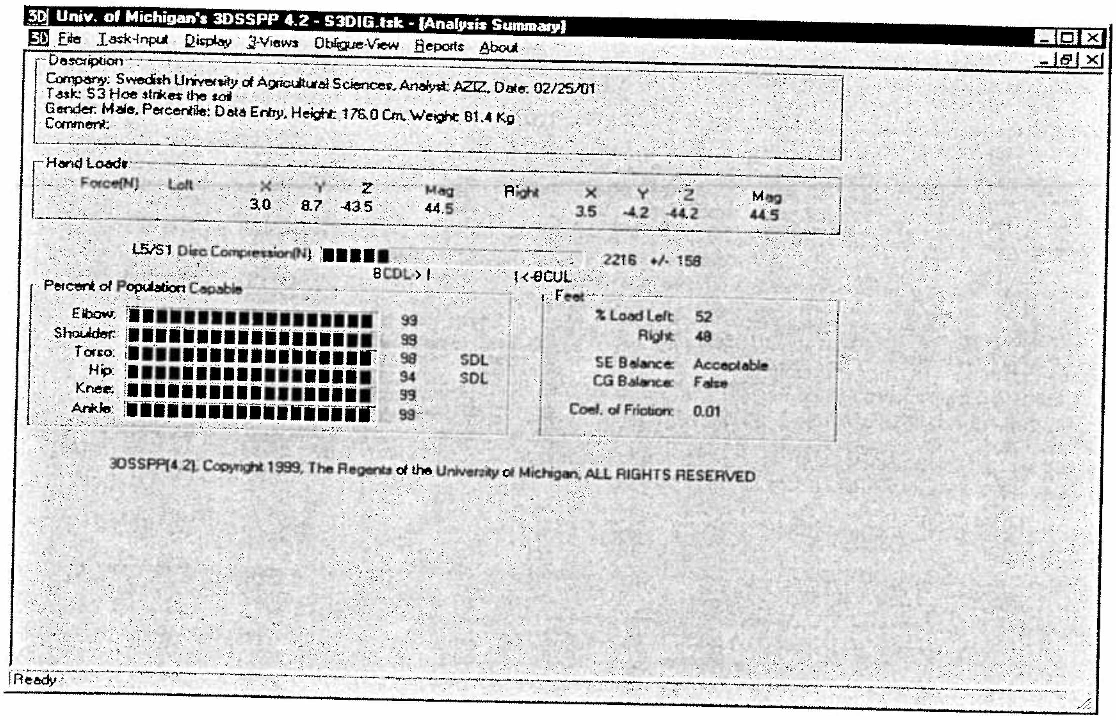


Figure 13. Analysis Summary for S3 while the hoe stroke the soil.

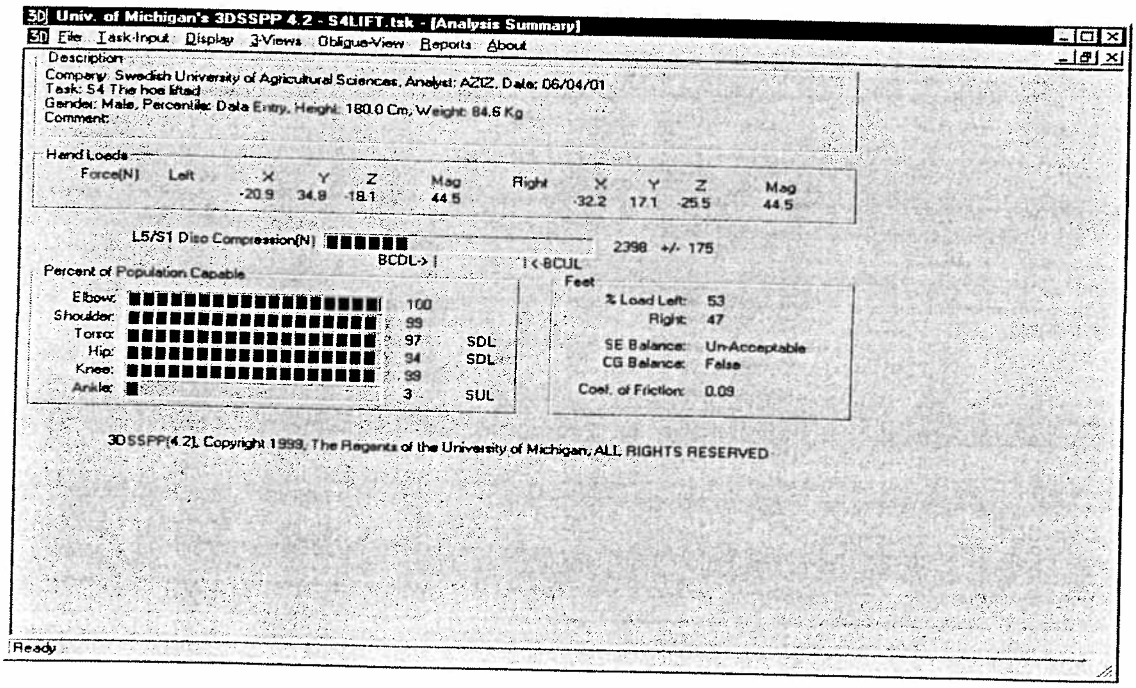


Figure 14. Analysis Summary for S4 while the hoe lifted up.

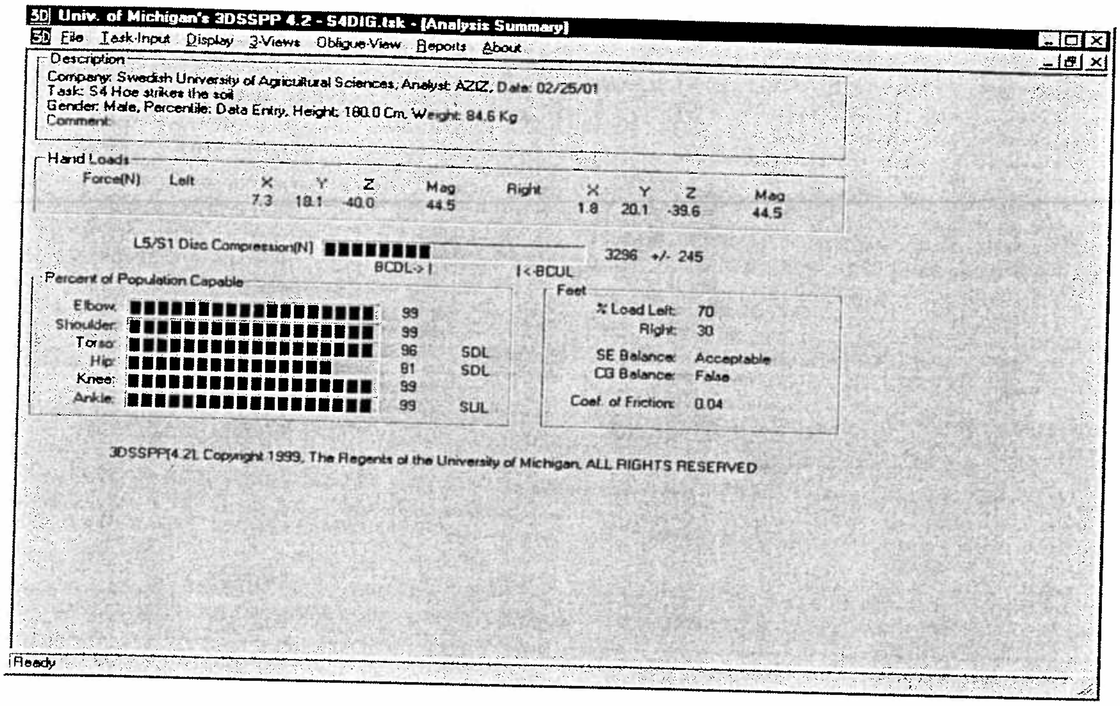


Figure 15. Analysis Summary for S4 while the hoe stroke the soil.

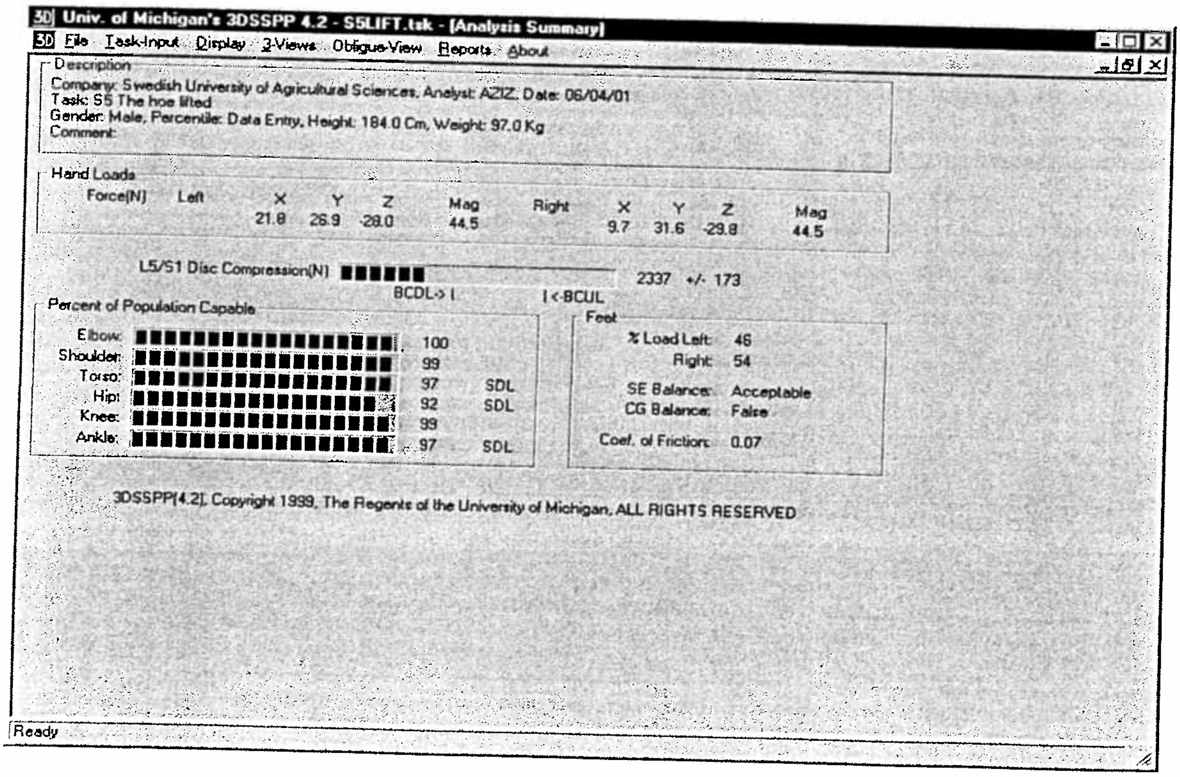


Figure 16. Analysis Summary for S5 while the hoe lifted up.

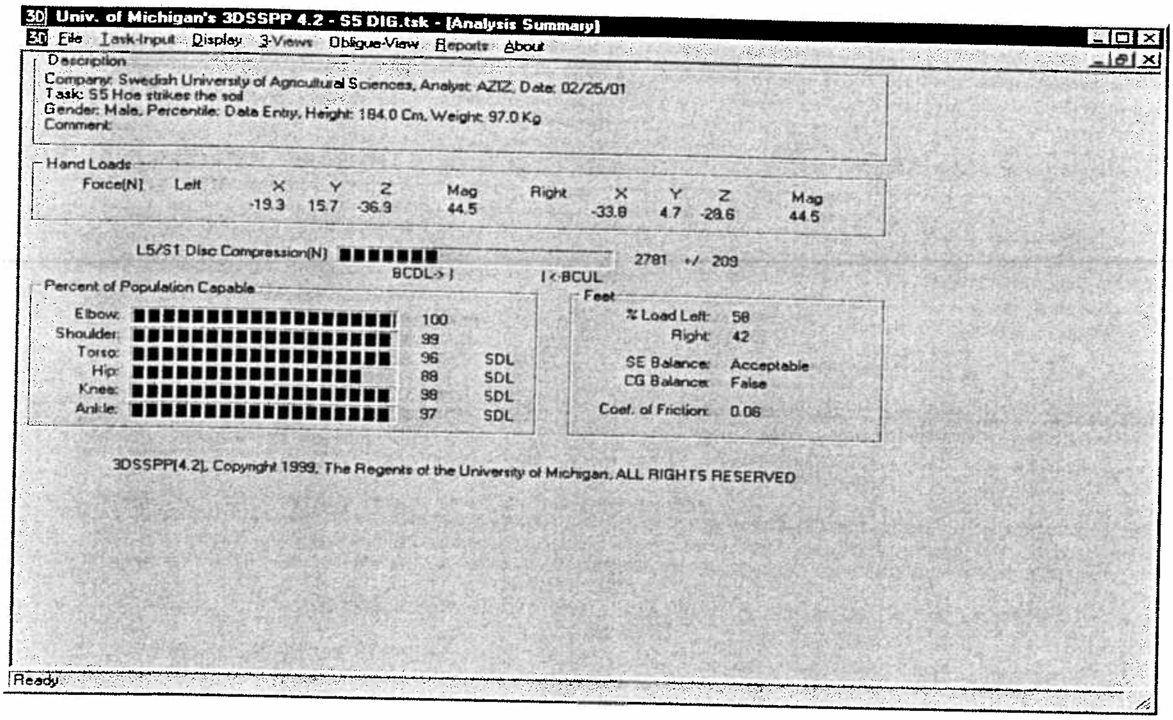


Figure 17. Analysis Summary for S5 while the hoe stroke the soil.

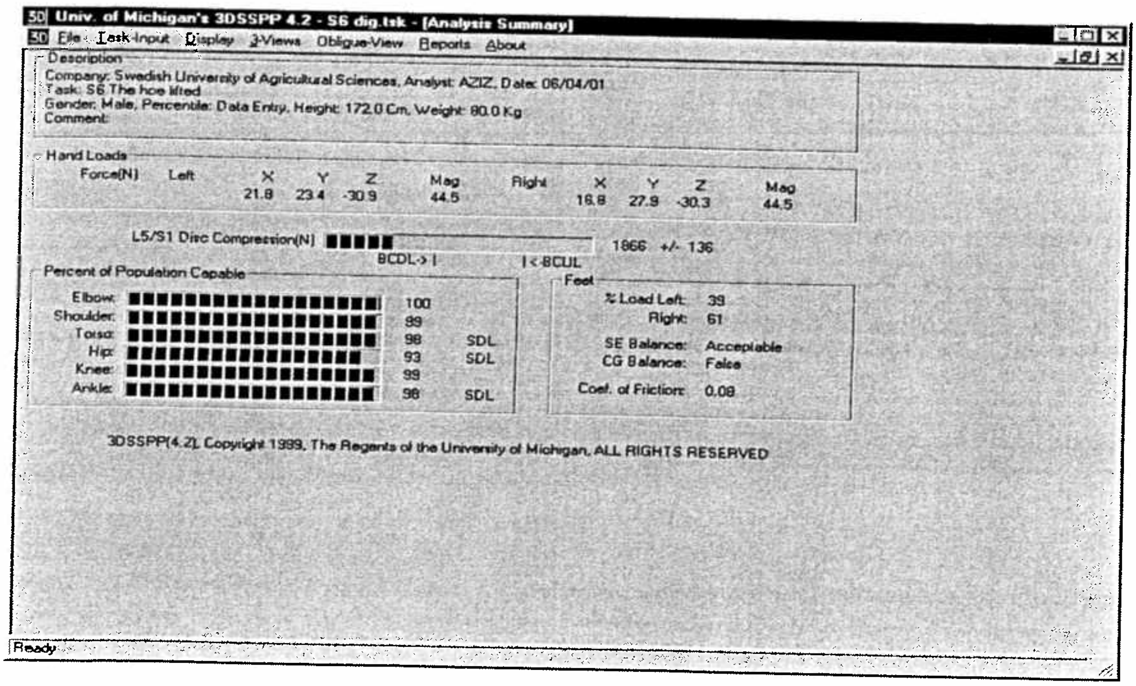


Figure 18. Analysis Summary for S6 while the hoe lifted up.

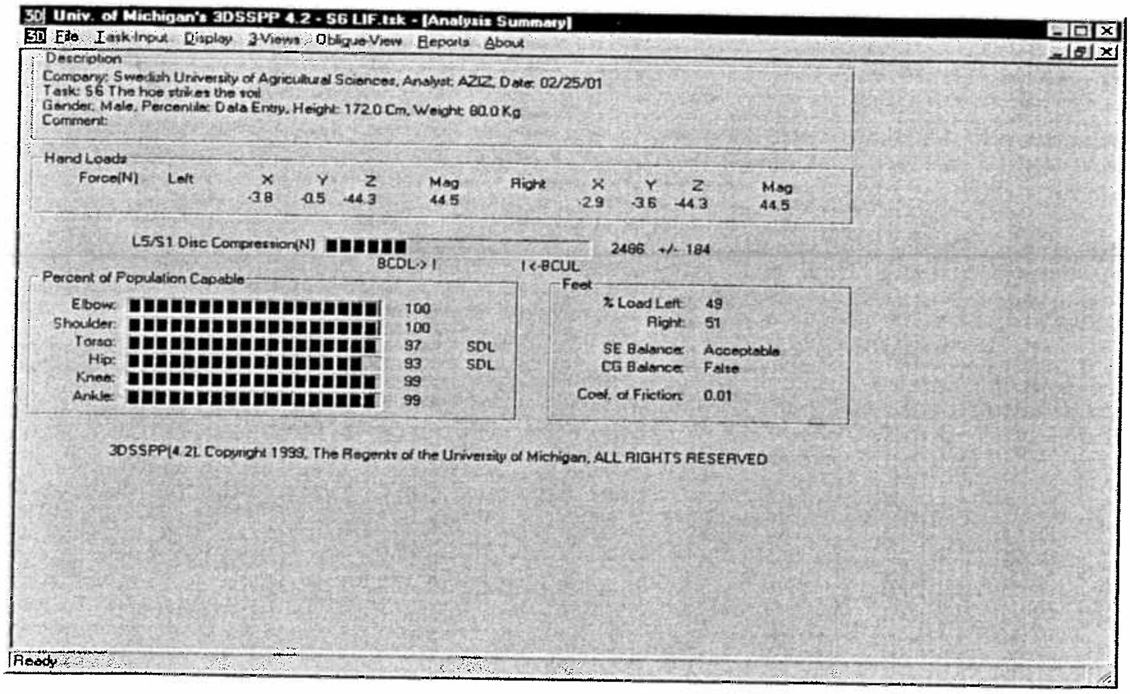


Figure 19. Analysis Summary for S6 while the hoe stroke the soil.

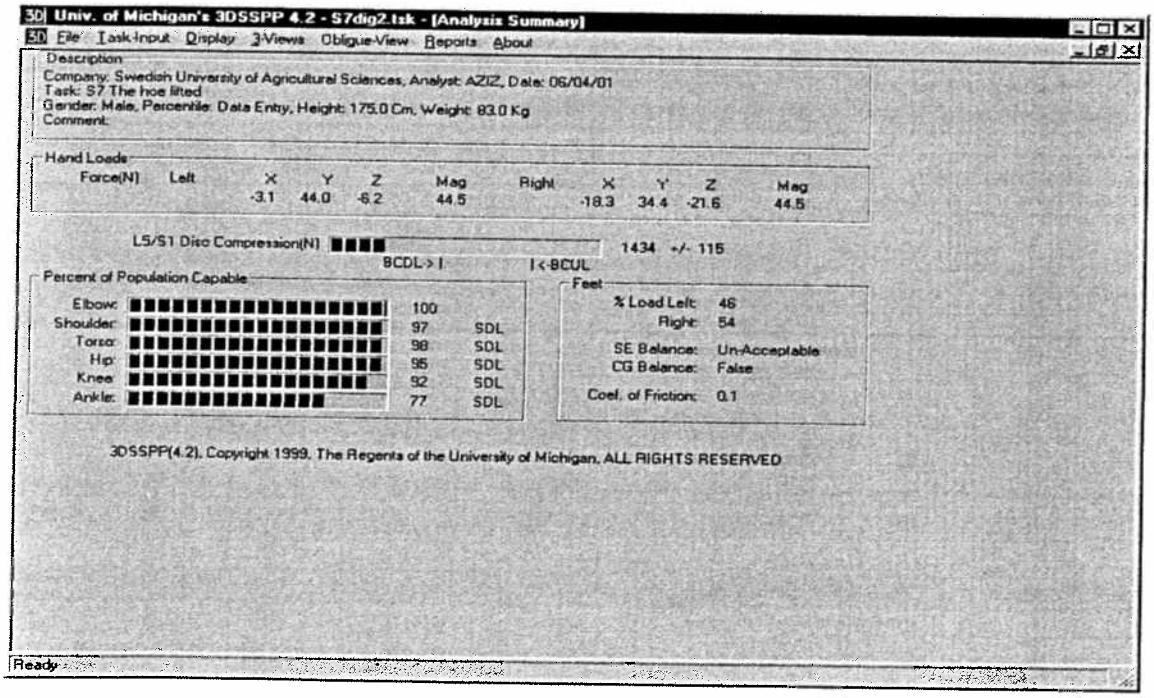


Figure 20. Analysis Summary for S7 while the hoe lifted up.

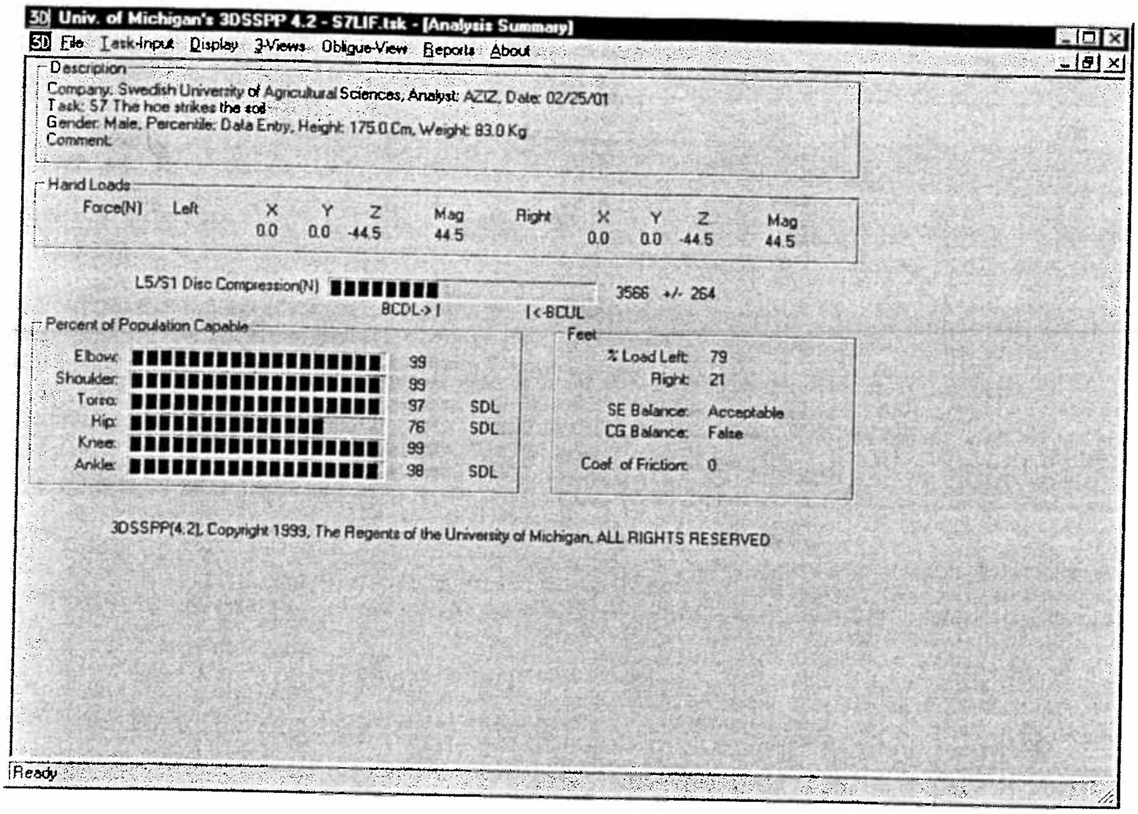


Figure 21. Analysis Summary for S7 while the hoe stroke the soil.

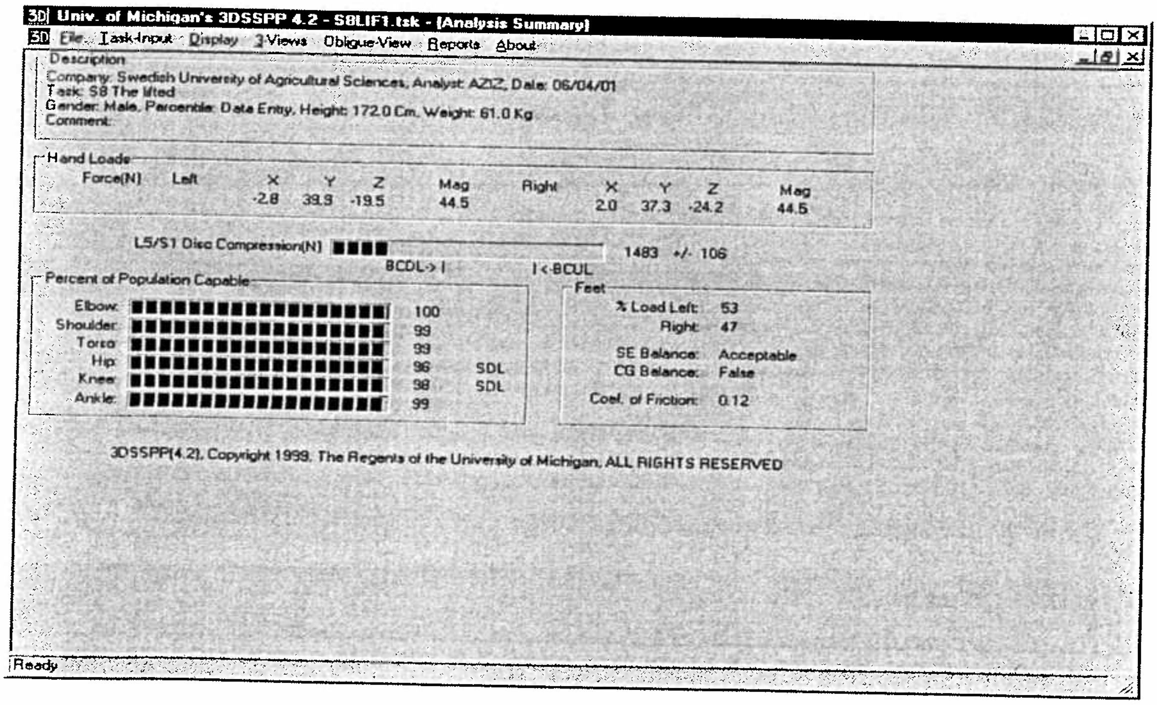


Figure 22. Analysis Summary for S8 while the hoe lifted up.

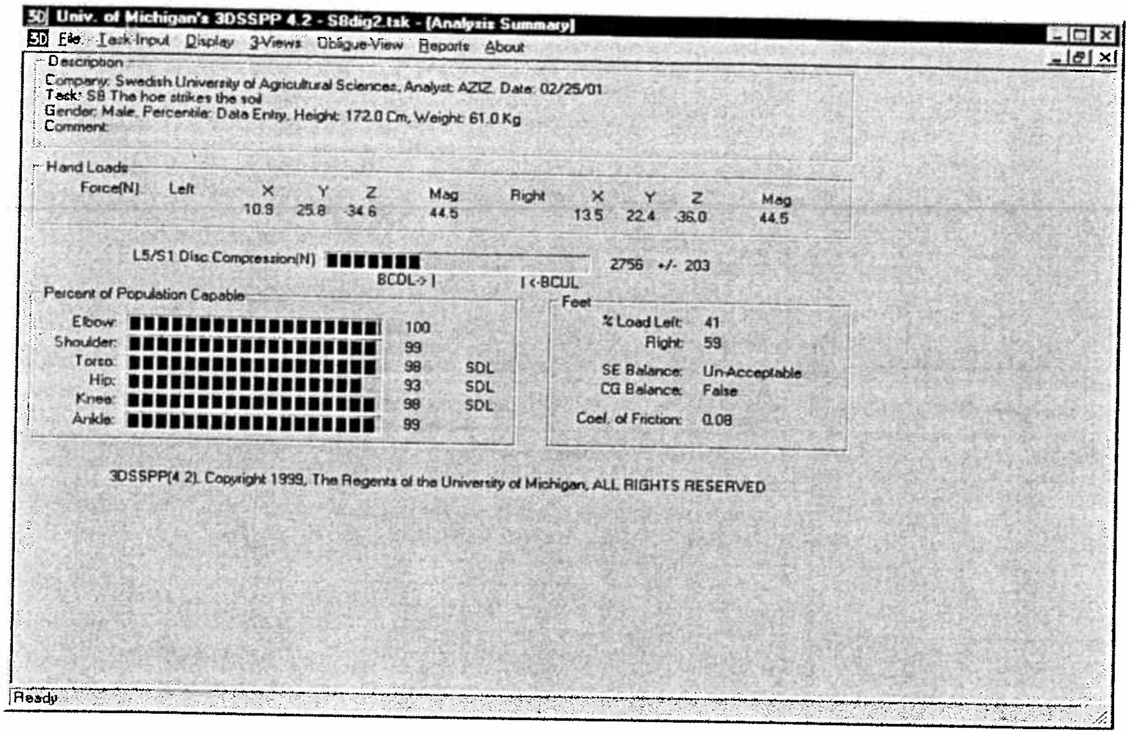


Figure 23. Analysis Summary for S8 while the hoe stroke the soil.

4.3 Forces on L5/S1 as a function of HR and RPE

When the subjects at assumed awkward posture (the hoe stroke the soil), forces imposed on L5/S1 and the parallel HR and RPE could be presented in figure 24 below.

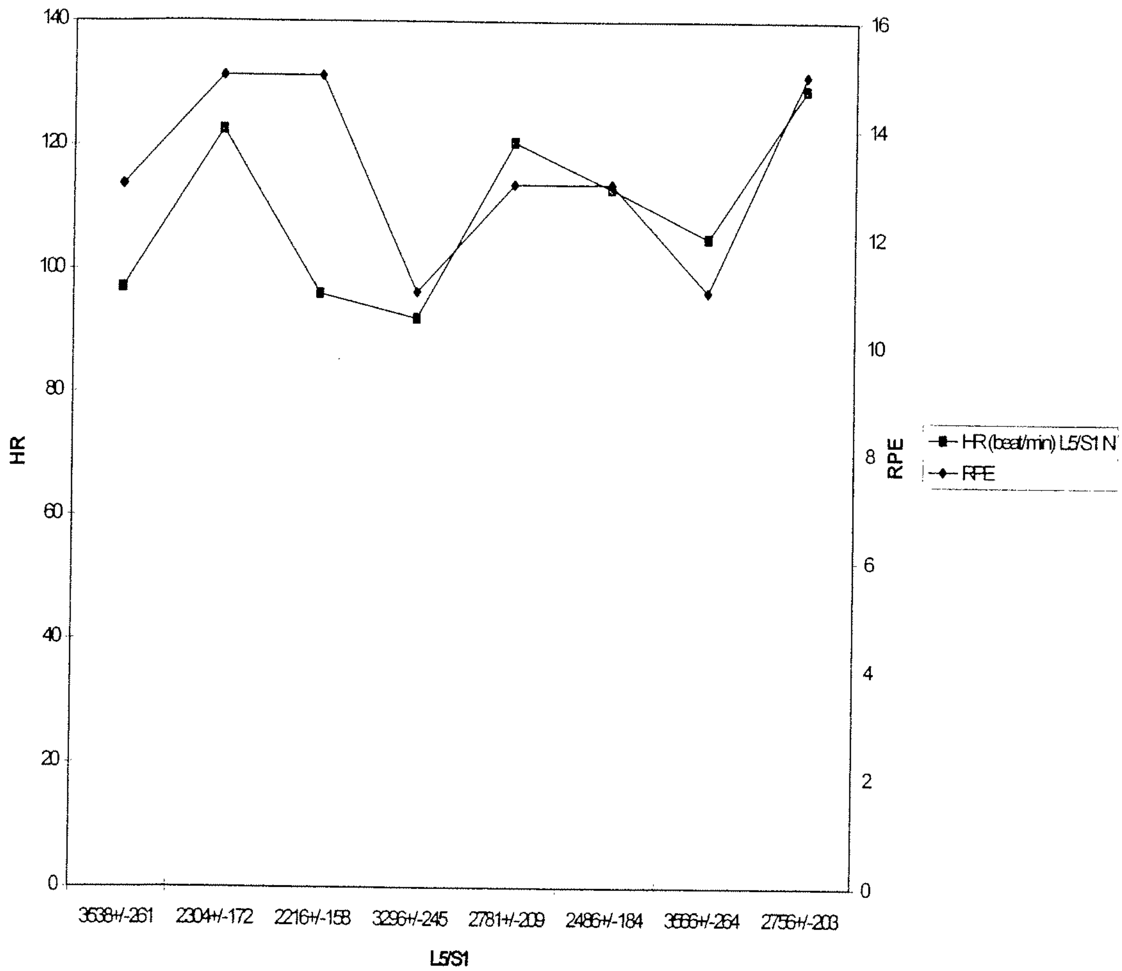


Figure 24. Compression forces on L5/S1 as a function of HR and RPE

5. DISCUSSION

This section interprets the results of the study in relation to the foregoing chapters and the objective. Having said that, the focus will be on HR along with RPE and the output obtained from 3D SSPP.

5.1 HR and RPE

From the physiological viewpoint, the measured HR ranged from 92 to 129 beats per minute. In this respect, working with the experimental hand hoe could be classified from light (75-100 beat/min) to heavy (125-150 beat/min) according to the study reported by Christensen (1963).

Regarding the rating of work load, it appears that 25% from the subjects perceived the work with hand hoe as light, 37.5% perceived as somewhat hard and 37.5% perceived as heavy. However, RPE rated high (RPE increased faster than HR) in relation to HR, this could be attributed to the awkward posture adopted by the subjects as they were unfamiliar with the hoeing task.

As overall, the regression equation (figure 7), coupled with the correlation coefficient ($r = 0.59$) at level of significant $p<0.05$, provides basic descriptive information to understand the relationship between HR and RPE. In this way, r-value indicates that a positive correlation exist between HR and RPE.

Nevertheless, r-value is relatively low compare to several studies reported in Borg (1998) where the correlation coefficient between HR and RPE exceeded 0.7.

Having said that, the low value could be attributed to the individual differences as well as to severity of the task for untrained subjects.

5.2 3D SSPP output

With reference to the output obtained from 3D SSPP software, while the subjects lifted the hoe up, the compression forces on L4/L5 and L5/S1 were below the NIOSH guidelines (770 pounds or 3400 N) for back injury. Nevertheless, 37.5 % from the subjects reported high compression forces. Bearing in mind that lifting the hoe up is relatively assumed as a normal posture. This probably resulted from the mismatch between the subject's anthopometry and the design specification as well as first exposure to hoeing task.

When the hand hoe stroke the soil, the highest L5/S1 disc compression force prediction were 3538+/-1 SD, 3296+/-1 SD and 3566+/-1 SD Newton. However, NIOSH guidelines, set the Back Compression Design Limit (BCDL) to 3400 and the Back Compression Upper Limit (BCUL) to 1430 pounds (6400 N). At this level some workers would be at increased risk of injury.

With regard to BCDL, when the hoe stroke the soil, 25% from the subjects were exceeded the safe limit and therefore, they are at very high risk of back injury. 12.5 % were somehow close to BCDL and that is to say it is still fairly high and the task should be considered for improvement.

Percent capable

From the figures presented in the results and Appendix D, the percent capable is displayed in numeric form with SDL (Strength Design Limit) or SUL (Strength Upper Limit) flag displayed for each joint which exceeds the NIOSH value set for these limits. The displayed value for each joint is the lowest value obtained from the strength capabilities calculated for the joint actions on each side of the body. The torso value is the smallest of axial rotation strength, lateral bending strength and flexion/extension strength.

SDL and SUL Limit Flags: For percent capable (percent of the population with sufficient strength) the NIOSH Strength Limit has been revised to the SDL (Strength Design Limit) and SUL (Strength Upper Limit). The SDL will appear if the percent capable is below either 99% for men or 75% for women while the SUL, on the other hand, appears when the percent capable is below 25% for men or below 1% for women.

Leg load and balance: The lower right corner shown in the results, reports the balance condition for the input posture. The percent load refers to the fraction of total body weight (body and load) supported by that foot.

To calculate the percent load on each foot, the programme inputs the X, Y, and Z locations of the upper body centre of gravity, hand force vectors, and upper and lower leg centres of gravity into two balance logarithm.

SE balance: The Static Equilibrium balance checking algorithm determines whether the moments about each ankle can be in static equilibrium. The output yields one of the following balance conditions:

Acceptable balance: The subject is capable of maintaining the posture defined in the data entry windows without losing balance. An acceptable balance status verifies that resultant moments (X, Y, Z) at ankles do not exceed the reactive moments created by the reaction forces on the feet on the ball-to-heel or foot breadth distances.

Unacceptable balance: In the case of a large horizontal hand force or posture with large horizontal hand force or posture with excessive lean (forward/backward or side-ways), the resultant ankle moments will exceed the reactive moments created by the ground reaction forces acting on the ball-to-heel or foot breadth distances. If the resultants lateral ankle moments exceed the reactive ankle lateral moment, balance is lost by falling sideways; if the resultant anterior-posterior moment exceeds the reactive anterior-posterior foot moment, the persons falls forward or backwards.

CG balance: The centre of gravity balance algorithm is currently incomplete and it should be ignored. When completed it will determine if the centre of mass of the body is within the basis of support provided by the feet.

Coefficient of friction: This coefficient of static friction between the floor and the shoe soles required to prevent slippage given this specific combination of posture and load.

3D Low-back report

This disc compression analysis can be run to consider the effect of additional muscle actions in the torso. The bottom section of the report (Appendix C) lists the L4/L5 disc compression force and can be compared to the NIOSH BCDL of 3400 N and BCUL of 6400 N as the case with L5/S1.

As overall, the compression forces acting on L5/S1 as a function of HR and RPE did not show any linear relationship. In this respect, it can be said that static whole-body biomechanical model is a useful tool for evaluating work load associated with hoeing task, however, it should not be used alone. In other words, a combination of biomechanical, psychophysical and physiological methods are worthwhile.

6. CONCLUSION

- Literature revealed that the tool in question relies only on human power and ergonomics was neglected at the design stage. Therefore, it could be concluded that, working with hand hoe is most likely less efficient, unsafe with low output. In this context, ergonomics methods of assessments can provide information regarding the work load (light or heavy), compression force on the back and interpreting strength prediction output. In turn, the gathered information can help in redesigning the hoe and hence the tasks are well worthwhile.
- When applying multi-methods such as physiological (HR) along with psychophysical (RPE) and the biomechanical (3D-posture recording) for assessing the work load, the study showed that the aforementioned methods work in parallel without any obstructing.
- 3D-posture recording has a potential to collect a tremendous data whereas the software 3D SSPP produces outputs with less time and expertise. Further, the software is most useful in the analysis of slow movements used in heavy materials handling.
- HR along with RPE has a practical application in the laboratory as well as in the field. Yet, 3D recording posture is applicable in the laboratory where advanced equipment can be installed. In the field, 3D would be inappropriate because advanced measuring devices are not always applicable and the available space may be limited and thus prevent the positioning of measuring apparatus.

- The study reported here is of critical importance in demonstrating the value of ergonomics methods in practical and effective prevention of musculoskeletal injuries.

7. RECOMMENDATIONS

- The foregoing chapters made it clear that 3D posture recording of manual work with hand tools can be developed in the laboratory. Nevertheless, in the field, one video camera can be used. In this respect, the recording posture should be taken from the front and sagittal plane. One interesting point is that the task input in 3D SSPP software can be set into 2D-entry mode and in turn, only five segment angles (fore and upper arm; upper and lower leg; and trunk flexion).
- The study limited only to male subject, however, the interesting part of 3D SPP is to find out the static strength of both male and female in performing a given task.
- When developing countries taken into account, future research should put greater emphasis on female as well male subject, hence the women comprise the majority of small-scale farms.
- Ergonomics assessment of such tools requires that many variables need to be considered effectively to come with reasonably accurate results. Thus, soil moisture, digging depth, trained subjects, anthopometric measurements in relation to the design specification and hand location when holding the hand hoe should be tackled by future research.
- The number of subjects participated in the study was relatively small and therefore a field study is needed for reliability and validity of the methods.
- Several studies reported that HR reaches steady level after 5 minutes. However, in this study the measures taken after 3 minutes due to time constrain. In this context, the results may be debatable and that is to say should be tackled by future research.

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APPENDIXES

APPENDIX A: Borg's Scale (in Swedish and English)

Instruktion till skalan.

Under arbetet vill vi att du ska uppskatta din upplevelse av ansträngning, dvs. hur tungt och påfrestande det är eller hur trött du känner dig. Upplevelsen av ansträngning känns i dina muskler, och i bröstet i form av andfåddhet och eventuell värk.

Vi vill att du skall använda den här skattningsskalan, från 6 till 20, där 6 betyder ”Ingen ansträngning alls” och 20 betyder ”Maximal ansträngning”.

9 motsvarar ett ”Mycket lätt” arbete, som tex att sakta promenera en kortare sträcka.

13 på skalan är ”Något ansträngande”, men det känns fortfarande bra och du kan fortsätta utan större besvär.

17 ”Mycket ansträngande”, är en väldigt stark påfrestning. Du kan fortsätta arbeta men du måste ta i mycket kraftigt. Det känns mycket tungt och du är mycket trött.

19 på skalan är en extremt hög nivå. För de flesta människor svarar detta mot den allra största ansträngning de någonsin upplevt.

Försök att vara så uppriktig och spontan som möjligt och fundera inte på vad den egentliga belastningen är objektivt sett. Det är endast vad du känner som är intressant. Försök att varken underskatta eller överskatta. Det viktiga är alltså din känsla av ansträngning, inte vad andra människor tycker. Titta på skalan och utgå från orden, men välj sedan en siffra. Du kan lika gärna använda jämna som udda siffror.

6	Ingen ansträngning alls
7	
	Extremt lätt
8	
9	Mycket lätt
10	
11	Ganska lätt
12	
13	Något ansträngande
14	
15	Ansträngande
16	
17	Mycket ansträngande
18	
19	Extremt ansträngande
20	Maximal ansträngning

Borg - RPE - Skalan
© Gunnar Borg 1985, 1994

RPE Scale in English

The RPE scale is based upon asking people how intense their level of exertion is on a scale of 6 to 20.

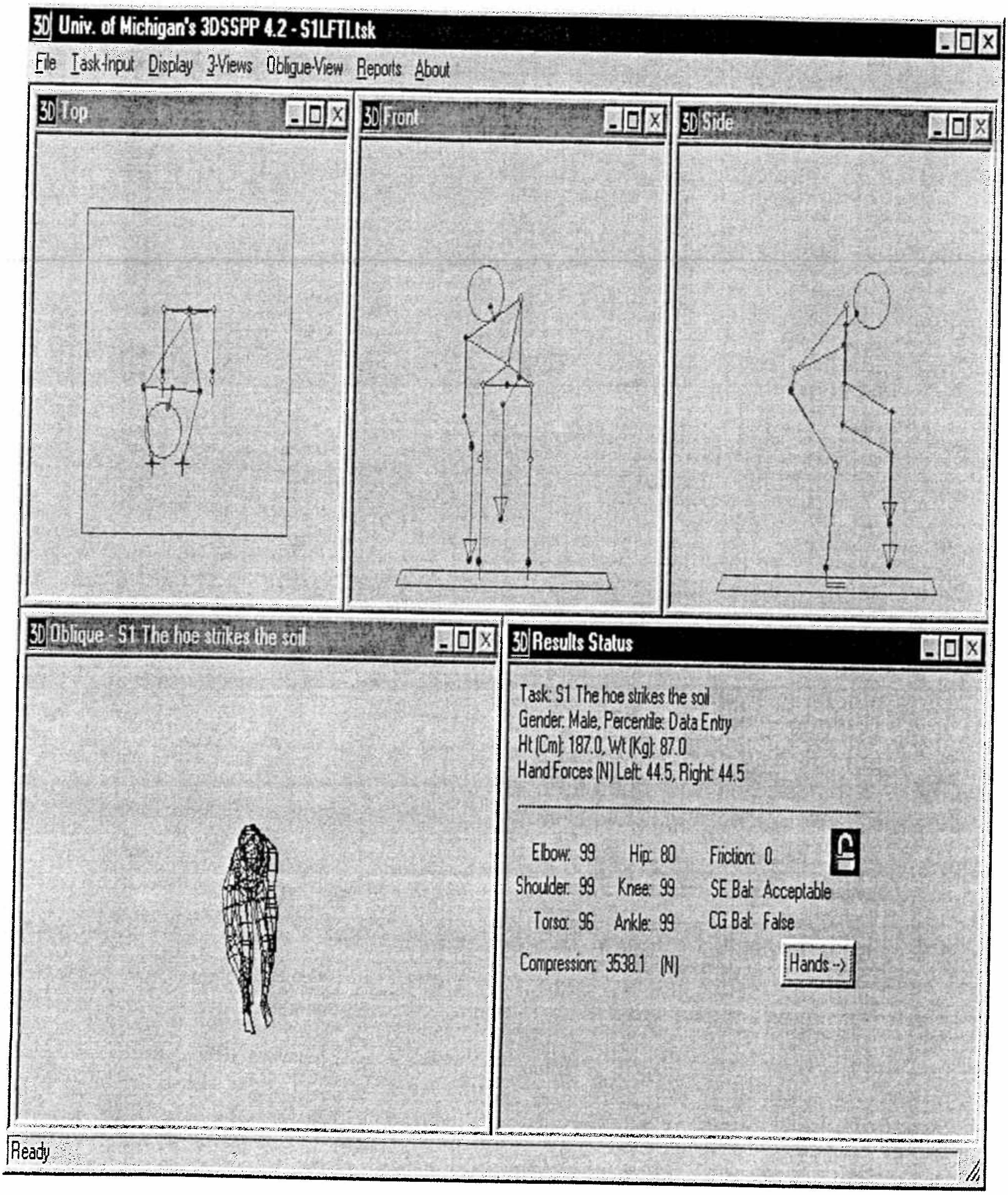
6 on the scale means no exertion at all

9 on the scale correspond to "very light" exercise. For a normal, healthy person it is like walking slowly at his or her own pace for some minutes.
13 on the scale is "somewhat hard" exercise, but it still okay to continue.
17 "very hard" is very strenuous. A healthy person can still go on, but he or she really has to push one self. It feels very heavy, and the person is very tired.
19 on the scale is an extremely strenuous exercise level. For most people this is the most strenuous exercise they have ever experienced.

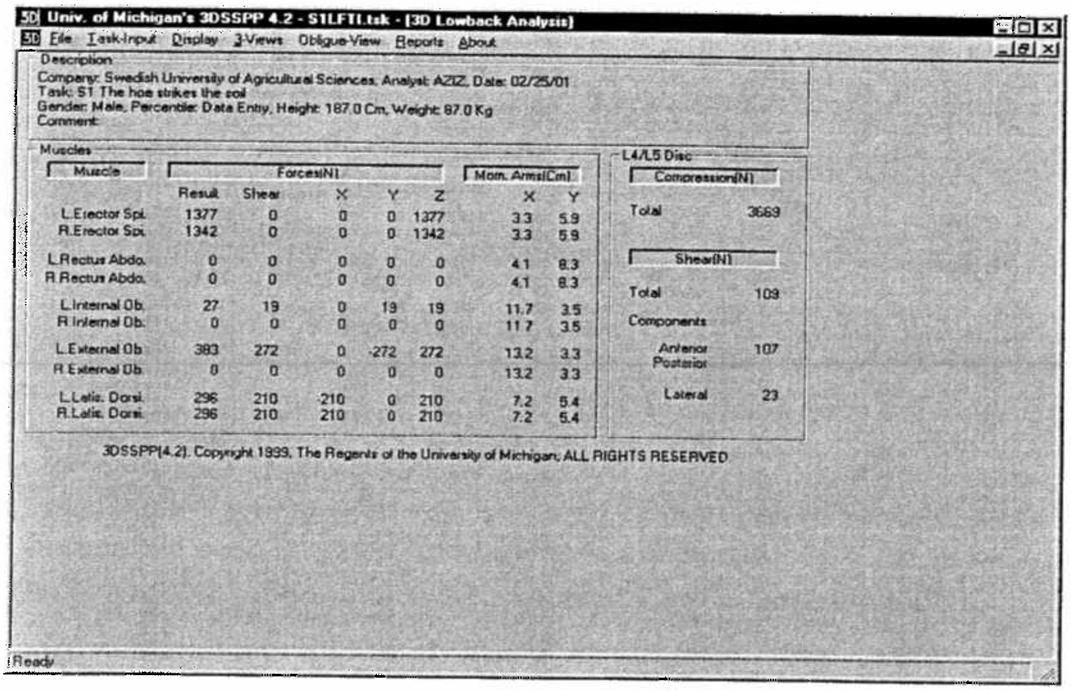
Number 20 on the scale refers to a kind of "absolute maximum", an intensity that most people never have reached previously in their lives. It is thus a kind of hypothetical construct. According to the definition of construction, 19 should be the highest intensity that most people have ever experienced in running extremely hard for several minutes or carrying objects that are so heavy that they can hardly manage to perform the task.

6	NO EXERTION AT ALL
7	
	EXTREMELY LIGHT
8	
9	VERY LIGHT
10	
11	LIGHT
12	
13	SOMEWHAT HARD
14	
15	HARD (HEAVY)
16	
17	VERY HARD
18	
19	EXTREMELY HARD
20	MAXIMAL EXERTION

APPENDIX B: Working postures taken from top, front and lateral.


Univ. of Michigan's 3DSSPP 4.2 - S1LFTI.tsk
File Task-Input Display 3-Views Oblique-View Reports About
Top
Front
Side
Oblique - S1 The hoe strikes the soil
Results Status
Task: S1 The hoe strikes the soil
Gender: Male, Percentile: Data Entry
Ht (Cm): 187.0, Wt (Kg): 87.0
Hand Forces (N) Left: 44.5, Right: 44.5
Elbow: 99
Hip: 80
Friction: 0
Shoulder: 99
Knee: 99
SE Bal: Acceptable
Torso: 96
Ankle: 99
CG Bal: False
Compression: 3538.1 (N)
Hands -->
Ready

APPENDIX C: 3D Lowback Analysis while the hoe stroke the soil
(assumed awkward postures)



Univ. of Michigan's 3DSSPP 4.2 - S1LFTI.tsk - [3D Lowback Analysis]

File Task-Input Display 3-Views Oblique-View Reports About

Description

Company: Swedish University of Agricultural Sciences, Analyst: AZIZ, Date: 02/25/01
Task: S1 The hoe strikes the soil
Gender: Male, Percentile: Data Entry, Height: 187.0 Cm, Weight: 87.0 Kg
Comment:

Muscles

Muscle	Forces(N) Result	Shear	X	Y	Z	Mom. Arms(Cm) X	Y
L.Erector Spi.	1377	0	0	0	1377	3.3	5.9
R.Erector Spi.	1342	0	0	0	1342	3.3	5.9
L.Rectus Abdo.	0	0	0	0	0	4.1	8.3
R.Rectus Abdo.	0	0	0	0	0	4.1	8.3
L.Internal Ob.	27	19	0	19	19	11.7	3.5
R.Internal Ob.	0	0	0	0	0	11.7	3.5
L.External Ob.	383	272	0	-272	272	13.2	3.3
R.External Ob.	0	0	0	0	0	13.2	3.3
L.Latis. Dorsi.	296	210	-210	0	210	7.2	5.4
R.Latis. Dorsi.	296	210	210	0	210	7.2	5.4

L4/L5 Disc

L4/L5 Disc	
Compression(N) Total	3669
Shear(N) Total	109
Components	
Anterior Posterior	107
Lateral	23

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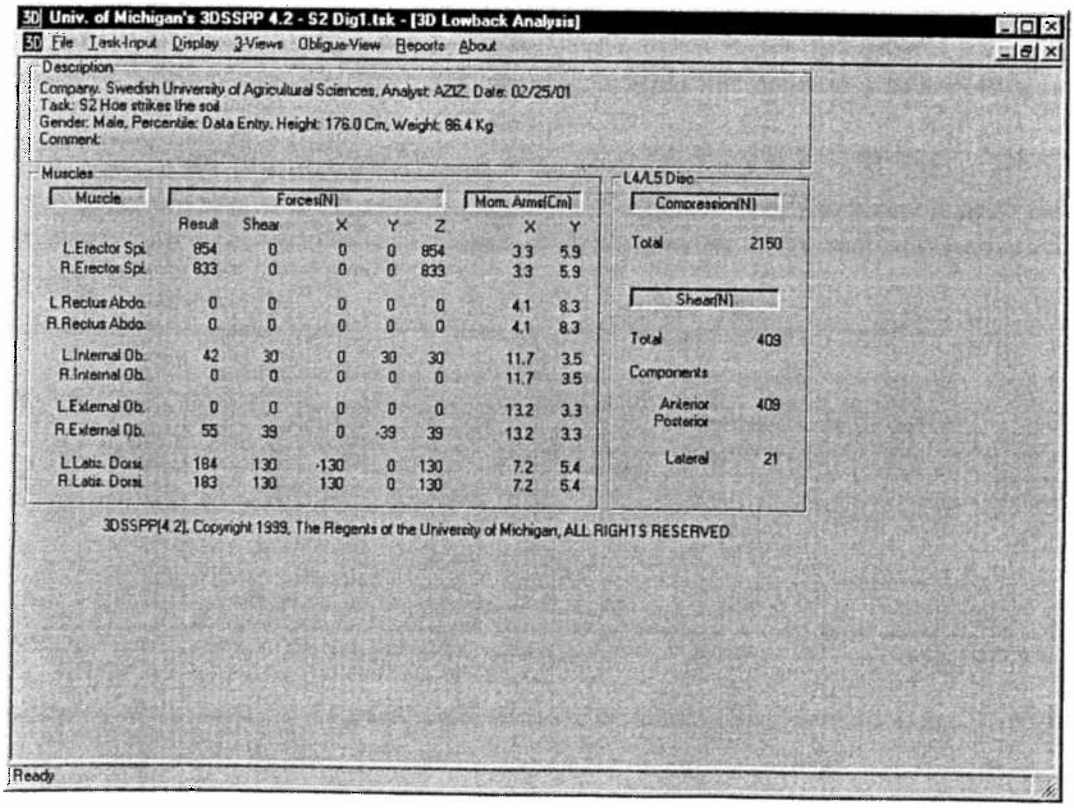
Ready

3D Lowback Analysis (force on L4/L5) for S1 while the hoe stroke the soil.



Univ. of Michigan's 3DSSPP 4.2 - S2 Dig1.tsk - [3D Lowback Analysis]

File Task-Input Display 3-Views Oblique-View Reports About

Description

Company: Swedish University of Agricultural Sciences, Analyst: AZIZ, Date: 02/25/01
Task: S2 Hoe strikes the soil
Gender: Male, Percentile: Data Entry, Height: 176.0 Cm, Weight: 86.4 Kg
Comment:

Muscles

Muscle	Forces(N) Result	Shear	X	Y	Z	Mom. Arms(Cm) X	Y
L.Erector Spi.	854	0	0	0	854	3.3	5.9
R.Erector Spi.	833	0	0	0	833	3.3	5.9
L.Rectus Abdo.	0	0	0	0	0	4.1	8.3
R.Rectus Abdo.	0	0	0	0	0	4.1	8.3
L.Internal Ob.	42	30	0	30	30	11.7	3.5
R.Internal Ob.	0	0	0	0	0	11.7	3.5
L.External Ob.	0	0	0	0	0	13.2	3.3
R.External Ob.	55	39	0	-39	39	13.2	3.3
L.Latis. Dorsi.	184	130	-130	0	130	7.2	5.4
R.Latis. Dorsi.	183	130	130	0	130	7.2	5.4

L4/L5 Disc

L4/L5 Disc	
Compression(N) Total	2150
Shear(N) Total	409
Components	
Anterior Posterior	409
Lateral	21

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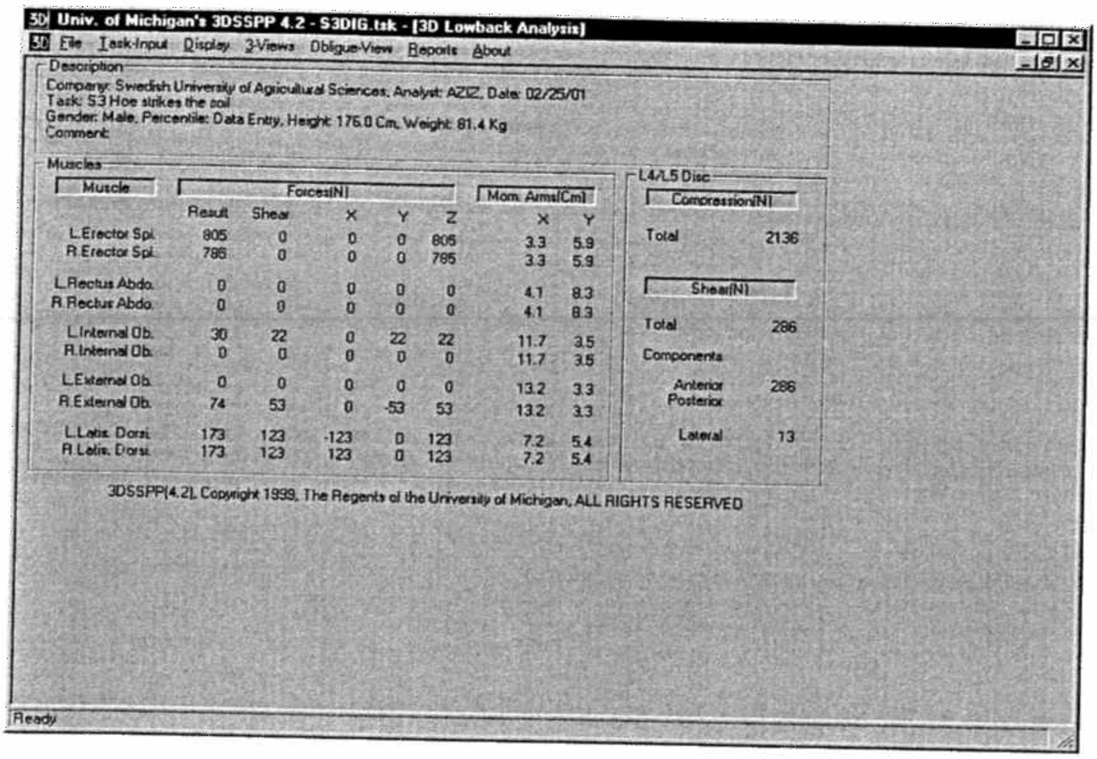
Ready

3D Lowback Analysis (force on L4/L5) for S2 while the hoe stroke the soil.



Univ. of Michigan's 3DSSPP 4.2 - S3DIG.tsk - [3D Lowback Analysis]

File Task-Input Display 3-Views Oblique-View Reports About

Description

Company: Swedish University of Agricultural Sciences, Analyst: AZIZ, Date: 02/25/01
Task: S3 Hoe strikes the soil
Gender: Male, Percentile: Data Entry, Height: 176.0 Cm, Weight: 81.4 Kg
Comment:

Muscles

Muscle	Forces(N) Result	Shear	X	Y	Z	Mom. Arms(Cm) X	Y
L.Erector Spi.	805	0	0	0	805	3.3	5.9
R.Erector Spi.	785	0	0	0	785	3.3	5.9
L.Rectus Abdo.	0	0	0	0	0	4.1	8.3
R.Rectus Abdo.	0	0	0	0	0	4.1	8.3
L.Internal Ob.	30	22	0	22	22	11.7	3.5
R.Internal Ob.	0	0	0	0	0	11.7	3.5
L.External Ob.	0	0	0	0	0	13.2	3.3
R.External Ob.	74	53	0	-53	53	13.2	3.3
L.Latis. Dorsi.	173	123	-123	0	123	7.2	5.4
R.Latis. Dorsi.	173	123	123	0	123	7.2	5.4

L4/L5 Disc

Compression(N) Total	2136
Shear(N) Total	286
Components	
Anterior Posterior	286
Lateral	13

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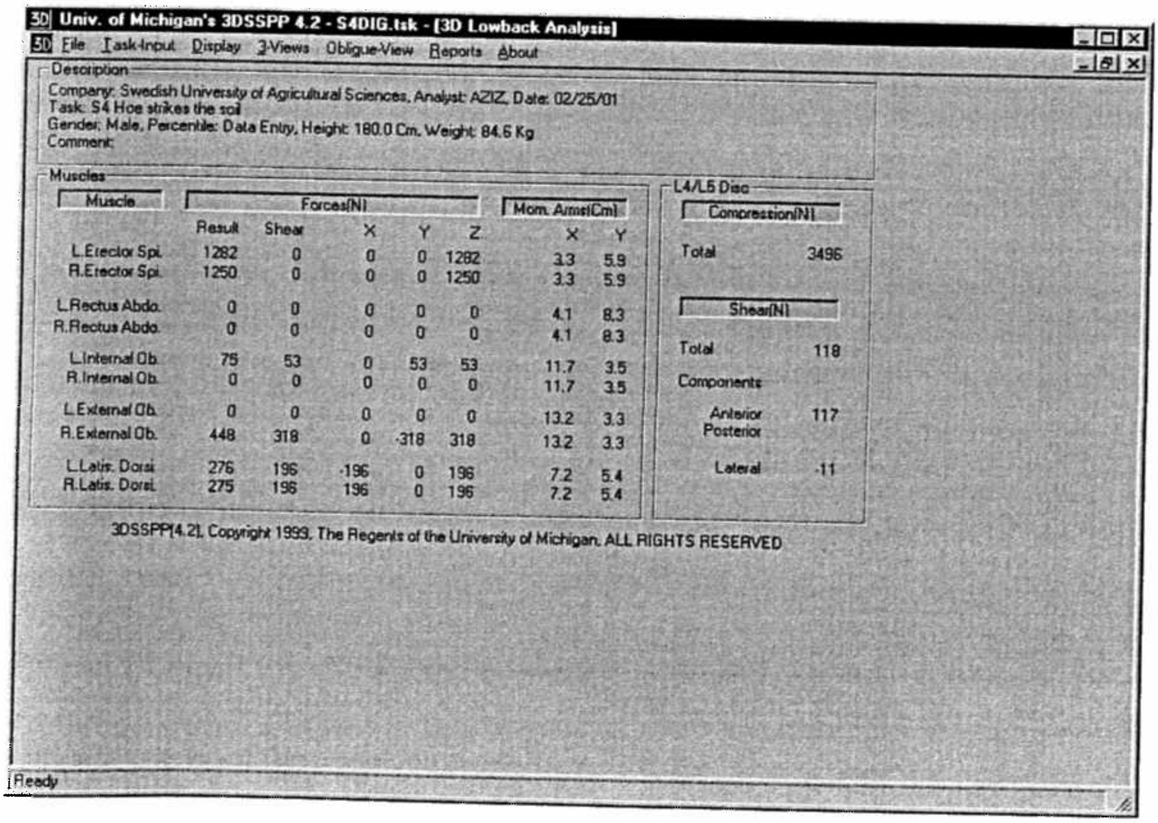
Ready

3D Lowback Analysis (force on L4/L5) for S3 while the hoe stroke the soil.



Univ. of Michigan's 3DSSPP 4.2 - S4DIG.tsk - [3D Lowback Analysis]

File Task-Input Display 3-Views Oblique-View Reports About

Description

Company: Swedish University of Agricultural Sciences, Analyst: AZIZ, Date: 02/25/01
Task: S4 Hoe strikes the soil
Gender: Male, Percentile: Data Entry, Height: 180.0 Cm, Weight: 84.6 Kg
Comment:

Muscles

Muscle	Forces(N) Result	Shear	X	Y	Z	Mom. Arms(Cm) X	Y
L.Erector Spi.	1282	0	0	0	1282	3.3	5.9
R.Erector Spi.	1250	0	0	0	1250	3.3	5.9
L.Rectus Abdo.	0	0	0	0	0	4.1	8.3
R.Rectus Abdo.	0	0	0	0	0	4.1	8.3
L.Internal Ob.	75	53	0	53	53	11.7	3.5
R.Internal Ob.	0	0	0	0	0	11.7	3.5
L.External Ob.	0	0	0	0	0	13.2	3.3
R.External Ob.	448	318	0	-318	318	13.2	3.3
L.Latis. Dorsi	276	196	-196	0	196	7.2	5.4
R.Latis. Dorsi	275	196	196	0	196	7.2	5.4

L4/L5 Disc

Compression(N) Total	3496
Shear(N) Total	118
Components	
Anterior Posterior	117
Lateral	-11

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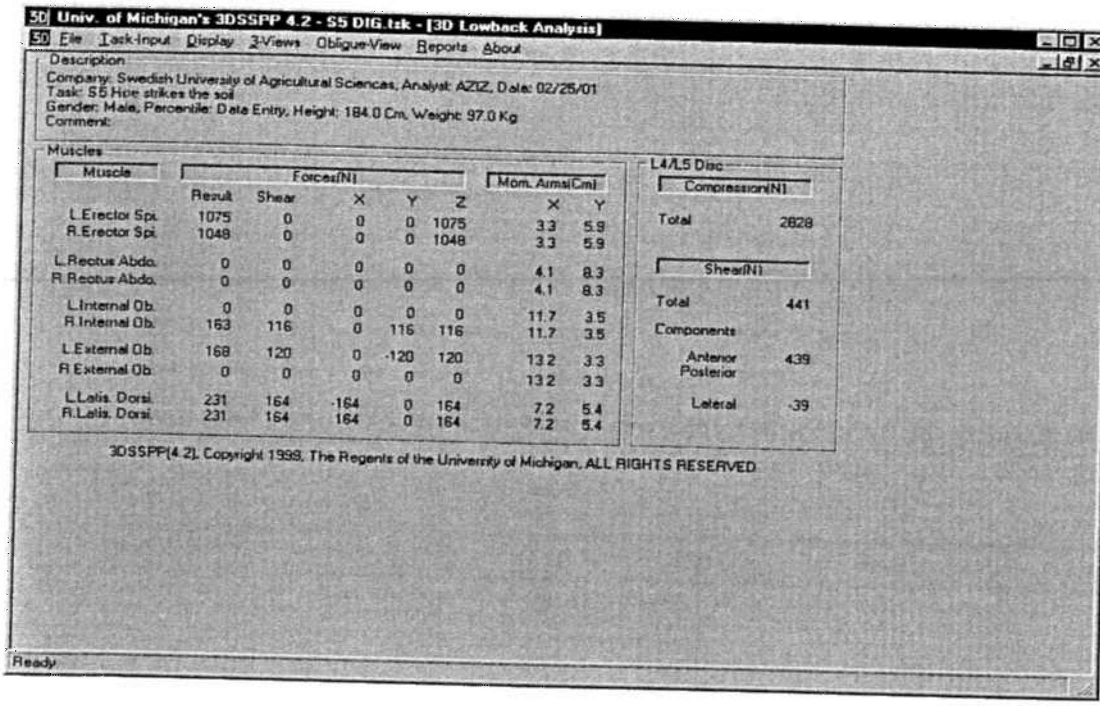
Ready

3D Lowback Analysis (force on L4/L5) for S4 while the hoe stroke the soil.



Univ. of Michigan's 3DSSPP 4.2 - S5 DIG.tsk - [3D Lowback Analysis]

File Task-Input Display 3-Views Oblique-View Reports About

Description

Company: Swedish University of Agricultural Sciences, Analyst: AZIZ, Date: 02/25/01
Task: S5 Hoe strikes the soil
Gender: Male, Percentile: Data Entry, Height: 184.0 Cm, Weight: 97.0 Kg
Comment:

Muscles

Muscle	Result	Shear	X	Y	Z	Mom. Arms(Cm) X	Mom. Arms(Cm) Y
L.Erector Spi.	1075	0	0	0	1075	3.3	5.9
R.Erector Spi.	1048	0	0	0	1048	3.3	5.9
L.Rectus Abdo.	0	0	0	0	0	4.1	8.3
R.Rectus Abdo.	0	0	0	0	0	4.1	8.3
L.Internal Ob.	0	0	0	0	0	11.7	3.5
R.Internal Ob.	163	116	0	116	116	11.7	3.5
L.External Ob.	168	120	0	-120	120	13.2	3.3
R.External Ob.	0	0	0	0	0	13.2	3.3
L.Latis. Dorsi.	231	164	-164	0	164	7.2	5.4
R.Latis. Dorsi.	231	164	164	0	164	7.2	5.4

L4/L5 Disc

Compression(N): Total 2828

Shear(N): Total 441

Components: Anterior Posterior 439; Lateral -39

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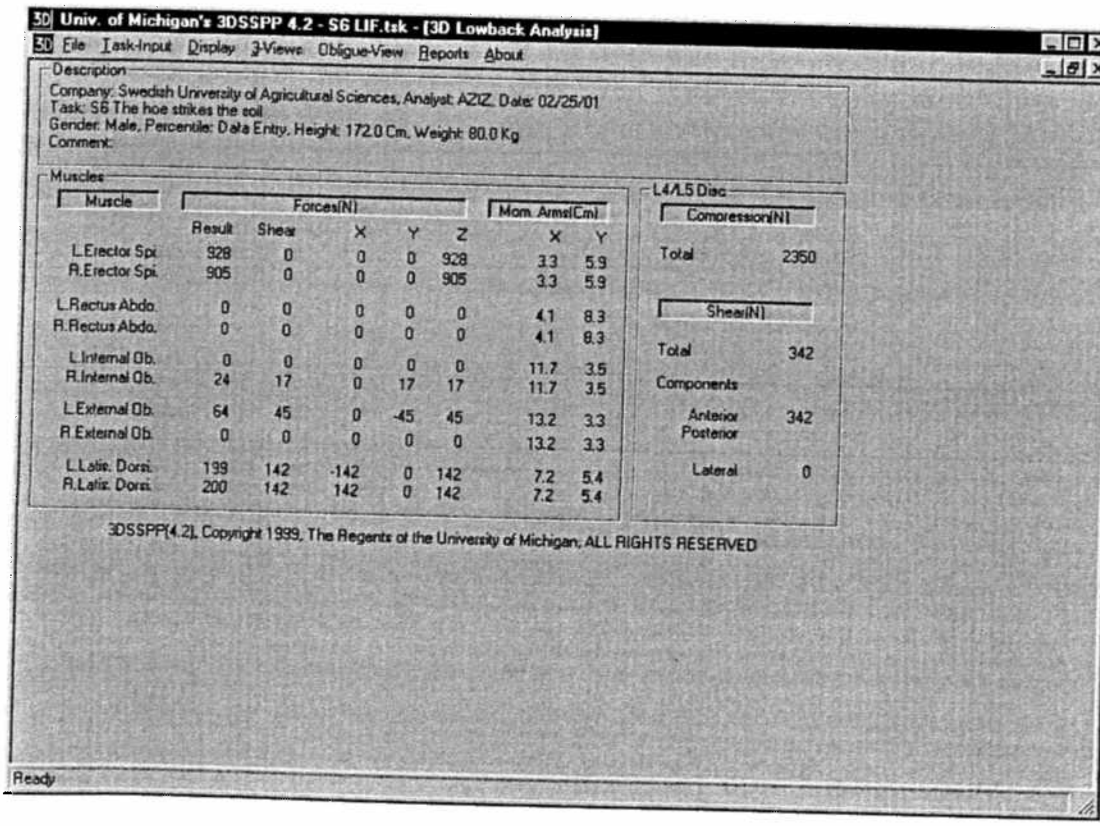
Ready

3D Lowback Analysis (force on L4/L5) for S5 while the hoe stroke the soil.



Univ. of Michigan's 3DSSPP 4.2 - S6 LIF.tsk - [3D Lowback Analysis]

File Task-Input Display 3-Views Oblique-View Reports About

Description

Company: Swedish University of Agricultural Sciences, Analyst: AZIZ, Date: 02/25/01
Task: S6 The hoe strikes the soil
Gender: Male, Percentile: Data Entry, Height: 172.0 Cm, Weight: 80.0 Kg
Comment:

Muscles

Muscle	Result	Shear	X	Y	Z	Mom. Arms(Cm) X	Mom. Arms(Cm) Y
L.Erector Spi.	928	0	0	0	928	3.3	5.9
R.Erector Spi.	905	0	0	0	905	3.3	5.9
L.Rectus Abdo.	0	0	0	0	0	4.1	8.3
R.Rectus Abdo.	0	0	0	0	0	4.1	8.3
L.Internal Ob.	0	0	0	0	0	11.7	3.5
R.Internal Ob.	24	17	0	17	17	11.7	3.5
L.External Ob.	64	45	0	-45	45	13.2	3.3
R.External Ob.	0	0	0	0	0	13.2	3.3
L.Latis. Dorsi.	199	142	-142	0	142	7.2	5.4
R.Latis. Dorsi.	200	142	142	0	142	7.2	5.4

L4/L5 Disc

Compression(N): Total 2350

Shear(N): Total 342

Components: Anterior Posterior 342; Lateral 0

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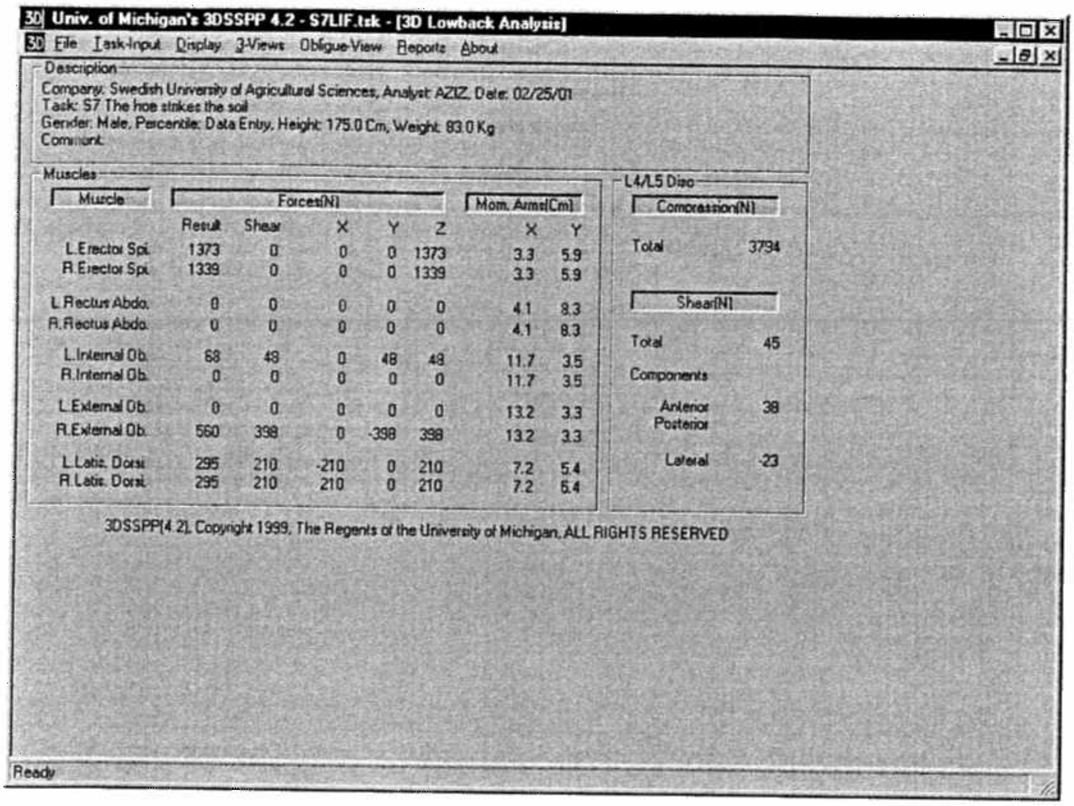
Ready

3D Lowback Analysis (force on L4/L5) for S6 while the hoe stroke the soil.



Univ. of Michigan's 3DSSPP 4.2 - S7LIF.tsk - [3D Lowback Analysis]

File Task-Input Display 3-Views Oblique-View Reports About

Description

Company: Swedish University of Agricultural Sciences, Analyst: AZIZ, Date: 02/25/01
Task: S7 The hoe strikes the soil
Gender: Male, Percentile: Data Entry, Height: 175.0 Cm, Weight: 83.0 Kg
Comment:

Muscles

Muscle	Forces(N) Result	Shear	X	Y	Z	Mom. Arms(Cm) X	Y
L.Erector Spi.	1373	0	0	0	1373	3.3	5.9
R.Erector Spi.	1339	0	0	0	1339	3.3	5.9
L.Rectus Abdo.	0	0	0	0	0	4.1	8.3
R.Rectus Abdo.	0	0	0	0	0	4.1	8.3
L.Internal Ob.	68	48	0	48	48	11.7	3.5
R.Internal Ob.	0	0	0	0	0	11.7	3.5
L.External Ob.	0	0	0	0	0	13.2	3.3
R.External Ob.	560	398	0	-398	398	13.2	3.3
L.Latis. Dorsi	295	210	-210	0	210	7.2	5.4
R.Latis. Dorsi	295	210	210	0	210	7.2	5.4

L4/L5 Disc

Compression(N) Total	3734
Shear(N) Total	45
Components: Anterior Posterior	38
Lateral	-23

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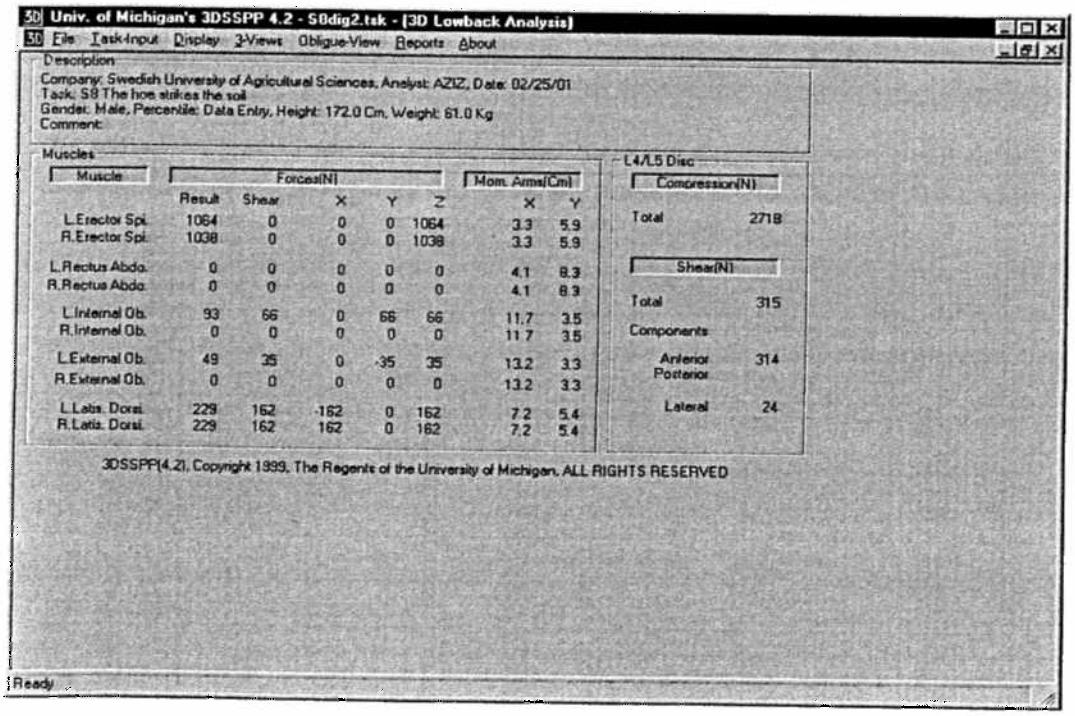
Ready

3D Lowback Analysis (force on L4/L5) for S7 while the hoe stroke the soil.



Univ. of Michigan's 3DSSPP 4.2 - S8dig2.tsk - [3D Lowback Analysis]

File Task-Input Display 3-Views Oblique-View Reports About

Description

Company: Swedish University of Agricultural Sciences, Analyst: AZIZ, Date: 02/25/01
Task: S8 The hoe strikes the soil
Gender: Male, Percentile: Data Entry, Height: 172.0 Cm, Weight: 61.0 Kg
Comment:

Muscles

Muscle	Forces(N) Result	Shear	X	Y	Z	Mom. Arms(Cm) X	Y
L.Erector Spi.	1064	0	0	0	1064	3.3	5.9
R.Erector Spi.	1038	0	0	0	1038	3.3	5.9
L.Rectus Abdo.	0	0	0	0	0	4.1	8.3
R.Rectus Abdo.	0	0	0	0	0	4.1	8.3
L.Internal Ob.	93	66	0	66	66	11.7	3.5
R.Internal Ob.	0	0	0	0	0	11.7	3.5
L.External Ob.	49	35	0	-35	35	13.2	3.3
R.External Ob.	0	0	0	0	0	13.2	3.3
L.Latis. Dorsi	229	162	-162	0	162	7.2	5.4
R.Latis. Dorsi	229	162	162	0	162	7.2	5.4

L4/L5 Disc

Compression(N) Total	2718
Shear(N) Total	315
Components: Anterior Posterior	314
Lateral	24

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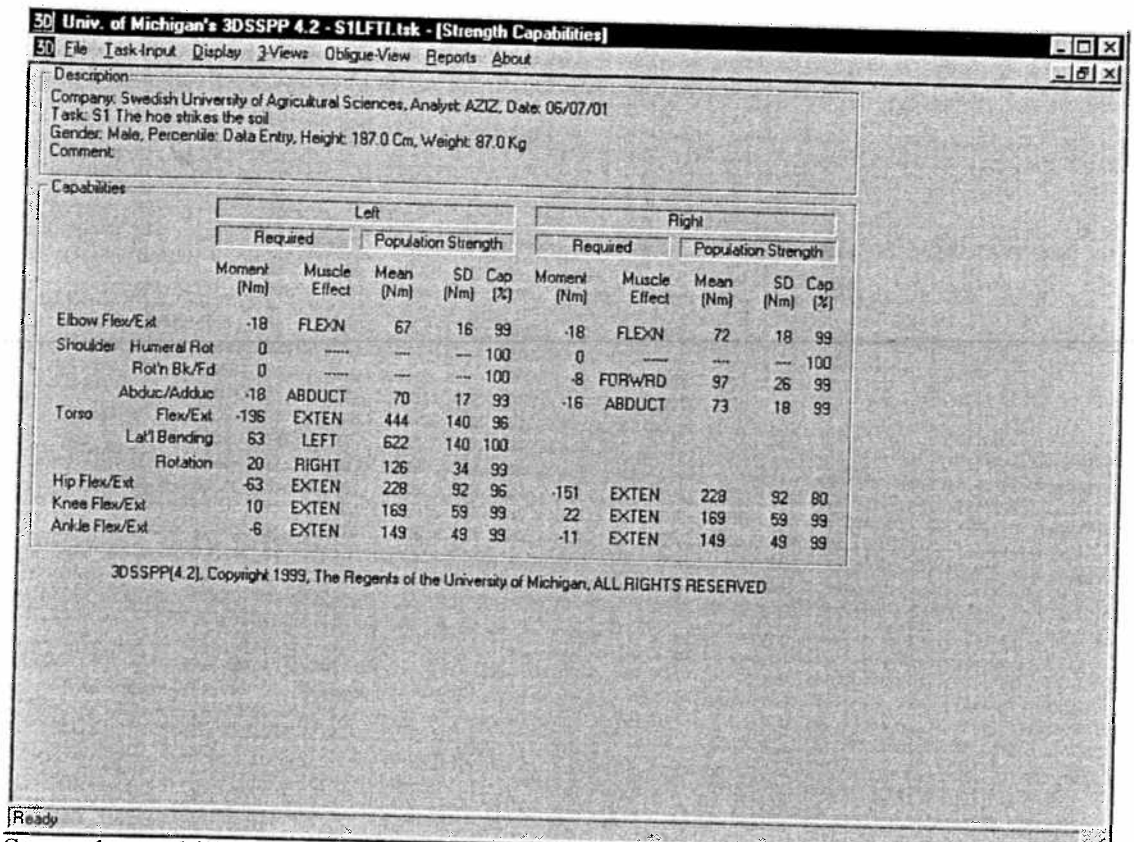
Ready

3D Lowback Analysis (force on L4/L5) for S8 while the hoe stroke the soil.

APPENDIX D: Strength Capabilities



Univ. of Michigan's 3DSSPP 4.2 - S1LFTI.tsk - [Strength Capabilities]

File Task-Input Display 3-Views Oblique-View Reports About

Description

Company: Swedish University of Agricultural Sciences, Analyst: AZIZ, Date: 06/07/01
Task: S1 The hoe strikes the soil
Gender: Male, Percentile: Data Entry, Height: 187.0 Cm, Weight: 87.0 Kg
Comment:

Capabilities

	Left					Right				
	Required		Population Strength			Required		Population Strength		
	Moment (Nm)	Muscle Effect	Mean (Nm)	SD (Nm)	Cap (%)	Moment (Nm)	Muscle Effect	Mean (Nm)	SD (Nm)	Cap (%)
Elbow Flex/Ext	-18	FLEXN	67	16	99	-18	FLEXN	72	18	99
Shoulder Humeral Rot	0	-----	---	---	100	0	-----	---	---	100
Rot'n Bk/Fd	0	-----	---	---	100	-8	FORWRD	97	26	99
Abduc/Adduc	-18	ABDUCT	70	17	99	-16	ABDUCT	73	18	99
Torso Flex/Ext	-196	EXTEN	444	140	96					
Lat'l Bending	63	LEFT	622	140	100					
Rotation	20	RIGHT	126	34	99					
Hip Flex/Ext	-63	EXTEN	228	92	96	-151	EXTEN	228	92	80
Knee Flex/Ext	10	EXTEN	169	59	99	22	EXTEN	169	59	99
Ankle Flex/Ext	-6	EXTEN	149	49	99	-11	EXTEN	149	49	99

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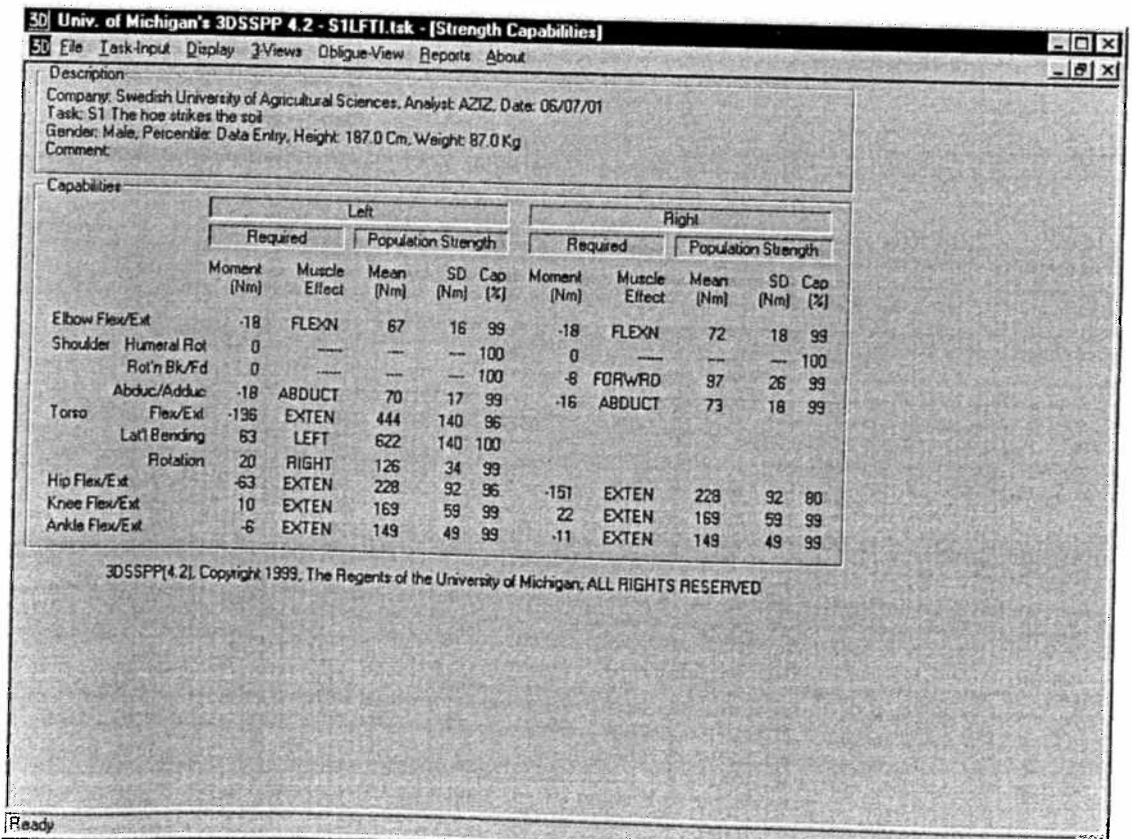
Ready

Strength capabilities for S1 while the hoe stroke the soil



Univ. of Michigan's 3DSSPP 4.2 - S1LFTI.tsk - [Strength Capabilities]

File Task-Input Display 3-Views Oblique-View Reports About

Description

Company: Swedish University of Agricultural Sciences, Analyst: AZIZ, Date: 06/07/01
Task: S1 The hoe strikes the soil
Gender: Male, Percentile: Data Entry, Height: 187.0 Cm, Weight: 87.0 Kg
Comment:

Capabilities

	Left					Right				
	Required		Population Strength			Required		Population Strength		
	Moment (Nm)	Muscle Effect	Mean (Nm)	SD (Nm)	Cap (%)	Moment (Nm)	Muscle Effect	Mean (Nm)	SD (Nm)	Cap (%)
Elbow Flex/Ext	-18	FLEXN	67	16	99	-18	FLEXN	72	18	99
Shoulder Humeral Rot	0	-----	---	---	100	0	-----	---	---	100
Rot'n Bk/Fd	0	-----	---	---	100	-8	FORWRD	97	26	99
Abduc/Adduc	-18	ABDUCT	70	17	99	-16	ABDUCT	73	18	99
Torso Flex/Ext	-196	EXTEN	444	140	96					
Lat'l Bending	63	LEFT	622	140	100					
Rotation	20	RIGHT	126	34	99					
Hip Flex/Ext	-63	EXTEN	228	92	96	-151	EXTEN	228	92	80
Knee Flex/Ext	10	EXTEN	169	59	99	22	EXTEN	169	59	99
Ankle Flex/Ext	-6	EXTEN	149	49	99	-11	EXTEN	149	49	99

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Ready

Strength capabilities for S2 while the hoe stroke the soil

3D Univ. of Michigan's 3DSSPP 4.2 - S3DIG.tsk - [Strength Capabilities]

File Task-Input Display 3-Views Oblique-View Reports About

Description

Company: Swedish University of Agricultural Sciences, Analyst: AZIZ, Date: 06/07/01
Task: S3 Hoe strikes the soil
Gender: Male, Percentile: Data Entry, Height: 176.0 Cm, Weight: 81.4 Kg
Comment:

Capabilities

		Left					Right				
		Required		Population Strength			Required		Population Strength		
		Moment (Nm)	Muscle Effect	Mean (Nm)	SD (Nm)	Cap (%)	Moment (Nm)	Muscle Effect	Mean (Nm)	SD (Nm)	Cap (%)
Elbow Flex/Ext		-5	FLEXN	68	17	100	-12	FLEXN	73	18	99
Shoulder	Humeral Rot	2	MEDIAL	59	15	100	5	MEDIAL	64	16	100
	Rot'n Bk/Fd	0	-----	---	---	100	-12	FORWRD	107	29	99
	Abduc/Adduc	9	ADDUCT	106	33	99	-7	ABDUCT	81	20	100
Torso	Flex/Ext	-126	EXTEN	367	116	98					
	Lat'l Bending	31	LEFT	472	106	100					
	Rotation	-10	LEFT	66	18	99					
Hip Flex/Ext		-73	EXTEN	207	83	94	-67	EXTEN	207	83	95
Knee Flex/Ext		-19	FLEXN	132	39	99	-18	FLEXN	132	39	99
Ankle Flex/Ext		-20	EXTEN	139	46	99	-19	EXTEN	139	46	99

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Ready

Strength capabilities for S3 while the hoe stroke the soil

3D Univ. of Michigan's 3DSSPP 4.2 - S4DIG.tsk - [Strength Capabilities]

File Task-Input Display 3-Views Oblique-View Reports About

Description

Company: Swedish University of Agricultural Sciences, Analyst: AZIZ, Date: 06/07/01
Task: S4 Hoe strikes the soil
Gender: Male, Percentile: Data Entry, Height: 180.0 Cm, Weight: 84.6 Kg
Comment:

Capabilities

		Left					Right				
		Required		Population Strength			Required		Population Strength		
		Moment (Nm)	Muscle Effect	Mean (Nm)	SD (Nm)	Cap (%)	Moment (Nm)	Muscle Effect	Mean (Nm)	SD (Nm)	Cap (%)
Elbow Flex/Ext		-12	FLEXN	61	15	99	-8	FLEXN	67	16	100
Shoulder	Humeral Rot	0	----	---	---	100	-1	LATERL	80	18	100
	Rot'n Bk/Fd	-8	FORWRD	90	24	99	4	BACKWD	73	21	99
	Abduc/Adduc	-13	ABDUCT	70	17	99	-8	ABDUCT	75	18	100
Torso	Flex/Ext	-190	EXTEN	450	142	96					
	Lat'l Bending	-10	RIGHT	601	130	100					
	Rotation	-26	LEFT	78	21	99					
Hip Flex/Ext		-147	EXTEN	231	93	81	-51	EXTEN	231	93	97
Knee Flex/Ext		13	EXTEN	166	58	99	6	EXTEN	166	58	99
Ankle Flex/Ext		1	FLEXN	139	46	99	0	-----	---	---	100

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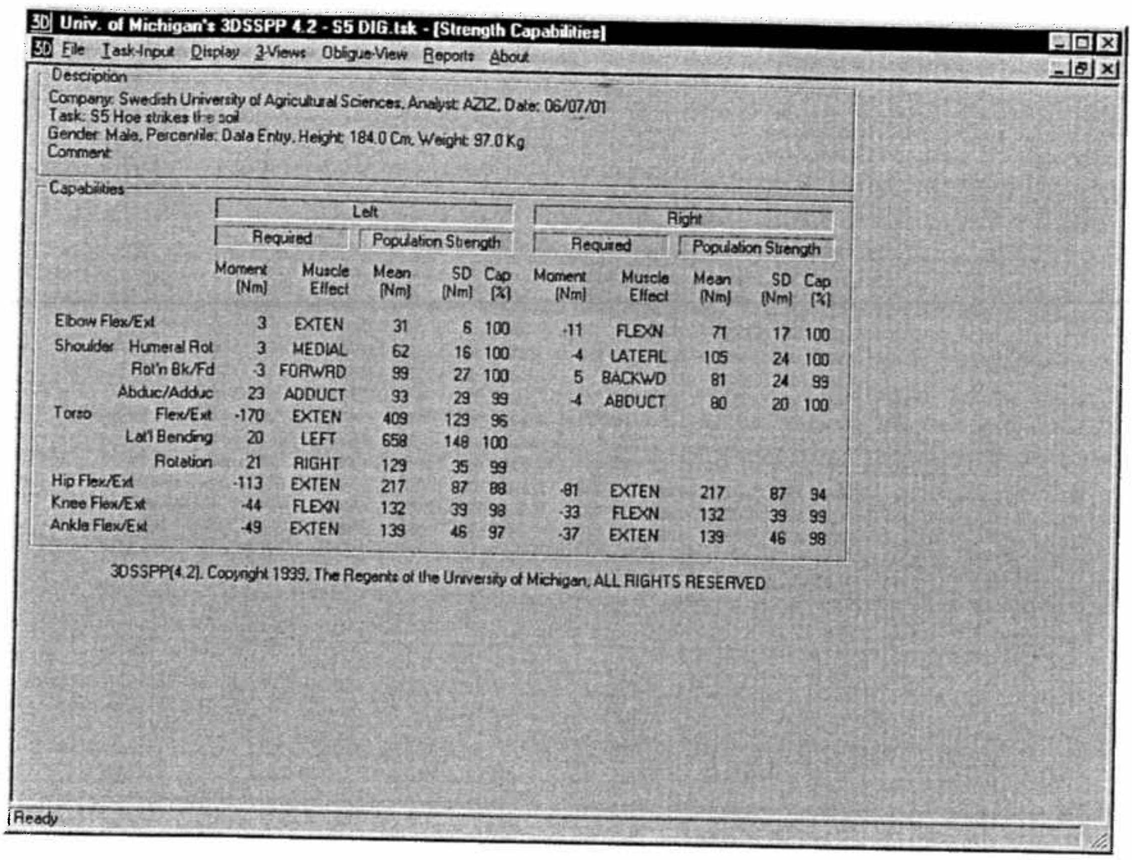
Ready

Strength capabilities for S4 while the hoe stroke the soil



Univ. of Michigan's 3DSSPP 4.2 - S5 DIG.tsk - [Strength Capabilities]

File Task-Input Display 3-Views Oblique-View Reports About

Description

Company: Swedish University of Agricultural Sciences, Analyst: AZIZ, Date: 06/07/01
Task: S5 Hoe strikes the soil
Gender: Male, Percentile: Data Entry, Height: 184.0 Cm, Weight: 97.0 Kg
Comment:

Capabilities

	Left					Right				
	Required		Population Strength			Required		Population Strength		
	Moment (Nm)	Muscle Effect	Mean (Nm)	SD (Nm)	Cap (%)	Moment (Nm)	Muscle Effect	Mean (Nm)	SD (Nm)	Cap (%)
Elbow Flex/Ext	3	EXTEN	31	6	100	-11	FLEXN	71	17	100
Shoulder Humeral Rot	3	MEDIAL	62	16	100	-4	LATERL	105	24	100
Rot'n Bk/Fd	-3	FORWRD	99	27	100	5	BACKWD	81	24	99
Abduc/Adduc	23	ADDUCT	93	29	99	-4	ABDUCT	80	20	100
Torso Flex/Ext	-170	EXTEN	409	129	96					
Lat'l Bending	20	LEFT	658	148	100					
Rotation	21	RIGHT	129	35	99					
Hip Flex/Ext	-113	EXTEN	217	87	88	-81	EXTEN	217	87	94
Knee Flex/Ext	-44	FLEXN	132	39	98	-33	FLEXN	132	39	99
Ankle Flex/Ext	-49	EXTEN	139	46	97	-37	EXTEN	139	46	98

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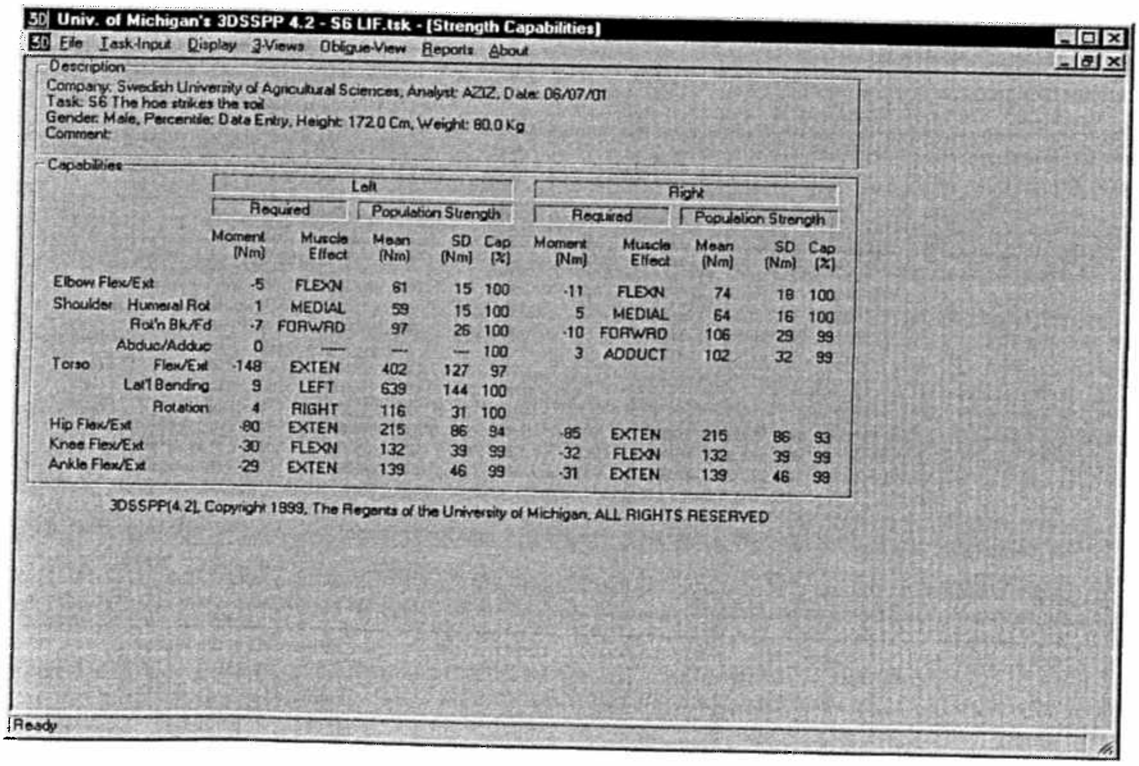
Ready

Strength capabilities for S5 while the hoe stroke the soil



Univ. of Michigan's 3DSSPP 4.2 - S6 LIF.tsk - [Strength Capabilities]

File Task-Input Display 3-Views Oblique-View Reports About

Description

Company: Swedish University of Agricultural Sciences, Analyst: AZIZ, Date: 06/07/01
Task: S6 The hoe strikes the soil
Gender: Male, Percentile: Data Entry, Height: 172.0 Cm, Weight: 80.0 Kg
Comment:

Capabilities

	Left					Right				
	Required		Population Strength			Required		Population Strength		
	Moment (Nm)	Muscle Effect	Mean (Nm)	SD (Nm)	Cap (%)	Moment (Nm)	Muscle Effect	Mean (Nm)	SD (Nm)	Cap (%)
Elbow Flex/Ext	-5	FLEXN	61	15	100	-11	FLEXN	74	18	100
Shoulder Humeral Rot	1	MEDIAL	59	15	100	5	MEDIAL	64	16	100
Rot'n Bk/Fd	-7	FORWRD	97	26	100	-10	FORWRD	106	29	99
Abduc/Adduc	0	---	---	---	100	3	ADDUCT	102	32	99
Torso Flex/Ext	-148	EXTEN	402	127	97					
Lat'l Bending	9	LEFT	639	144	100					
Rotation	4	RIGHT	116	31	100					
Hip Flex/Ext	-80	EXTEN	215	86	94	-85	EXTEN	215	86	93
Knee Flex/Ext	-30	FLEXN	132	39	99	-32	FLEXN	132	39	99
Ankle Flex/Ext	-29	EXTEN	139	46	99	-31	EXTEN	139	46	98

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Ready

Strength capabilities for S6 while the hoe stroke the soil

Univ. of Michigan's 3DSSPP 4.2 - S7LIF.tsk - [Strength Capabilities]

File Task-Input Display 3-Views Oblique-View Reports About

Description

Company: Swedish University of Agricultural Sciences, Analyst: AZIZ, Date: 06/07/01
Task: S7 The hoe strikes the soil
Gender: Male, Percentile: Data Entry, Height: 175.0 Cm, Weight: 83.0 Kg
Comment:

Capabilities

	Left					Right				
	Required		Population Strength			Required		Population Strength		
	Moment (Nm)	Muscle Effect	Mean (Nm)	SD (Nm)	Cap (%)	Moment (Nm)	Muscle Effect	Mean (Nm)	SD (Nm)	Cap (%)
Elbow Flex/Ext	-16	FLEXN	65	16	99	-16	FLEXN	69	17	99
Shoulder Humeral Rot	0	-----	---	---	100	0	-----	---	---	100
Rot'n Bk/Fd	-7	FORWRD	88	24	99	7	BACKWD	79	23	99
Abduc/Adduc	-14	ABDUCT	68	17	99	-14	ABDUCT	79	19	99
Torso Flex/Ext	-192	EXTEN	476	150	97					
Lat'l Bending	-48	RIGHT	686	148	100					
Rotation	-32	LEFT	104	28	99					
Hip Flex/Ext	-171	EXTEN	240	96	76	-33	EXTEN	240	96	98
Knee Flex/Ext	14	EXTEN	170	59	99	3	EXTEN	170	59	99
Ankle Flex/Ext	-36	EXTEN	154	51	98	-10	EXTEN	154	51	99

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Ready

Strength capabilities for S7 while the hoe stroke the soil

Univ. of Michigan's 3DSSPP 4.2 - S8dig2.tsk - [Strength Capabilities]

File Task-Input Display 3-Views Oblique-View Reports About

Description

Company: Swedish University of Agricultural Sciences, Analyst: AZIZ, Date: 06/07/01
Task: S8 The hoe strikes the soil
Gender: Male, Percentile: Data Entry, Height: 172.0 Cm, Weight: 61.0 Kg
Comment:

Capabilities

	Left					Right				
	Required		Population Strength			Required		Population Strength		
	Moment (Nm)	Muscle Effect	Mean (Nm)	SD (Nm)	Cap (%)	Moment (Nm)	Muscle Effect	Mean (Nm)	SD (Nm)	Cap (%)
Elbow Flex/Ext	0	-----	---	---	100	-10	FLEXN	66	16	100
Shoulder Humeral Rot	2	MEDIAL	34	9	100	4	MEDIAL	63	16	100
Rot'n Bk/Fd	-14	FORWRD	88	24	99	-9	FORWRD	94	26	99
Abduc/Adduc	-9	ABDUCT	80	20	100	-11	ABDUCT	77	19	100
Torso Flex/Ext	-148	EXTEN	535	169	98					
Lat'l Bending	16	LEFT	625	141	100					
Rotation	2	RIGHT	117	31	100					
Hip Flex/Ext	-60	EXTEN	268	108	97	-102	EXTEN	268	108	93
Knee Flex/Ext	24	EXTEN	166	58	99	35	EXTEN	166	58	98
Ankle Flex/Ext	15	FLEXN	139	46	99	23	FLEXN	139	46	99

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Ready

Strength capabilities for S8 while the hoe stroke the soil