LOAD TRANSFER HAND FORCES DURING A TWO DIMENSIONAL SAGITTAL PLANE BOX LIFT

by

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ABSTRACT

Few studies have examined the effect of load transfer to the hands when calculating lumbar moments during lifting tasks. The purpose of this study was to investigate this relationship in order to develop a model that provides an accurate estimate of measured load transfer force to the hands and is applicable to an industrial setting. The effect of gender, load lifted, lift speed, lift style and subject strength were examined as possible variables to improve the prediction of load transfer force.

Ten healthy men and eleven healthy women, with no past history of back pain volunteered to participate in the study. Kinematic data were collected using the OPTOTRACK™, a 3-D motion tracking system and a portable video camera. Load transfer to the hands was measured as the total load minus measured values from an AMTI™ force plate. Two methods of estimating load transfer to the hands, called the SLOPE and POINT methods, were calculated and independently input into a quasi-dynamic hands-down link segment model in order to calculate lumbar moments.

Results of the study indicated that the SLOPE method of estimating load transfer to the hands was superior to the POINT method and thus resulted in lumbar moment estimations closer to the lumbar moment values obtained when the measured force values were used in calculation. The ability of the SLOPE method to estimate load transfer to the hands was improved when information about load lifted, lift style, gender and strength were considered. Regression analysis revealed the following prediction equation for

measured load transfer force (MLTF), y, derived with the independent variables slope cubed load transfer force, (SCLTF), gender (G), lift style (ST), load weight (W) and subject strength (SS):

$$\mathbf{MLTF = -5.996 + 1.044(SCLTF) - 0.873(W) + 8.964(G) + 0.157(ST) - 0.066(SS)}$$

$$\mathbf{r^2 = 0.887, SEE = 18.40\ N, p>0.001}$$

These variables are simple to collect in an industrial setting, which makes this strategy for estimating load transfer forces both improved and practical. However, the improvement was less than expected. Slope load transfer force (SLTF) alone significantly predicted MLTF ($r^2 = 0.867$). Therefore, ergonomists can use the SLOPE method to predict load transfer forces since the predictive power gained with the above regression equation may be negligible considering other sources of error for data collection in industry.

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A special thank you is also extended to members both past and present of the biomechanics and ergonomics lab. Everyone was quick to drop their own work and lend a hand when needed especially Wayne, Jon, and Pat. But most of all I would like to thank everyone for making my experience at Queen's both fun and educational. Laughs and antics during grad hockey, conference road trips, baseball, the Petawawa experience and in the lab will be fondly remembered.

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LIST OF DEFINITIONS

Enhanced Load Transfer Force (ELTF): ELTF was the force calculated at 0.1 second intervals using SCLTF, and information about subject gender, subject strength, lifting style and load weight.

Enhanced Lumbar Moments (ELM): Lumbar moments calculated using ELTF data.

Gender (G): When entering a value for gender in the regression equations MALE = 0 and FEMALE = 1.

Lift Speed (LS): The time in seconds to complete load transfer represents lifting speed.

Lift Style (ST): Lifting style was represented by the degree of knee bend measured at the start of load transfer.

Load (W): The weight of the load being lifted in kilograms.

Load Transfer (LT): Load transfer was the term used to describe the time period over which dynamic changes from a load resting on a supported surface with 0 % load in the hands to having 100 % load in the hands.

Load Transfer Force (LTF): The force calculated or estimated to be in the hands during load transfer was referred to as load transfer force.

Maximal Acceptable Weight of Lift (MAWL): The load value for a specific lifting condition that an individual determines they can lift with out fatigue, strain or injury.

MEASURED Method: This term was used to refer to load transfer force data collected with the use of a force plate and was considered the "gold standard".

Measured Load Transfer Force (MLTF): MLTF was the load weight minus the measured force at 0.01 second intervals from the force plate.

Measured Lumbar Moments (MLM): Lumbar moment values calculated using MLTF data.

Point Load Transfer Force (PLTF): PLTF was the force at 0.01 intervals calculated using the POINT method.

Point Lumbar Moments (PLM): Lumbar moments calculated using PLTF data.

POINT Method: A method of estimating load transfer to the hands in which the load being lifted was applied to the hands entirely just as the load being lifted clears the lift off surface.

Pre-load: An increase in force, above box weight, recorded by the force plate, that resulted from a subject applying a downward force on the box handles prior to starting the lift off phase of load transfer.

SLOPE Method: This was a method of estimating load transfer force to the hands using the weight of the load lifted divided into equal load increments over the load transfer period until the full weight of the load being lifted was in the hands.

Slope Cubed Load Transfer Force (SCLTF): SCLTF was determined using SLTF in a cubic regression equation.

Slope Cubed Lumbar Moments (SCLM): Lumbar moment values calculated using SCLTF.

Slope Load Transfer Force (SLTF): SLTF was determined using the SLOPE method but subdivided into equal force increments from the start to the end of lift.

Slope Lumbar Moments (SLM): Lumbar moments calculated using SLTF data.

Strength (SS): The ranking obtained according to the hand grip protocol outlined in the Canadian Standardized Test of Fitness manual was used to represent subject strength.

Video Lumbar Moments (VLM): Lumbar moments calculated using VLTF data.

Video Load Transfer Force (VLTF): VLTF was determined from SCLTF and information about subject gender, lifting style and load weight.

CHAPTER 1

INTRODUCTION

Lifting is a regular requirement of many industrial, custodial and manufacturing occupations. Unfortunately, lifting is also a major factor in the development and reoccurrence of low back pain and injury. In 1993, back complaints accounted for over 30 % of the entire Workers' Compensation Board claims in Ontario. Of these, 50 % resulted in just under 12 lost time days, while 25 % of the claims resulted in over 47 lost time days (WCB, 1993). Low back pain and injuries attributed to lifting are also a problem in the United States. Back injuries accounted for 20 % of the reported claims and accounted for nearly 25 % of the workers' compensation payments (Waters et al., 1994). An estimated 15 billion dollars in direct costs are spent by US industries on disabling back injuries and low back pain, while the indirect costs are estimated to be over four times this amount (Mital et al., 1993). Hence, it is critical that the mechanisms behind lifting injuries are studied, and that safe criteria for lifting are established.

In order to develop safe criteria, lifting guidelines were established in the United States by the National Institute for Occupational Safety and Health (NIOSH, 1981; Waters et al., 1994). One body of research underlying these guidelines was based on biomechanical evidence of tissue damage and estimates of mechanical loading on the spine. Simple or complex biomechanical link segment models were developed to predict the loads experienced by the back, especially at the L4/L5 or L5/S1 discs. One type of model begins the calculations for determining back moments at the hand segments. The predictive power of this approach rests, in part, with an accurate determination of the load transfer for the object resting on the floor to the subject's hands. Unless the box or object being lifted is instrumented, the transfer of the load to the hands can only be estimated. In industry, full instrumentation is not feasible, therefore, the ability to estimate the load transfer to the hands is critical.

The goal of this study was to develop a method of estimating load transfer force, LTF, that would be both applicable in industry and as close to the measured values for LTF as possible. Measured load transfer force (MLTF), recorded using a force plate, was treated as the "gold standard" for calculation of lumbar moment values. Using the same subject positional data, two methods of estimating LTF were used to calculate lumbar moment values and compared to lumbar moment values calculated using the MLTF "gold standard". This step was taken to confirm that LTF had a significant effect on the prediction of corresponding lumbar moments and to demonstrate that accurate calculation and/or estimation of LTF was important. The purpose of this study was to investigate different strategies of estimating LTF to the hands. The effects of lift style, lift weight, lift speed, gender, and subject strength on the prediction of LTF was also investigated. It was hypothesized that these strategies, in the absence of the "gold standard", would enhance the prediction of load transfer force to the hands and thus improve the calculation of lumbar moment values in industrial settings.

CHAPTER 2

LITERATURE REVIEW

2.1 Back Pain and Injury in Manual Materials Handling

Despite advances in technology including automation, lifting aids and power tools, manual materials handling is still regularly performed in many industries. Unfortunately, manual lifting activities are one of the major factors in the development and reoccurrence of low back pain and injury. In fact, over 65 % of industrial workers report low back pain symptoms during their careers (Rodgers, 1985). Not only are the costs of treatment expensive, but injury greatly affects the quality of life of those afflicted. In a report by Kelsey et al.(1979), low back pain (LBP) was found to be the most frequent cause of activity limitation in individuals under 45 years of age and the third leading cause in individuals between 45 and 64 years of age. Hence, more effort needs to be focused on the prevention of lifting related back pain and injury.

2.2 Lifting Guidelines

In 1981 and 1991, the National Institute for Occupational Safety (NIOSH) and Health came out with guidelines to help reduce the number and severity of low back injury and pain incidents. Epidemiological, physiological, psycho-physical and biomechanical criteria, each with different strengths and weaknesses, have all been used to develop guidelines for safe lifting (NIOSH, 1981).

Epidemiological research is important to consider when establishing safe lifting limits since a causal relationship has been made between individual back pain and injury data and workplace factors. For example, epidemiological surveys have found a strong association between frequent heavy lifting and low back pain (Kelsey et al., 1984; Svensson and Andersson, 1983; Kumar, 1990). Twisting and bending while lifting have also been identified as significant manoeuvres which increased the risk of suffering from low back pain (Snook, 1978; Troup et al, 1970; Punnett et al., 1991). An association between reaching away from the body to lift and low back pain has also been identified through epidemiological research (Damkot et al., 1984).

Physiological studies focus on the metabolic costs associated with lifting loads of different weights, heights, frequencies and durations. Physiological research has also shown energy expenditure varies with lifting technique. For example, Garg and Saxena, in 1979, found energy expenditures of subjects to be highest when lifting with a squat technique. In a similar study, Kumar (1984) found the stoop technique to be the least expensive metabolically when compared to the freestyle and squat technique. Welbergen and colleagues (1991) found the energy costs of using the squat technique to be nearly twice as high when compared to the stoop technique. In an effort to minimize the risks associated with lifting loads above "safe" physiological limits, an energy expenditure of less than 9.5 kilocalories per minute, for repetitive lifting tasks, was established by the National Institute of Occupational Safety and Health (NIOSH, 1991).

The psycho-physical approach is based on the ability of individuals to predict loads that they can safely lift under a given set of lifting conditions for a defined period of time; the load is termed the maximal acceptable weight of lift (MAWL). This approach has led to the development of capacity models designed to predict MAWL for both men and women under a variety of lifting conditions (Snook and Ciriello, 1991; Mital, 1984; Ayoub et al, 1980). In 1978, Snook evaluated the relationship between MAWL and back pain. He found workers were 3 times more likely to develop low back injuries if they performed manual handling tasks that were acceptable to less than 75 % of the popluation.

Maximal acceptable weight limits have greatly influenced the criteria set for industrial load limits but, in some lifting conditions, researchers have found the loads people perceive to be "safe" are actually above biomechanical and physiological safe limits (Chaffin and Page, 1994; Karwowski and Yates, 1986; Waikar et al, 1991). Specifically, lifts originating near the floor were highlighted as needing more study since subjects are unable to perceive "safe" load limits when beginning lifts at the floor level and back pain and injury continue to occur (Buckle et al., 1992; Waikar et al, 1991). The inability to perceive "safe" lifting limits can result if a subject exceeds his/her tissue tolerance limits by applying excessive force or lifting above his/her physiological limits.

The biomechanical approach computes the moments and forces experienced by the body during lifting. A limit of 3400 Newtons of compressive force at the L5/S1 level was established by biomechanical research as a load that minimizes the risk of a back injury (NIOSH, 1991). In a study by Anderson (1983), men in jobs with a predicted compressive force above 3400 Newtons had a 40 % higher incidence rate for low back pain when compared to men working in similar occupations with compressive forces below 3400 Newtons. In a cadaveric study by Jager and Luttman (1989), 30 % of lumbar motion segments were found to have an ultimate compressive strength of less than 3400 Newtons. In a similar study, Brinckmann and colleagues (1988) found the compressive strength of vertebral segments to range from 2100 to 9600 Newtons. Specifically, they reported less than 21 % of the vertebral segments fractured or experienced end plate failure at compressive loads below 3400 Newtons. These studies have been used to substantiate recommended tolerance limits for lumbar compressive forces.

The compressive load on the spine can be measured directly (Nachemson and Morris, 1964; Schultz et al., 1982), although the practical application of direct measurement outside a laboratory setting is limited. In 1964 Nachemson and Morris inserted a needle with a pressure sensitive membrane tip, into a nucleus pulposus to measure intradiscal pressure. Pressures were measured with subjects sitting, standing, reclining, holding weights up to 11.4 kg and performing the Valsalva manoeuvre. This type of needle inserting procedure is invasive and not permitted in many countries. Therefore, indirect measures such as biomechanical models or link segment models have been developed to predict spinal loads.

2.3 Biomechanical Link Segment Models

Simple link segment models such as the "feet up" and "hands down" models and complex link segment models, that incorporate biological inputs are currently used by researchers interested in estimating lumbar loads during lifting. Although complex link segment models are capable of providing more detail and accuracy when predicting lumbar moments, compression and shearing forces, they are often difficult to apply outside a laboratory setting. For example, a three dimensional (3D) motion model developed by Marras et al.(1991) incorporates electromyography, trunk kinematics and kinetics in order to predict lumbar spine compression, shear and torsional forces. However, the authors indicated the usefulness of the model was restricted to assessing spinal loading in a laboratory setting. A 3D dynamic 19-segment human model, developed by Jager and Luttmann (1989), which includes the influence of intra-abdominal pressure also has limited applicability outside the laboratory.

Despite the increased detail and accuracy gained with complex link segment models, "simple" link segment models are predominately used outside the laboratory due to their ease of application. The "feet up" approach begins modelling the lift from the feet using ground reaction force (GRF) from a load cell or forceplate as the starting point (de Looze et al., 1992; Buseck et al., 1988;

Schipplein et al., 1990). The "hands down" method begins at the hand-load segment and uses the force at the hand-load segment as the starting point (de Looze et al., 1992; Freivalds et al., 1984; Leskinen et al., 1983; Kromodihardjo and Mital, 1986; Wheeler, 1994). The output values of both models are highly dependent on the quality of the initial input information. For example, when analysis begins at the feet, GRF is obtained directly from the force readings recorded by the forceplate. Therefore, when a subject lifts an object, the subsequent increase in load is observed as an increase in GRF. When analysis begins at the hands, the load transfer must be measured over the period of time from no loading to complete loading onto the hands. Measuring this load transfer is important since the load (force) acting at the hands is the starting point for hands down link segment modelling.

In 1992, de Looze and colleagues conducted a comparative study of the feet up and hands down methods in an effort to validate the models. A correlation coefficient of $r = 0.99$ was found when L5-S1 moments calculated starting at the hands were compared to L5-S1 moments calculated by starting at the feet. In this study, the entire load was estimated to be in the hands at one point in time. Hence the "load transfer" period was assumed to be negligible. Other researchers have instrumented the "box" so the exact load taken up by the hands could be measured. In 1985, McGill and Norman calculated hand forces using a linear variable differential transducer attached to the load. In a study by Pinder et al. (1993), three mutually perpendicular force transducers were mounted to handles in order to measure the hand forces exerted in both the x, y and z directions. Danz and Ayoub (1991) also measured hand forces directly using a "specially designed strain gauge apparatus" and found measured hand forces to be greater than modelled hand forces. The speed of lift, frequency of lift and percent maximal weight of lift had a significant effect on peak hand forces.

2.4 The Need to Study Load Transfer in Lifts at Floor Level

In the original NIOSH guidelines, biomechanical and epidemiological data were used to identify an increased risk for low back pain and injury within the first few seconds of lifts beginning at the floor level (NIOSH, 1981). In 1983, Garg and colleagues stressed the need to study the dynamics of lifting since the start of the lift could be a factor in low back injury. Furthermore, peak hand forces during a lift generally occurred about 200-300 ms after the object being lifted began to move (Garg, 1989). In 1991, Punnett and colleagues reported a larger percentage of low back injuries were associated with lifting near the floor. Lumbar moments were also higher while lifting loads near the floor (Bean et al., 1988).

Therefore, load transfer, defined as the period between 0% and 100% of the load being supported by the hands, must be examined carefully when using link segment models to calculate lumbar moments. The predictive power of hands up link segment models rests in the determination of the "load" in the hands. "True hand load" can be measured directly if the "box" being lifted is instrumented, but generally this is not a possibility in the majority of industrial settings since full instrumentation is too cumbersome and interrupts the natural job process.

In the past, some researchers (de Looze et al., 1992; Wheeler, 1994) have applied the full load to the hands at one instant, yet little or no research is available to justify this approach. This assumption may be an oversimplification since peak accelerations and back moments occur near the start of the lift. Hence, load transfer to the hands is a critical issue and needs to be investigated during hands up link segment modeling. This approach of applying the force at one instant will be evaluated in this study.

2.5 Evaluation of Factors that may Affect Load Transfer

Since load transfer is important in link segment modelling, it is also important to understand variables that could affect load transfer and thus affect the prediction of load transfer force. From a review of the literature, it will be argued that weight lifted, lifting style, lifting speed, subject gender and subject strength are all variables that could affect load transfer and the prediction of load transfer forces.

Research has shown that lumbar moments increase as the weight of the load being lifted increases (Frievalds et al., 1984; Schipplein et al., 1995). In 1988, Buseck and colleagues calculated flexion-extension moments at the L5-S1 level of the spine for loads of 50, 100, 150, 200 and 250 Newtons and found a linear relationship between increased load and lumbar moments. In 1992, Danz and Ayoub found peak vertical and horizontal hand forces to be significantly influenced by load. The average peak vertical hand forces, for floor to knuckle lifts at 35, 60 and 85 % maximal acceptable weight of lift, were 212, 328 and 418 Newtons respectively. Although load lifted had an effect on the prediction of load transfer forces, and thus lumbar moment calculations, it was unclear how this variable interacted with other factors.

Researchers have also studied the effect lifting style has on lumbar moments (Busek et al., 1988; Dolan et al., 1994; Chaffin and Page, 1994). According to biomechanical researchers, lumbar moments were generally higher when lifting with the "stoop" technique. In 1994, Dolan and colleagues found the stoop technique resulted in a 75 % increase in bending torque when compared to the "squat" technique. In a study by Garg and co-workers (1983), the freestyle technique resulted in the lowest lumbar moments since subjects were able to lift and pull the load towards their bodies. In the same study, subjects who used the squat technique had higher peak moments because the box was held further away from their bodies in order to clear their knees. Hence, further research is needed to determine if lifting style has an effect on the prediction of load transfer force and lumbar moment calculations.

Lifting speed has also been shown to affect the moment-load relationship. Several researchers have shown higher peak moments occurred when lifts were performed quickly (Buseck et al., 1988; de Looze et al., 1992). In the study by Buseck and colleagues, the mean moment for normal speed lifts (1.08 m/s) was found to be 18.8 % of body weight times height, while the mean moment for fast speed lifts (1.66 m/s) was found to be 21.6 % of body weight times height. Furthermore, the researchers did not find a statistically significant relationship between the speed of lift and the magnitude of the load being lifted. Researchers have also shown peak vertical and horizontal hand forces, during floor to knuckle lifts, to be significantly influenced by lift speed (Danz and Ayoub, 1992). The average peak vertical hand force, for a floor to knuckle lift, at 85 % maximal acceptable weight of lift, was 418 Newtons for a normal speed lift and 727 Newtons for a fast speed lift. Thus, further research is warranted to examine the interplay of these variables.

Gender may also be an important variable to understand load transfer. Strength studies have shown that men tend to be stronger than women. On average, lifting strengths of women are roughly 60 % of men's lifting strengths (Snook, 1978). Furthermore, the aerobic capacity of average women is around 70 % that of average men (Astrand andRodahl, 1977). Psycho-physical studies have also shown women tend to choose lower MAWL values than men (Snook and Ciriello, 1991). When these factors are considered, it is not surprising that several researchers have found higher rates of back pain amongst women in physically heavy jobs (Magora, 1970; Pope et al., 1984). Yet, other researchers have reported no gender differences in the incidence of low back pain in manual handling jobs (Chaffin and Park, 1973). Therefore, the effect of gender on the prediction of load transfer force should be investigated.

In the area of ergonomics and manual materials handling, measurements of strength are often used to provide a database to design jobs and equipment that can be operated within the capabilities of workers. Strength tests are also used to select workers who have the physical capabilities to match the requirements of certain jobs (Garg and Beller, 1994). Therefore, further research is needed to determine if strength has an effect on the prediction of load transfer force.

2.6 Summary

This literature review has been designed to: provide some scientific background underlying lifting guidelines; examine the use of simple link segment models that are used to estimate lumbar moments from forces at the hands; explain the rationale for studying the load transfer phase of lifts from floor height; and examine other variables that may affect the load transfer phase. Based on this review, it would appear that researchers realize that the load transfer phase of a lift is important and, for the most part, account for this transfer in link segment models where calculations start at the hands. However, no literature was found to describe strategies to estimate this load transfer phase in industrial settings. Typically, an ergonomist uses video-based approaches to estimate lumbar moments. Therefore, the goal of this research is to develop a video-based method of estimating load transfer force that will be applicable in industry.

CHAPTER 3

METHODOLOGY

3.1 Subject Selection

Eleven healthy women and ten healthy men with no past history of low back pain volunteered to participate in this study. Each volunteer completed a consent form and a PAR-Q screening questionnaire before being accepted as a subject (Appendix A). A subset of six women and six men was randomly extracted for a comparison of hand forces and back moments during the box lift-off phase. The average age, height, and mass of the 21 subjects and the subset sample are shown in Table 3.1.

Table 3.1: Summary data of the subjects' anthropometrics.

Gender	Age (Years)	Height (Meters)	Mass (Kilograms)
Males n=10	25 (2)	1.82 (.07)	80 (7.6)
Females n=11	24 (2)	1.68 (.073)	65 (10.2)
Subset			
Males n=6	26 (2)	1.82 (.081)	80.7 (8.7)
Females n=6	23 (2)	1.70 (.079)	65 (11.6)

3.2 Experimental Protocol

3.2.1 Anthropometrics

Each subject was asked to change into shorts, a T-shirt and comfortable shoes. The age, body mass and height of each subject were then recorded. The grip strength of each subject was also measured (Figure 3.1) by following the protocol outlined in the 1987 Canadian Standardized Test of Fitness manual (Appendix B). Hand grip was selected as a strength measure since it has been shown to be a reasonable measure of lean body muscle mass (CSTF, 1987).

3.2.2 Marker Placement

Infrared light-emitting diodes (IREDS) were attached to both the subject and the box being lifted. In total, four IREDS were attached to the right side of each subject at the first knuckle of the middle finger, the middle of the wrist joint, 40 mm proximal to the middle of the wrist joint, and at the lateral epicondyle of the elbow (Figure 3.2). IREDS were attached first with double sided sticky pads, and then secured in place with a stretchy mesh fabric called Retelast ™. Three IREDS were attached to the box by using double sided sticky pads (Figure 3.3). Markers were also placed at the level of the right greater trochanter, lateral epicondyle of the knee, and the lateral malleolus of the ankle in order to aid joint detection from the video. Knee bend was measured as a proxy for lifting style since stoop and squat lifting styles are most affected by the positioning of this joint (Burgess-Limerick and Abernethy, 1997).

3.2.3 Lifting Setup

A square box with a height, width and depth of 0.26, 0.37 and 0.30 m respectively was used for all lift trials in this study. The box had two cylindrical handles 0.15 m above the floor. The empty box weighed 5 kg but had a top lid to allow additional weight to be added. The box was placed on an AMTI™ force plate that was one meter away from an adjustable shelf. Figure 3.4 illustrates the set-up.

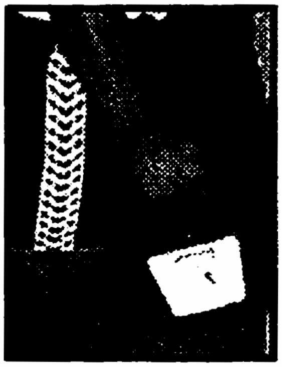


Figure 3.1: Hand Grip Dynamometer used to measure grip strength.

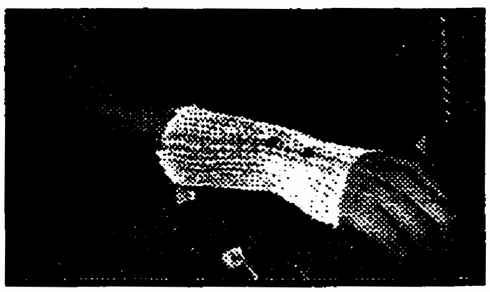


Figure 3.2: IRED marker placement on the subject.

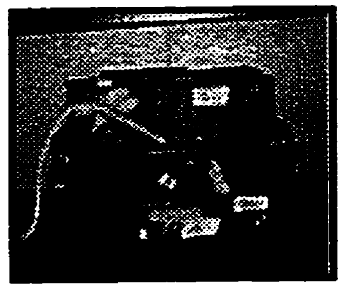


Figure 3.3: The white squares with black outline show the location of the IRED markers on the box.

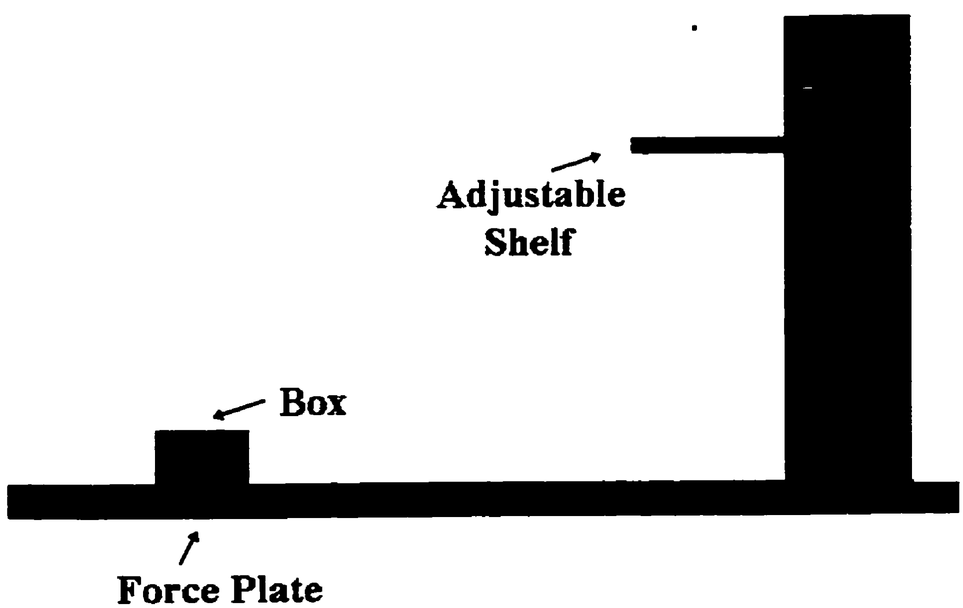


Figure 3.4: Setup of the lifting apparatus.

3.2.4 Lifting Procedure

Each subject completed five sagittal plane box lifts in a freestyle manner at loads of 5, 9, 13 and 18 kg. Lifting order was randomized, and each subject was given one practice lift with each new weight. Each lift started with the box placed squarely on top of the force plate and ended when the box was placed on a shelf located 0.15 m below the height of each subject's acromium process (Figure 3.5). The subject was not permitted to step on or load the forceplate in any way. A research assistant then lifted the box down and placed it back squarely on the force plate. The subject awaited a verbal signal from the researcher before beginning his/her next lift. The time between lifts in a series was generally one minute, however, subjects could request more time if needed to negate the effects of any fatigue.

3.3 Equipment

Load transfer of the box to the hands was measured using an AMTI ™ force plate, at a sampling rate of 100 Hz. The box was placed directly on the force plate at the start of the lift. As the box was lifted, the force recorded by the force plate dropped until the box was completely off the force plate and thus the load on the force plate was recorded as zero Newtons.

Kinematic data were collected simultaneously at 100 Hz using the OPTOTRACK ™, a 3-D optoelectric motion tracking system from Northern Digital Inc. The OPTOTRACK ™ incorporates multiple cameras and makes use of active infrared light-emitting diodes (Figure 3.6). The system used a calibration frame to define a global co-ordinate system

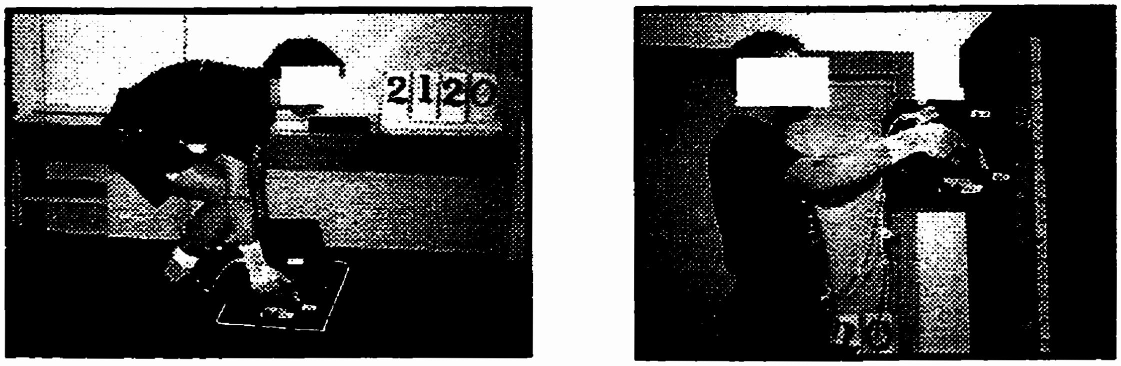


Figure 3.5: A subject is shown completing one box lift from the floor to a shelf 0.15 m below shoulder height. The force plate (outlined in white) is shown in the left picture.

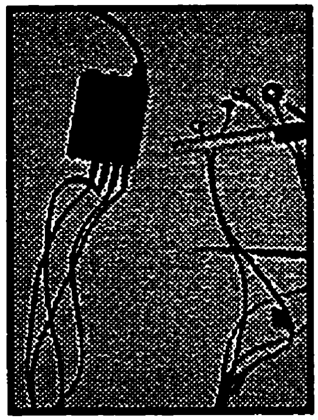


Figure 3.6: Infrared light-emitting diodes.

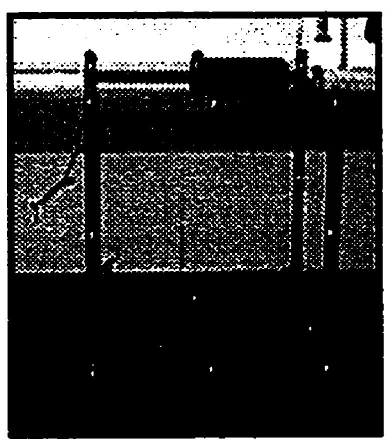


Figure 3.7: The calibration frame of the OPTOTRACK™.

from which position and orientation information could be collected for any segment defined by three non-colinear markers (DeLuzio et al., 1993) (Figure 3.7). The OPTOTRACK ™ and the AMTI ™ force plate were synchronized and all sampling occurred at 100 Hz. In addition, lifts were also filmed from the right side using a portable videocassette recorder. Kinematic data were obtained by digitizing the video using QDIG, a digitizing program written by Dr. Bill Pearce at Queen's University.

3.4 Data Reduction

OPTOTRACK ™ and forceplate data were stored on an IBM compatible 286 computer, processed and then transferred onto disk for future analysis. The kinematic data collected with the OPTOTRACK ™ were immediately calibrated and stored on disk. Force data in A/D units were subsequently calibrated and converted to Newtons by using a calibration program written by Dr. Pat Costigan of the Queen's University Human Motion Laboratory.

Kozar (1995), found that subjects were very consistent in their lifting profile with a high level of repeatability within subjects. Danz and Ayoub (1992) also found hand force patterns for floor to knuckle lifting to be repeatable. To verify their conclusions, 60 trials (three subjects lifting 5 times at 4 loads) were chosen to examine the consistency of the load transfer when subjects lifted under identical lifting conditions. A one way ANOVA revealed no significant difference in load transfer curves across subject trials ($p>0.05$). Therefore, the third lift under each new lifting condition was chosen for subsequent analyses.

3.5 Load Transfer

Load transfer was defined as the period in which 0 % of the load to 100 % of the load was transferred to the hands. Load transfer to the hands was measured as the load weight minus the force plate value. The beginning of load transfer to the hands was identified by the first force value that was one standard deviation below the average baseline noise as measured across the first 15 recorded force values when the box was resting on the force plate. The completion of load transfer was identified as the first force value greater than one standard deviation above the average baseline noise of the last 15 recorded force values when the box was completely in the subjects' hands (Figure 3.8). This approach was called the MEASURED method.

Since a force plate is generally not available to measure load transfer in industry, two easily derived methods from video analysis were used to estimate load transfer to the hands. The "POINT" method assumed load transfer to the hands occurred completely at one point in time. Wheeler (1994) and De Looze et al. (1992) used the POINT method with no discussion about the consequences of this approach. The load transfer POINT was defined at a time equal to one video frame before the box completely cleared the force plate (Figure 3.9).

The "SLOPE" estimation method was determined by using the load weight divided by the total lift time to calculate the linear slope of the measured load transfer curve from the estimated start and end of each lift. Hence, this method assumed that the

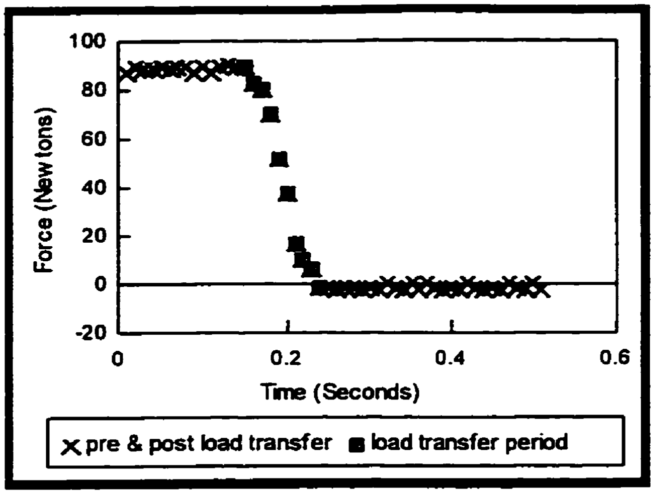


Figure 3.8:The identification of the load transfer period.

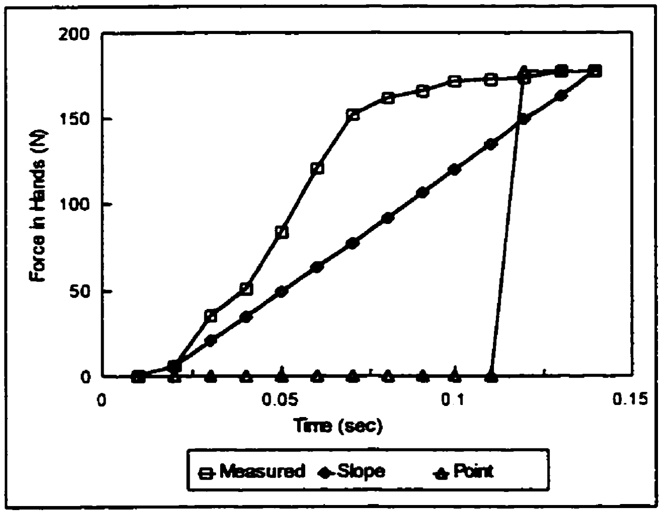


Figure 3.9: MEASURED, SLOPE and POINT load transfer values are shown for one subject.

load would be transferred to the hands equally throughout the load transfer period (Figure 3.9). Load transfer values were calculated for all 21 subjects who participated in this study under four load conditions.

3.6 2-D Quasi Dynamic Link Segment Model

In occupational settings, it is generally not possible to apply a full dynamic analysis to estimate joint loading. A dynamic model includes force plate and subject positional data as inputs to the link segment model, with segment accelerations also taken into account in the determination of joint moments (Winter, 1990). A quasi-dynamic model is more accurate than a static model because it includes measurements of external forces at the hands or feet, while ignoring segment accelerations (McGill and Norman 1985; Lindbeck and Arborelius, 1991). Therefore, a two-dimensional, quasi-dynamic hands-down link segment model was used to calculate L4/L5 moments in this study.

The model consisted of four segments: hand, forearm, upper arm, and head-neck-trunk. The hand segment was defined by the middle knuckle of the right hand and the middle of the right wrist joint. The forearm segment continued from the same wrist joint marker to the lateral epicondyle of the right elbow. The upper arm segment was defined by the right elbow and the head of the right humerus, while the head-neck-trunk segment was defined by the same humerus axis to the right anterior superior iliac spine (Figure 3.10). Force and moment calculations began at the hand-load segment. Newtonian mechanics were then applied to each segment in succession until the moment at the L4/L5 level of the spine was determined. All calculations were carried out in a Lotus ™

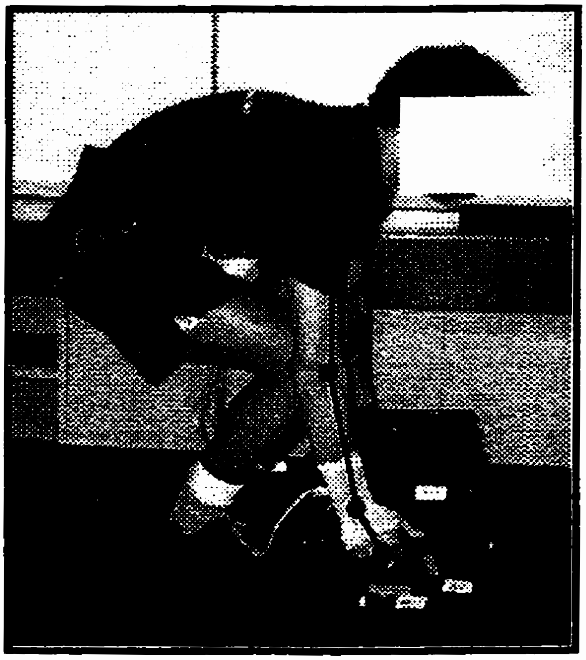


Figure 3.10: Segments in the hands-down link segment model.

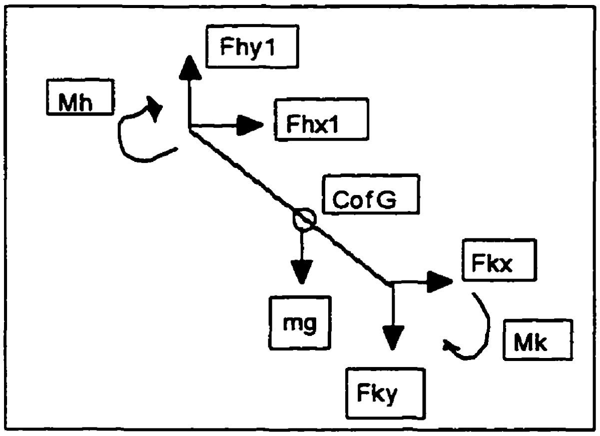
spreadsheet. For each load transfer frame the following calculations were carried out in order to determine the corresponding moment on the spine at the L4/L5 level:

1. Digitized X and Y coordinate data for the knuckle, wrist, elbow, shoulder and hip were input into the spreadsheet.

2. The mass of each segment was then calculated as outlined in Winters (1990). For example the mass of the head-neck-trunk segment accounted for 43.6 % of the subjects total body weight.

3. The location of the center of gravity for each segment was also calculated as outlined in Winters (1990). For example the location of the center of gravity for the head-neck-trunk was 63% from the location of the hip coordinate. The perpendicular distance to the center of gravity, for each segment, in both the X and Y direction were then calculated.

4. Calculation of forces and moments began at the hand segment. Load transfer force at each frame represented the force at the knuckle in the Y direction. The body was assumed to be static, therefore, joint accelerations were ignored and the sum of all forces in the X direction were equal to zero and the sum of all forces in the Y direction were equal to zero. Therefore, the force at the wrist (Fhy1) was calculated using the following formulae:



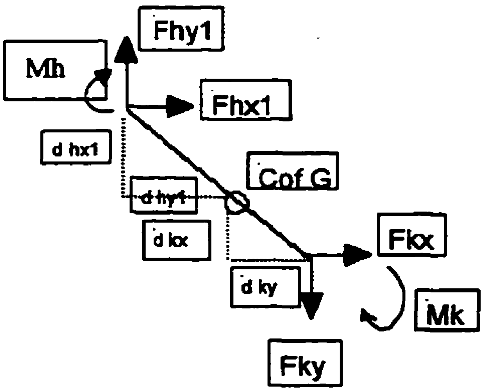
$Fhy1 = Fky + mg$

Where
Fky = force at the knuckle in the y direction
m = mass of the hand segment
g = the acceleration due to gravity (9.81 m/s^2)

Note: Fkx and Fhx1are both equal to zero

Where
Fkx = force at the knuckle in the X direction
Fhx1 = force at the hand in the X direction

5. The moment about the wrist (Mh) was then calculated. Since the body was assumed to be static the sum of all moments were equal to zero. The moment created by Fky, Fkx, Fhx1 and Fhy1 were calculated in order to find the resultant moment about the wrist. The following calculations were carried out:

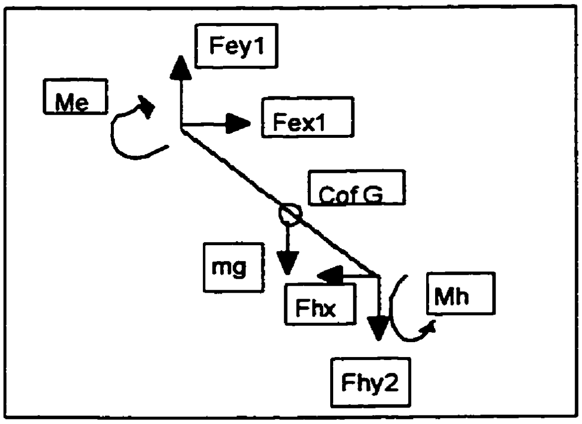


$Mky = Fky * dky$ Recall
$Mkx = Fkx * dkx$ $Fkx = 0$
$Mhy1 = Fhy1 * dhy1$ $Fhx1 = 0$
$Mhx1 = Fhx1 * dhx1$ $Mk = 0$

$Mh = Mk + Mky - Mkx + Mhy1 + Mhx1$

Where
Mky = moment at the knuckle in the Y direction
Mkx = moment at the knuckle in the X direction
Mhy1 = moment at the wrist in the Y direction
Mhx1 = moment at the wrist in the X direction
Mk = moment about the knuckle joint

6. The forces and moments calculated at the wrist joint were then used to calculate the forces and moments at the elbow joint. However, the direction of the forces and moments at the wrist were reversed in order to calculate forces and moments about the elbow (Newtons 3rd Law). Again the subject was considered to be static, hence, the sum of all forces in both the X and Y direction equal zero and the sum of all moments was also equal to zero. The following equation was used to calculate Fey1:



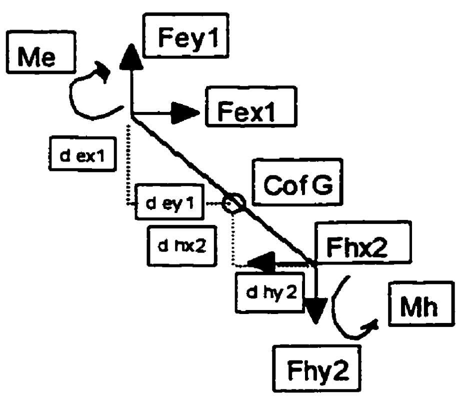
Fey1 = Fhy2 + mg

Where
Fhy2 = force at the wrist in the y direction
m = mass of the forearm segment
g = the acceleration due to gravity (9.81 m/s^2)

Note: Fhx and Fex1are both equal to zero

Where
Fhx = force at the hand in the X direction
Fex1 = force at the elbow in the X direction

7. The moment about the elbow (Me) were then calculated. Since the body was assumed to be static the sum of all moments were equal to zero. The moment created by Fhy2, Fhx2, Fex1 and Fey1 were calculated in order to find the resultant moment about the elbow. The following calculations were carried out:



Mhy2 = Fhy2 * dhy2
Mhx2 = Fhx2 * dhx2
Mey1 = Fey1 * dey1
Mex1 = Fex1 * dex1

Me = Mhy2 + Mhx2 + Mey1 + Mex1 - Mh

Where
Mhy2 = moment at the wrist in the Y direction
Mhx2 = moment at the wrist in the X direction
Mey1 = moment at the elbow in the Y direction
Mex1 = moment at the elbow in the X direction
Mh = moment about the wrist joint

8. The forces and moments calculated at the elbow joint are then used to calculate the forces and moments at the shoulder joint which in turn are used to calculate the forces at the hip. The process illustrated in step 6 and 7 are repeated for each joint. The resultant moment value obtained at the hip represents the moment value at the L4/L5 level since the anterior superior illiac spine was digitized at the hip joint and lines up with the L4/L5 level.

Kinematic data were imported into the spreadsheet and L4/L5 moments were calculated using MEASURED, POINT and SLOPE methods. Hereafter, the MEASURED load transfer force or force-time history will be described as MLTF, POINT method as PLTF and SLOPE method as SLTF. Moment values using each method were calculated for six male and six female subjects for 5, 9, 13 and 18kg loads. Moments calculated with MLTF data will be referred to as MLM, while moments calculated with PLTF and SLTF data will be called PLM and SLM respectively.

3.7 Statistical Analysis

3.7.1 Relationship between Load Transfer Force and Load Transfer Moment

The first step in the analysis was to confirm a relationship between measured load transfer force values and corresponding lumbar moment values. A regression analysis was carried out and the strength of the correlation between load transfer force and lumbar moments was determined.

3.7.2 Estimating Load Transfer Force by Methods

Since the MEASURED method represented the 'gold standard', root mean square (RMS) differences and percent error were determined between MLTF values and SLTF and PLTF values from the SLOPE and POINT methods. Average RMS scores and average percent errors for 11 males and 10 female subjects at 5, 9, 13 and 18 kg were subsequently grouped for comparison.

3.7.3 Confirming the Relationship between LTFs and LTMs

The next step involved a comparison of the three methods of hand force input data (MLTF, SLTF, and PLTF) to their respective lumbar moment calculations (MLM, SLM, and PLM) for 12 subjects at all load values. Calculations were made of the RMS differences between methods of determining lumbar moments, with the MEASURED method treated as the "gold standard".

3.7.4 Estimating Load Transfer Forces with Variables

First, a correlational matrix was used to examine relationships between discrete variables: gender (G), lift style (ST), load weight (W), and subject grip strength (SS) and the continuous variable (SLTF). Then a series of stepwise regression analyses were used to predict the dependent variable, MLTF, across all load conditions. The regressions were: a) SLOPE CUBED method, with SLTF only; b) ENHANCED SLOPE method, with SCLTF and all variables (G, ST, W, SS), and, c) VIDEO SLOPE method with SCLTF and only variables collected during videotaping (G, W, ST). The RMS differences were subsequently calculated between MLTF values and the predicted LTF values for each strategy. Average RMS scores were then determined for comparison of the predicted LTF values with the "gold standard" MLTF values.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 General Description of Moments

The first step of the analysis was to confirm that the results of L4/L5 calculated lumbar moment were reflective of the scientific literature. The L4/L5 lumbar moment increased gradually as the subject bent down and reached the arms out from the body to start the box lift. Moment values then rose quickly during load transfer as the box was taken up into the hands and then leveled off as the subject completed the lift-off phase (Figure 4.1). The moment curve then reduced further as the subject stood up and set the box on the shelf. The average mean, standard deviation, minimum and maximum lumbar moment values derived with MLTF are shown in Table 4.1.

Table 4.1: Summary data of average mean, minimum and maximum measured lumbar moments.

	MALE			FEMALE		
Load (kg)	Mean (SD) (Nm)	Min. (SD) (Nm)	Max. (SD) (Nm)	Mean (SD) (Nm)	Min. (Nm)	Max. (Nm)
5	156.2 (16.8)	129.0 (16.9)	190.0 (19.2)	155.3 (10.6)	124.8 (12.0)	184.9 (9.2)
9	179.1 (23.6)	126.6 (14.9)	244 (16.2)	175.3 (20.8)	128.0 (30.0)	227.5 (13.9)
13	208.5 (16.9)	128.0 (18.0)	300.9 (29.8)	202.8 (8.67)	138.7 (26.5)	318.9 (24.5)
18	240.4 (30.3)	128.0 (16.2)	356.3 (31.5)	226.2 (19.7)	131.4(28.3)	351.8 (23.4)

The values obtained in this study were consistent with the magnitudes of lumbar moment values reported in the literature where values of 240 Nm – 340 Nm have been recorded for 15 kg lifting tasks (Leskinen et al, 1983; Freivalds et al., 1984). When the magnitude of the lifted weight increased, the MLM at the L4/L5 level also increased.

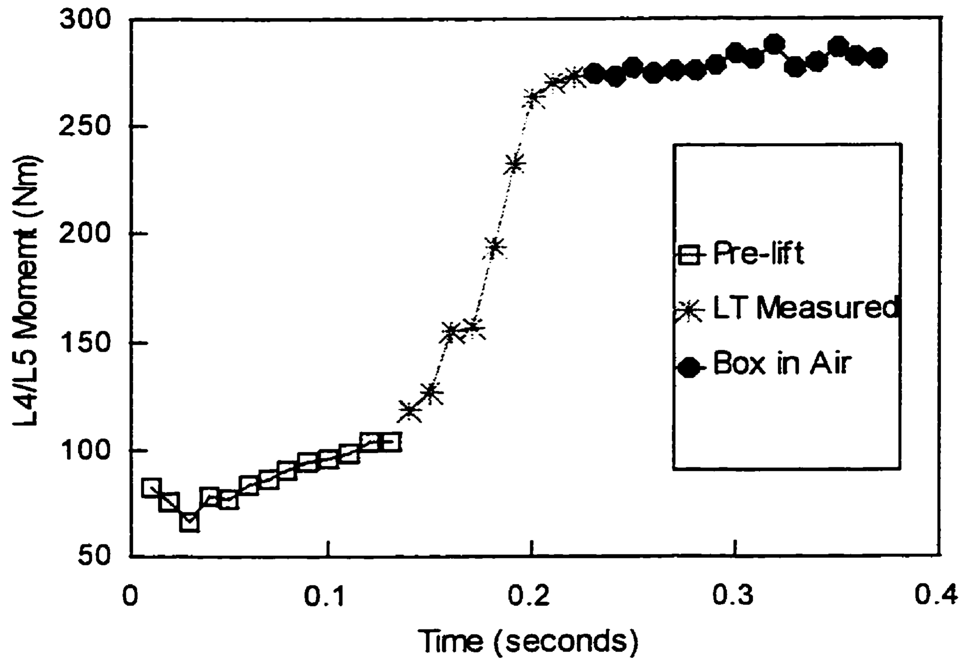


Figure 4.1: Lumbar moments are shown for one complete lift-off phase. Notice the sharp increase in lumbar moment values during the load transfer phase of the lift.

This was expected, and confirmed previous static and dynamic studies of lifting (Schipplein et al, 1995; Leskinen et al, 1983;Freivalds et al., 1984). In a study by Garg et al. (1983), the freestyle technique produced lower lumbar moments since subjects were able to lift and pull the load towards their bodies. In the same study, subjects who used the squat technique had higher peak moments because the box had to be held out further from the body in order to clear the knees. Similar findings were observed in this study. When pooled by gender, subjects with a knee angle between 140 and 90 degrees of knee flexion, typical of a squat technique, had a lumbar moment average of 272 Nm for the load transfer period; subjects with a knee angle between 90 and 40 degrees of knee flexion, typical of a stoop lifting style, had a lumbar moment average of 112 Nm. When separated by gender, men averaged 89 degrees of knee flexion, whereas, women, on average, had a knee angle of 101 degrees of flexion, indicative of a squat lifting style, and thus higher relative moments than their male counterparts. This finding helps to explain the smaller than expected difference between male and female average lumbar moments.

4.2 Relationship between MLTF and MLTM

A regression analysis confirmed hand forces were a significant predictor of corresponding lumbar moments during the load transfer phase for the 12 subjects. (MLM = 132.4 + 1.30(MLTF), $r^2 = 0.815$, SEE = 33.2 Nm, $P < 0.001$). Correlational analysis confirmed the above relationship between MLTF and MLM ($r = 0.9$, $P < 0.01$). Full details are shown in Appendix D. Other researchers have found that the moments on the back increased with increasing load and were highly reflective of the load in the hands (Frievalds et al., 1984; Schipplein et al., 1995; Buseck, 1988; Danz and Ayoub, 1992).

These researchers also recorded peak lumbar moments about 200-300 ms after the object being lifted began to move, and were typically higher when lifting from floor level than other lift heights (Garg, 1989; Punnett et al., 1991). Therefore, capturing the profile of the load transfer force, during the lift-off phase is important to accurately estimate peak lumbar moments.

4.3 Comparison of Load Transfer Forces by Methods

Since an accurate estimate of LTF was important for calculation of lumbar moment data, it was important to minimize the errors caused by either the SLOPE or POINT methods. Using MLTF for comparison with SLTF and PLTF, RMS errors were determined for the 21 male and female subjects at loads of 5, 9, 13 and 18 kg (Table 4.2). In 75 out of 83 possible cases, the SLOPE method was superior to the POINT method of estimating MLTF. A one way ANOVA confirmed a significant difference between SLTF RMS error values and PLTF RMS error values ($p>0.05$; Appendix D). The average RMS error between MLTF and PLTF was almost 30 N while the error between MLTF and SLTF was just under 12 N. These data would suggest that previous researchers, who used the POINT method to determine load forces, may have had as much as 30 N of error in their calculations of hand force, which would have carried through and had an impact on their back moment calculations. In fact, the error might have been even higher if loads above 18 kg were being lifted since data from this study indicated RMS error increased with increasing load. A one way ANOVA confirmed a significant relationship between RMS error and load lifted for both men and women ($p>0.05$; Appendix D). Average errors at 5 kg between MLTF and PLTF were 7 N for men and 10 N for women, while the average errors at 18 kg were 46 N for men and 60 N for women. Therefore, most of the subsequent discussion will center on the SLOPE method of estimating LTF, rather than the POINT method.

Table 4.2: Summary of the average RMS difference between MLTF and SLTF, and MLTF and PLTF. Standard deviations are shown in brackets.

Load Lifted		MLTF compared to SLTF*		MLTF compared to PLTF*	
		Male	**Female**	**Male**	**Female**
Kg	N	RMS (N)	RMS (N)	RMS (N)	RMS (N)
5	49.1	4.06 (2.99)	6.54 (4.85)	6.91 (2.25)	9.66 (3.89)
9	88.3	9.25 (5.72)	13.22 (6.87)	18.8 (5.83)	24.23 (8.36)
13	127.5	11.84 (6.45)	11.35 (6.63)	33.7 (15.42)	40.06 (16.68)
18	176.6	21.28 (9.16)	14.74 (4.29)	45.5 (22.17)	59.85 (18.52)
Means by gender		11.61 (6.08)	11.46 (5.66)	26.23 (11.41)	33.46 (11.86)
Overall Mean by method		**11.54 (5.87) N**		**29.8 (11.63) N**	

*** Significant difference (p>0.05) between LTF approaches (SLTF and PLTF) , and loads lifted. There is no significant between genders (Appendix D)**

Although the average load transfer force values estimated using the SLOPE method were closer to the MLTF values than the POINT method, the LTF profiles were not always the same (Figure 4.2). A reasonable curve-shape approximation of MLTF was present in 32 trials (Figure 4.2a) with an overprediction occurring in 19 trials (Figure 4.2b), an underprediction in 17 trials (Figure 4.2c) and an over- and underprediction in 15 trials (Figure 4.2d). A breakdown of this relationship by load is shown in Table 4.3.

When subjects lifted in a smooth manner (Figure 4.2a), load transfer forces, as calculated using the SLOPE method, were almost equal to the MLTF values. Seventeen subjects, during one or more of their loads lifted, performed these types of lifts. However,

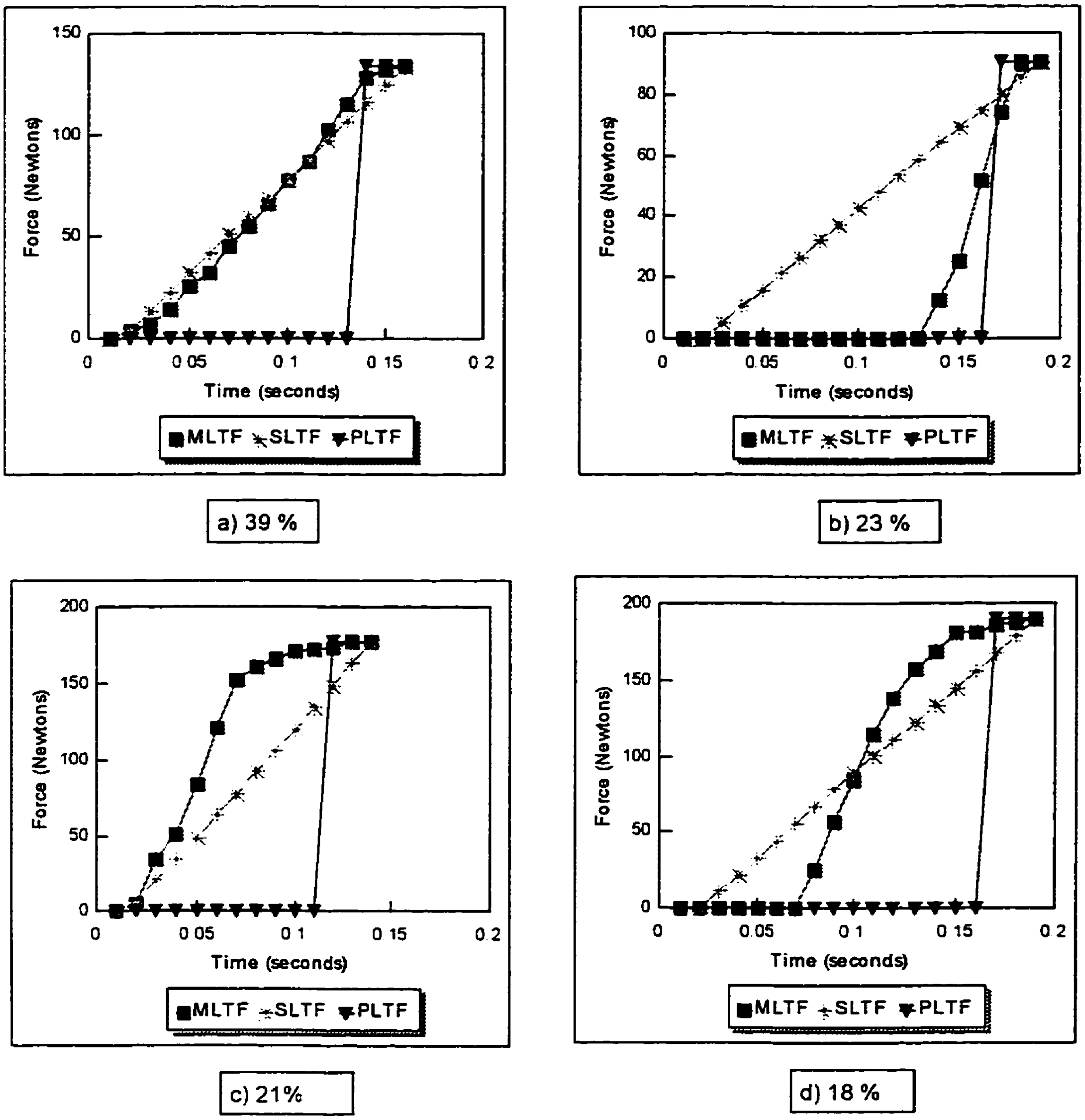


Figure 4.2: Load transfer force values estimated using the SLOPE method when compared to MLTF values were; a) closely matched b) overpredicted c) underpredicted and d) over-and-underpredicted.

only two subjects lifted smoothly under all load conditions and three subjects lifted smoothly except at the heaviest load. Smooth lifts were observed at all loads although they were more common for lighter loads.

Table 4.3 Relationship between MLTF values and SLTF values.

Load (kg)	Close Match	Overestimation	Underestimation	Over – and underestimation
5	10	12	2	2
9	8	5	6	2
13	10	4	2	6
18	4	3	7	5
Total	32	19	17	15

The scientific literature suggests that smooth lifts without a jerking action would result in lower moments on the lumbar spine and thus, safer lifting conditions (NIOSH, 1981). Therefore, the NIOSH lifting guidelines recommended that lifts be performed in a smooth and well-planned manner. The smooth lifting profile was the most prevalent of the four relationships observed in this study at 39 percent. These results were similar to Danz and Ayoub (1992), who found 20 % of their subjects lifted with a smooth style. They felt that it was possible to perform lifts from the floor level in a smooth manner, but that some subjects, especially under heavier loading conditions, might not be capable of performing a smooth lift.

One consistent pattern within load transfer forces was that every incident of an overprediction by SLTF was preceded by a "pre-load" in the MLTF on the force plate (Figure 4.3). A "pre-load" was defined as a box force greater than one standard deviation above the average baseline noise when the box was resting on the force plate. The "pre-load" was caused by the subject applying a downward force on the handles prior to starting the lift-off load transfer phase. This resulted in a more rapid lift-off style, as evident in the MLTF data. A review of all MLTF data showed 28 out of 83 lift trials had a "pre-load" just before the load started to be taken up into the hands (Figure 4.3). In every case the presence of a "pre-load" resulted in an overprediction of the MLTF. However, 19 of the cases were just overestimated while the other 9 trials with a "pre-load" were overestimated at the start of the load transfer phase and then underestimated near the end of the load transfer phase (Figure 4.2 d). Reasons for the underestimation will be discussed later.

Although peak hand forces were not measured in this study, "pre-load" measured from the force plate can be equated to the peak hand forces reported by Danz and Ayoub, (1992) and Ayoub and Danz (1991). In their 1991 study of hand forces during floor to knuckle lifting tasks, Ayoub and Danz reported peak hand forces sometimes occurred just before lift-off. In 1992, they reported peak vertical hand forces generally occurred within 0.07 seconds of lift-off for fast lifts and as late as 0.18 seconds after lift-off for normal speed lifts. In this study, maximal LTFs occurred between 0.09 and 0.20 seconds from the start of load transfer. Therefore, maximal load transfer forces in this study occurred around the same time Danz and Ayoub (1992) recorded peak vertical hand forces. Furthermore, speed, frequency, and percent maximal acceptable weight of lift (MAWL) had significant effects on both peak horizontal and peak vertical hand forces (Danz and Ayoub, 1992; Danz and Ayoub 1991). Larger peaks were observed at fast lifting speeds, higher MAWL and lower lifting frequencies.

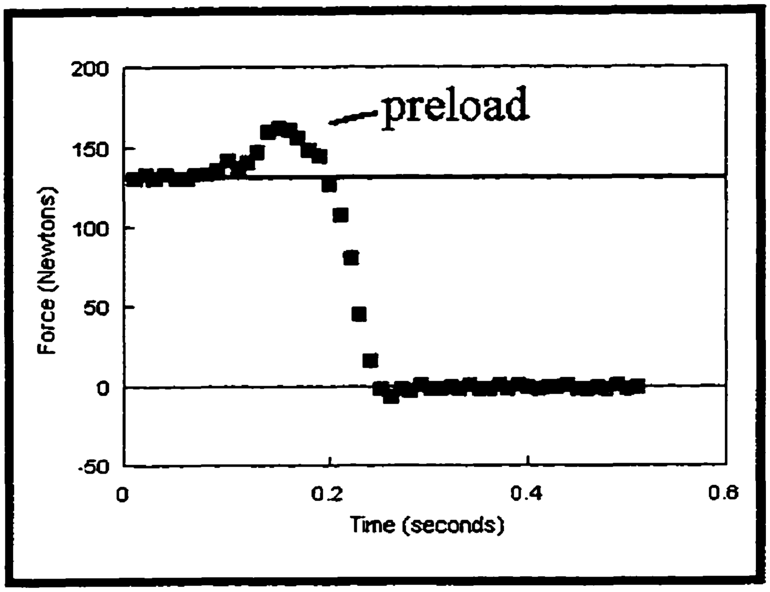


Figure 4.3: A "pre-load' was recorded in 34 % of the measured load transfer force data.

In order to generate the force needed to lift the box off the floor, some subjects might have been using the "elastic energy" gained from applying a downward force to the box. The initial downward force, which creates passive stretch to the muscles, then could be used to help initiate movement in the opposite direction and thus lift the box. The added "energy" gained from this type of lifting style could be important since researchers have indicated that hand forces were typically 3.7-3.8 times the weight for lighter loads (under 10 kg) and 2.6-3.5 times the weight for heavier loads (under 20 kg) (Danz and Ayoub, 1992; Danz and Ayoub, 1991; Grieve, 1975).

In a 1994 study, Hagen and Harms-Ringdahl discussed the possibility of using "elastic energy" to reduce the lifting effort. Squat lifters, with high velocity of movements during the lift, were hypothesized to be using rapid movements to allow storage and reuse of "elastic energy" thus requiring less effort from the knee extensors (Hagen and Harms-Ringdahl, 1994). In a report by Thomas (1988), stored "elastic energy" in the muscles was found to result in greater force production when a subject stretched their muscles before moving in the opposite direction. Hence, future analysis is warranted to determine if higher peak hand forces are observed in subjects who "pre-load" the box during load transfer.

Slowing down load transfer near the end of the load transfer period led to an underprediction of MLTF with the SLOPE method. However, there was no consistent pattern for either the underestimation (Figure 4.2 c) or the over- and underestimation (Figure 4.2 d) of the MLTF by the SLOPE method. Of the combined 34 trials in this category, ten trials were in the last load series which might indicate that fatigue was a factor. Load might also be a factor since underestimation occurred 4, 8, 8, and 12 times for loads of 5, 9, 13 and 18 kg respectively. Therefore, some subjects might not have been physically capable of maintaining their initial lift acceleration at the heavier loads. In the remaining 5 trials in which underestimation occurred, the box was not lifted off the force plate "cleanly". Instead, the subjects "rolled" the box off the force plate near the end of the load transfer period. This style of lift could indicate that technique was involved in eliciting this pattern. Hence, further analysis is warranted to study the relationship between fatigue, load lifted and technique to determine their effect on load transfer forces.

4.4 Confirming the Relationship between LTF and LTM

In section 4.2, it was shown that measured load transfer force (MLTF) values significantly predict corresponding measured lumbar moment (MLM) values. In section 4.3, definite patterns were observed between estimated load transfer force values, especially SLTF, and MLTF curve profiles. If an easy-to-use SLOPE was proposed for industry, then it would be important to determine if the SLTF data impacted the slope-based lumbar moment (SLM) curve profiles. It was hypothesized that RMS errors and curve shape profiles, using the SLTF to calculate SLM, would not be significantly different from using the MLTF data to calculate the MLM data. SLMs were calculated for six male and six female subjects at all loads, resulting in a total of 48 lifting trials for comparison.

Calculation of root mean square difference scores between MLMs compared to SLMs and PLMs are shown in Table 4.4. A one way ANOVA confirmed a significant difference between SLM RMS error values and PLM RMS error values (p>0,05; Appendix D). As with the hand force RMS errors, there was approximately 14 Nm of error when SLTF was used to calculate SLM but 42 Nm of error when PLTF was used to calculate PLM, thus confirming that the POINT method was not an acceptable strategy for estimating lumbar moments.

Table 4.4: Summary of the average RMS difference between MLM data compared to SLM and PLM data. Standard deviations are shown in brackets.

		MLM compared to SLM *		**MLM compared to PLM ***	
Load Lifted		**Male**	**Female**	**Male**	**Female**
Kg	Nm	RMS (Nm)	RMS (Nm)	RMS (Nm)	RMS (Nm)
5	49.1	5.03 (3.41)	4.71 (2.78)	8.97 (3.52)	15.22 (4.32)
9	88.3	10.38 (7.22)	16.89 (10.24)	23.98 (8.36)	34.56 (12.31)
13	127.5	17.43 (10.29)	14.66 (6.08)	38.46 (22.09)	60.46 (20.51)
18	176.6	21.51 (8.54)	19.99 (3.13)	69.79 (31.7)	81.44 (23.91)
Means by gender		13.58 (7.37)	14.09 (5.56)	35.30 (16.42)	47.92 (15.26)
Overall Mean by method		**13.84 (6.47)**		**41.61 (15.84)**	

*** Significant differences (p>0.05) between evaluation strategy (SLM and PLM) and loads. There is no significant difference between genders (Appendix D)**

The next comparison involved an examination of lumbar moment curve profiles (MLM, SLM and PLM) during load transfer to the hands. In 26 of the 48 lifting trials, estimated lumbar moment values closely approximated the MLM curve shape (Figure 4.4 a); in 7 trials the lumbar moment values were overestimated (Figure 4.4 b); in 8 trials the lumbar moment values were underestimated (Figure 4.4 c); and in the remaining 7 trials the lumbar moments were overestimated near the beginning of load transfer phase and underestimated near the end of load transfer phase (Figure 4.4 d). In 100% of the cases, hand force profiles were reflected in the lumbar force profiles. For example, if there was an overestimation by the SLOPE method then SLM, as calculated using SLTF, was also overestimated when compared to MLM calculated using MLTF (Figure 4.5).

The relationship of lumbar moments to compression and shear forces is highly related to posture and moment arms. Individuals with higher calculated lumbar moments will also have higher compression and shear forces. Therefore, the accurate estimation of lumbar moments and/or calculation of shear and compression forces are important since research has implicated compressive forces on the L5/S1 joint above 3.4 kN with an increased risk in the development of low back pain and/or injury (Waters et al., 1993). Four studies in particular have reported a direct relationship between lifting related low back pain and compressive force on the lumbar discs (Herrin et al., 1986; Bringham and Garg., 1986; Anderson 1983; Chaffin and Park, 1973). In the study by Herrin and colleagues (1986), workers employed in jobs involving lifting tasks that generated compressive forces between 4.5 and 6.8 kN had 1.5 times the rate of back problems when compared to workers in jobs with compressive forces below 4.5 kN. In a similar study, workers performing jobs with a predicted compressive force greater than 3.4 kN had a 40 % higher incidence rate of low back pain when compared to workers with exposure below 3.4 kN (Anderson, 1983). Therefore, accurate prediction of load transfer to the hands should be considered critical for accurate calculation of lumbar moments and compression and shear force data. Failure to accurately predict LTFs might distort the calculated moment values such that an increased risk of injury may be undetected in an ergonomic analysis of lifting tasks.

4.5 Estimating Load Transfer Forces with Additional Variables

In sections 4.2 and 4.4, it was shown that the SLOPE method had an average error of 12 N when estimating load transfer force to the hands, whereas the POINT method had an average error of 30 N. It was also shown that the curve shapes for the estimated LTFs followed one of four patterns that were mirrored in the hands and lumbar moments. The scientific literature has suggested that gender (Snook and Ciriello, 1991), lift style (Chaffin and Page, 1994), load weight (Schipplein et al., 1995), lift speed (Buseck et al., 1988) and subject strength (Garg and Beller, 1994) also have an effect on lumbar moments. These easy to measure variables from the subject or videotape were collected as possible factors which might affect the prediction of MLTF. It was hypothesized that additional information regarding load lifted, gender, strength, lift style and lift speed would further improve the ability of the SLOPE method to estimate load transfer to the hands, thus leading to improved lumbar moment calculations. Additional subject information and LTF variables are summarized in Table 4.5.

Table 4.5: Mean, standard deviation, and average minimum and maximum score summary for parameters used in regression analysis.

		MALE			FEMALE		
Parameter	Variable	Mean(SD)	Min.	Max.	Mean(SD)	Min.	Max.
Strength*	hand grip (% ranking)	41.7 (30)	9	93	68(24)	13	100
Lift Style**	knee angle (degrees)	89.1 (4.3)	39	137	101(5.9)	46	122
Lift Speed***	lift speed (LT time)	0.15 (0.01)	0.06	0.3	0.16 (0.09)	0.08	0.9

* rank score obtained from the grip strength testing protocol outlined in CSTF manual
** degree of knee flexion
*** time to complete load transfer (seconds)

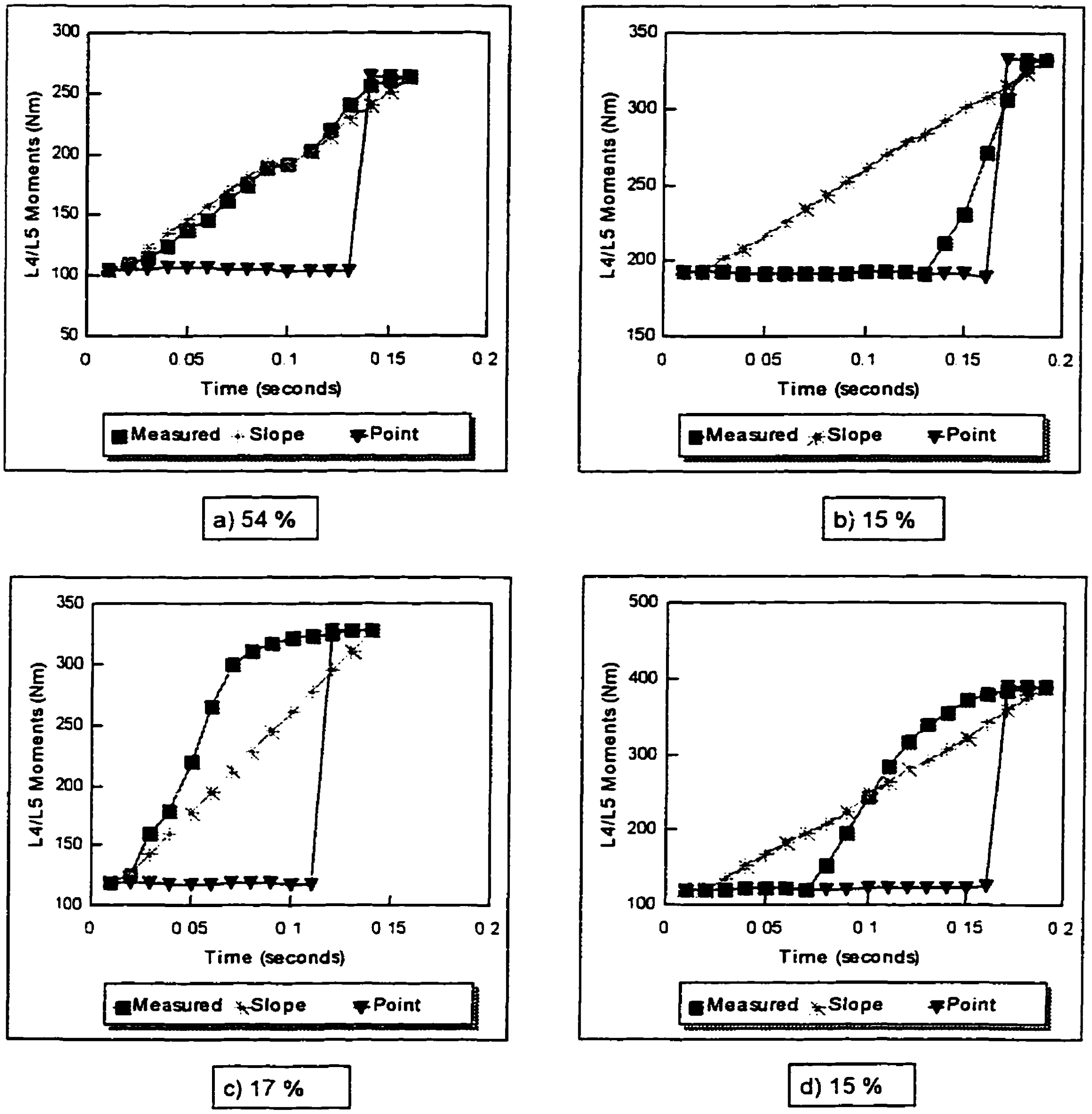


Figure 4.4: Lumbar moments calculated with SLTF compared to lumbar moments calculated with MLTF were; a) closely matched b) overpredicted c) underpredicted and d) over- and underpredicted.

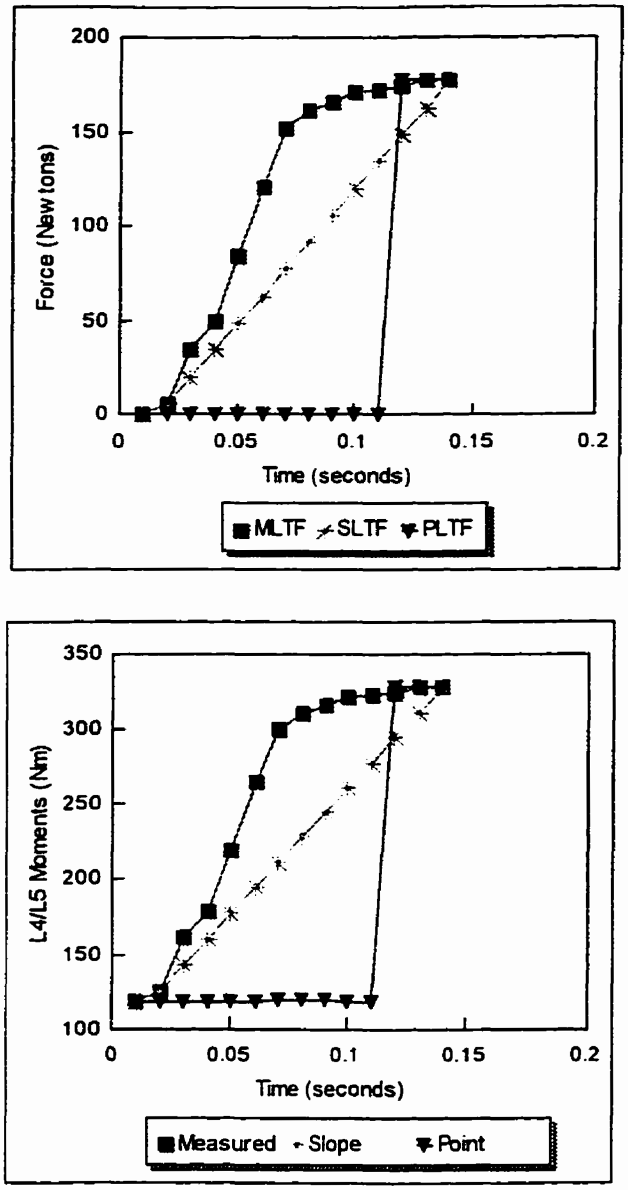


Figure 4.5: The relationship between MLTF and SLTF carried through 100 % of the time when lumbar moments were calculated using SLTF and MLTF

4.5.1 Correlational Analysis

Table 4.6 shows the correlations between the independent variables used in regression analysis. Significant relationships were found between strength and gender and between gender and lifting style (p>0.01). Significant relationships were also seen between strength and lifting style (p>0.05). The relationship between gender and strength was expected and confirmed findings in the literature (Chaffin and Andersson, 1991). However, the relationship between gender and style was somewhat unexpected. Earlier in section 4.1, it was reported that women tended to adopt a more squat-like lifting style when compared to their male counterparts. In fact, an interaction between style and strength might have been present as greater upper body strength would be required to lift heavier loads using a stoop lifting style.

Table 4.6. Correlation matrix for variables used in regression analysis.

	Gender	Strength	Style	Load	SLTF
Gender	1	0.458**	-0.150 **	-0.036	-0.004
Strength		1	0.075*	0.012	0.025
Style			1	-0.053	-0.040
Load				1	0.476**
SLTF					1

** p 0.01 , * p 0.05

4.5.2 Regression Analysis

In the regression analysis, the variable for gender (G) was described by using a value of 1 for women and 0 for men. The degree of knee bend represented lifting style (ST) and was measured from the video at the start of load as the joint coordinates for the hip, knee and ankle (180 degrees represented a straight leg). The value for subject strength (SS) was obtained using the hand grip protocol outlined in the Canadian

Standardized Test of Fitness manual and the mass of the load lifted was represented as load (W).

4.5.2.1 SLOPE Method

Linear, cubed and quadratic regressions were applied to the data in order to determine the most appropriate method for fitting the linear SLTF to the MLTF values. The cubic regression model yielded the best fit ($r^2 = 0.875$). Cubic SLTF, y, was calculated using the following equation:

$$\text{Cubic SLTF} = -0.3845 + (0.4385 * \text{SLTF}) + (0.0089 * \text{SLTF}^2) - (0.00003 * \text{SLTF}^3)$$

Using the cubed SLTF as the only independent variable to predict MLTF, y, regression analysis yielded the following equation:

$$\text{MLTF} = -0.076 + 1.001 \text{ (cubic SLTF)}; \quad r^2 = 0.875; \quad \text{SEE} = 19.38 \text{ N}; \quad p>0.001$$

In the future, LTF data generated with this equation will be referred to as Slope Cubed Load Transfer Force (SCLTF) data. The fact that 87.5 % of the variance in the MLTF data can be explained by SCLFT indicates that this information was critical to improve lumbar moment calculations. For more information on how to use this equation in an industrial setting, refer to Appendix C.

4.5.2.2 ENHANCED SLOPE Method

Regression analysis to predict MLTF using the variables SCLTF, gender (G), Strength (SS), style (ST) and load mass (W) resulted in the following equation:

$$\text{MLTF} = -5.996 + 1.044(\text{SCLTF}) - 0.873(\text{W}) + 8.964(\text{G}) + 0.157(\text{ST}) - 0.066(\text{SS})$$

$$r^2 = 0.887, \text{SEE} = 18.40 \text{ N}, p>0.001$$

In the future, LTF data generated with this equation will be referred to as Enhanced Load Transfer Force (ELTF). Information on how to apply this equation in an industrial setting can be found in Appendix C.

4.5.2.3 VIDEO SLOPE Method.

All the variables in the ELTF equation could easily be obtained from video except for subject strength. Although the protocol to measure subject strength using a hand grip dynamometer is not difficult, it might be impractical in some industrial applications. Furthermore, the strength variable added the least to the previous equation. Therefore, the stepwise regression analysis without the presence of subject strength was:

$$\mathbf{MLTF = -7.571 + 1.044(SCLTF) - 0.884(W) + 7.161(G) + 0.145(ST)}$$

$$\mathbf{r^2=0.887,\ SEE = 18.46\ N,\ p >0.001}$$

LTF data generated with this equation will be referred to as Video Load Transfer Force (VLTF). Steps to employ this equation in industry can be found in Appendix C.

4.6 Comparing LTF with Additional Variables

The root mean square difference between MLTF data compared to SCLTF, VLTF and ELTF are shown in Table 4.6. It was hypothesized that information about load lifted, gender, strength and lifting style would enhance the ability of the SLOPE method to predict MLM. This hypothesis was confirmed, although the improvement in predictive power over simply using the SLOPE method to predict MLTF was less than expected. Average RMS error between MLTF and SLTF was 11.8 N; it decreased to 11.1 N when a cubic function was used to predict MLTF and decreased further to 10.1 N when the ELTF

Table 4.6 : Summary of the average RMS difference between MLTF data compared to SCLTF, VLTF, ELTF data expressed in Newtons. Standard deviations are shown in brackets.

		MLTF compared to SCLTF		MLTF compared to VLTF		MLTF compared to ELTF	
Load Lifted		**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
Kg	N	RMS (N)	RMS (N)	RMS (N)	RMS (N)	RMS (N)	RMS (N)
5	49.1	5.08 (1.33)	6.75 (3.66)	4.50 (1.17)	6.57 (4.15)	4.71 (2.04)	6.82 (3.76)
9	88.3	9.72 (4.27)	10.42 (5.09)	8.49 (2.64)	10.12 (5.1)	7.20 (2.77)	10.27 (5.38)
13	127.5	10.89 (6.23)	11.06 (6.39)	9.27 (5.71)	9.41 (6.13)	8.97 (5.15)	8.99 (5.47)
18	176.6	20.12 (9.13)	14.81 (3.94)	19.44 (6.77)	14.21 (4.18)	19.26 (6.10)	14.33 (3.73)
Means by gender		11.45 (5.24)	10.76 (4.77)	10.43 (4.07)	10.08 (4.89)	10.04 (4.02)	10.10 (4.56)
Overall Mean by method		**11.10 (5.01)**		**10.26 (4.48)**		**10.07 (4.29)**	

method was used. A Test-statistic confirmed significant improvement in predictive power for MLTF in the following ascending order: SLTF, SCLTF, VLTF and ELTF (Appendix D). When strategies were compared to one another, the Test Statistics were 8.66, 11.03 and 3.06 p>0.01) between SLTF and SCLTF, SCLTF and VLFT, and VLFT and ELTF respectively indicating significant differences between pairs of regression equations.

RMS difference scores and regression analyses confirm the use of the three cubic models (VLTF, SCLTF and ELTF) for improved prediction of MLTF. Figure 4.6 illustrates the minor improvements gained with these cubic models. If SLTF closely approximated MLTF, then the cubic models did not appear to improve the prediction over SLTF (Figure 4.6a). However, the cubic models improved the estimation of MLTF if SLTF underpredicted (Figure 4.6b), overpredicted (Figure 4.6c) or over- and underpredicted MLTF (Figure 4.6d). The cubic models did not "climb" as quickly if a "pre-load" was observed in the MLTF data. Therefore, the overestimation of MLTF was less with the cubic models when compared to the SLTF data (Figure 4.6b). The cubic models were also better at estimating MLTF data that "curved" near the end of the load transfer period. Load transfer force values calculated with the cubic models also "curved" slightly at the end of the load transfer period therefore the underestimation of MLTF was less when the cubic models were compared to the SLTF data (Figure 4.6c).

From a clinical perspective, despite slight but significant improvements in prediction of MLTF with the cubic models, the improvements were not substantial.

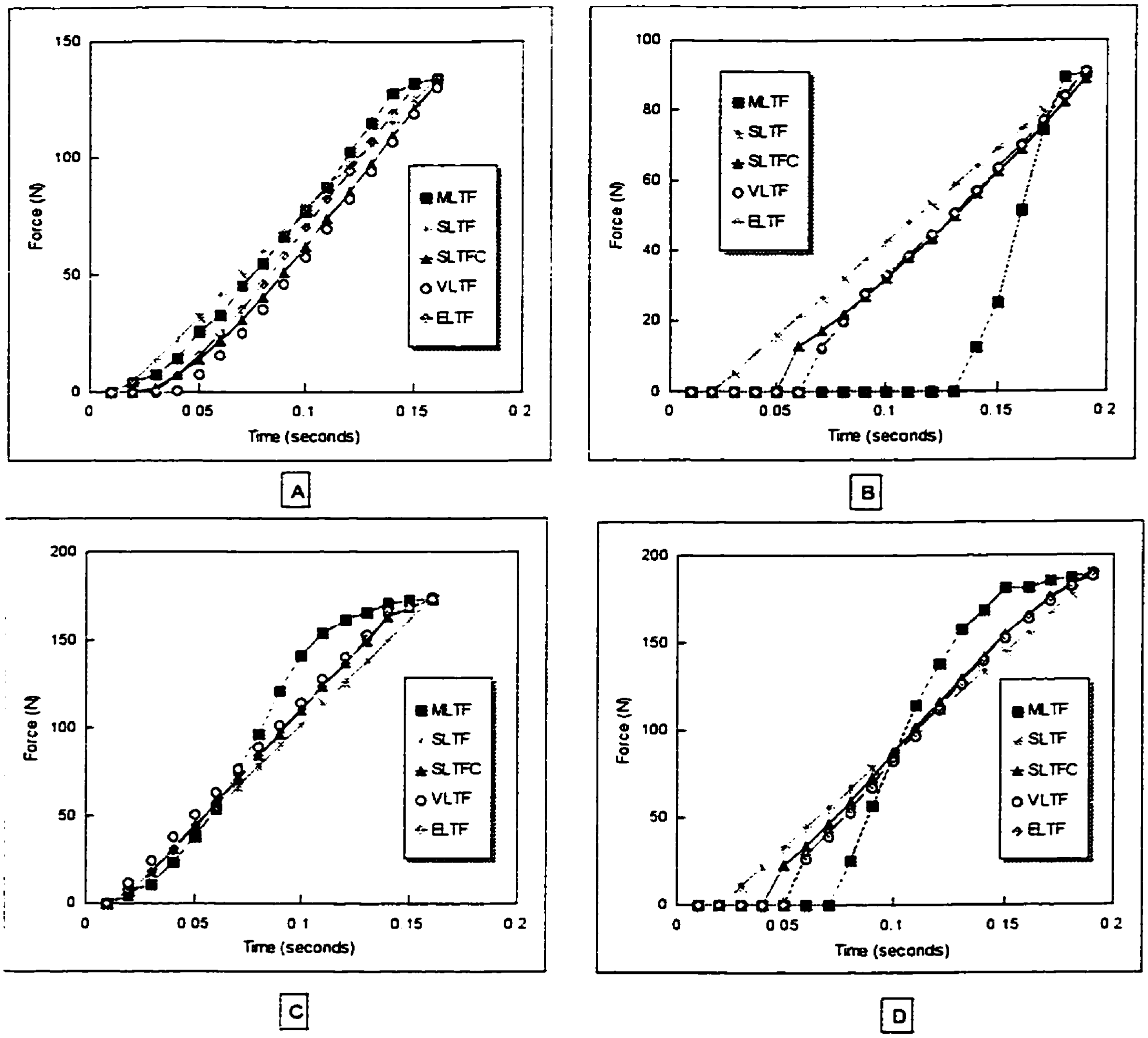


Figure 4.6: Relationships between MLTF. SLTF. SCLTF. VLTF and ELTF; a) closely matched b) overprediction c) underprediction d) over- and underprediction.

While the average RMS error was 11.8 N between MLTF and SLTF values, it was only 10.1 N between ELTF and MLTF, a mere 1.7 N difference. In proportion to box masses for 5 kg and 18 kg, this represents a 3 % and 0.1% error respectively. When data are acquired in an applied situation with a video camera, an improvement of approximately 2 N with the ELTF equation would be non-consequential given other sources of error, such as: body anthropometrics, digitizing video and determining total load transfer time from a video source. Therefore, it is recommended that ergonomists employ the SLOPE method when predicting load transfer force.

4.7 Applying the Results in Industry

Current laboratory methods to calculate lumbar moments typically use force plate data and 2D or 3D subject coordinate data for link segment modelling and sometimes add electromyography, inter-abdominal pressure or neural networks as input parameters (Marras et al., 1991; Kee and Chung, 1996). However, these approaches are not easily transferable to an industrial setting. Typically an ergonomist has a one camera system and endeavours to examine tasks that are carried out in the sagittal plane where filming is done perpendicular to the task. The goal of this study was to make the 2D sagittal plane approach as accurate as possible during load transfer, especially since lumbar moments are generally at or close to maximum near the start of the lift.

In order to employ the SLTF method in industry, the load weight, subject weight and total load transfer time need to be determined. The lifting task should be filmed at a right angle and converted to lifesize co-ordinates using a conversion factor. Kinematic information needed for input into the quasi-dynamic link segment model can then be digitized and recorded. A time code should also be put on the video in order to aid in the determination of load transfer time. The number of video frames between the start and end of load transfer to the hands can then be counted. The start of load transfer is determined by the video frame in which the vertical displacement of the wrist is at the lowest value after the hands have made contact with the box. The end of the load transfer phase is determined by the video frame where separation between the box and the floor can first be seen clearly. The weight of the load being lifted should then be divided and applied equally over the number of load transfer frames until the full weight of the load being lifted is in the hands. This represents calculated slope load transfer force, SLTF. Lumbar moments at the L4/L5 level can then be calculated by inputting SLTF and kinematic data into a quasi-dynamic link segment model. For more information on estimating LTF in industry please refer to Appendix C.

CHAPTER 5

SUMMARY AND CONCLUSIONS

Biomechanical link segment models are often used to predict the moments experienced by the back during lifting. The kinematic and force collection equipment available in industrial settings often limits the accuracy of lumbar moment calculations. In situations where the load being lifted cannot be instrumented, load transfer force (LTF) to the hands can be estimated from videotape. In this study, LTFs were taken from force plate data using three methods: actual force plate output, called MEASURED method, and two estimation approaches called SLOPE and POINT methods. Lumbar moments were calculated using digitized subjects' body segment co-ordinates from videotape and three input strategies for LTF to depict the forces acting at the hands.

Results revealed that the SLOPE method of estimating LTF was superior to the POINT method. The SLOPE method required the start and end of the load transfer phase from videotape to be defined, by identifying the total number of frames, or seconds, needed to complete load transfer to the hands. Slope load transfer force (SLTF) was then calculated by subdividing the load lifted into equal intervals for each frame or time period of load transfer.

In this paper, the SLOPE method was shown to be superior to the POINT method in predicting MLTFs. A correlational analyses revealed that the SLOPE method using SLTF was superior ($r=0.931$; $p= 0.01$) to the POINT method using PLTF ($r = 0.580$; $p =$

0.01). Average RMS errors between MLTF and the PLTF were 30 N but decreased to 11.8 N when SLTF values were compared to MLTF values. Improving the prediction of MLTF by over 18 N warrants the use of the SLOPE method to estimate load transfer forces.

A number of curve estimations, indicated by cubic SLTF functions, significantly improved the prediction of measured load transfer force. A regression analysis with the independent variables Slope Cubed Load Transfer Force (SCLTF), gender (G), strength (SS), load mass (W) and lift style (ST) showed the greatest improvement in prediction of MLTF:

$$\mathbf{MLTF = -5.996 + 1.044(SCLTF) - 0.873(W) + 8.964(G) + 0.157(ST) - 0.066(SS)}$$
$$\mathbf{r^2 = 0.887,\ SEE = 18.40\ N,\ p>0.001}$$

This equation was called the enhanced load transfer function (ELTF). These results confirmed the hypothesis that SLTF and additional variables would improve the prediction of load transfer force to the hands during lifting. However, the improvement with the above regression equation was less than expected. Average RMS errors between SLTF and MLTF were 11.8 N and decreased to 10.1 N when ELTF values were compared to MLTF values. Clinically, improving the prediction of MLTF by less than 2 N did not warrant the use of the more elaborate ELTF strategy. Therefore, the SLOPE method was recommended for use by ergonomists to estimate load transfer and calculate lumbar moments. This recommendation was limited to 2D quasi-dynamic link segment models where video or film input was the only data acquisition source.

Future software systems, developed to calculate lumbar moments from videotape only, should also incorporate the SLOPE strategy in order to improve the prediction of load transfer forces and thus calculated lumbar moments. In addition, future research to improve video-based techniques should be conducted on the "pre-load" transfer phase to determine if the subjects' postural preparations for lifting can be used to improve the estimation of LTF and thus accuracy of the lumbar moment estimations.

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APPENDIX A

Consent Form & Par-Q

Consent Form

Load Transfer Investigation during a Sagittal Plane Box Lift

The purpose of this study is to examine load transfer during a sagittal plane box lift from the floor to a shelf located 15 cm below each subject's acromium. Each subject will be asked to complete 5 lifts at 5, 10, 15 and 20 kilograms. Load transfer, the period in which load is transferred from the floor to the subject's hands, will be examined in detail to determine the relationship between load transfer and gender, subject strength, box load, lift style, and lift speed. Information regarding load transfer will be used to improve lumbar moment predictions using hands-down link-segment models.

As a subject, you will be asked to complete a total of 20 lifts ie. 5 each at 5, 10, 15, and 20 kg. In order to monitor your lifting style, skin markers will be placed on your right knuckle, wrist, forearm, and elbow. Kinematic data will then be monitored using an OPTOTRACK 3-D motion video system. You will also be filmed with a portable camera in order to monitor your trunk position during the lifting tasks. Prior to testing, your height, weight, and grip strength will be recorded. Furthermore, you will be asked to complete a Par Q activity form to screen for any medical conditions that may prevent you from participating in this study. Total testing time will be approximately 45 minutes.

The direct benefit to you as a subject is minimal. You will, however, benefit from the experience of participating in a scientific study. Moreover, the information obtained from your participation will be used to help improve the predictive power of link-segment models in lumbar moment calculations. Furthermore, you can receive feedback about your lifting style upon completion of the test battery.

Scientific literature does suggest some risk due to lifting heavy weights. Prior to lifting you will be given time to become familiar with the lifting task and loads. Please lift in your own style and at your own pace. If at any time, you feel a load is too heavy, stop lifting and inform the researcher.

By signing this form, I, ________________________, realize that I may withdraw from the study at any time without coercion to continue. If I have any questions about the study I may speak to Tammy Eger (545-2658) or Dr. Joan Stevenson (545-6288) at any time. If I am dissatisfied with the study I may contact Dr. Joan Stevenson at any time to express my concerns. I realize that confidentiality will be maintained and anonymity will be preserved. I have read and understand the explanation of procedure for this study of Load Transfer. I agree to participate in the outlined experimental study.

Volunteer: ________________________ Date: ________________________

Witness: ________________________ Date: ________________________

Par –Q

	No	Yes	Screened No	Screened Yes
1. Has your doctor ever said you have heart trouble?			☐	☐
2. Do you frequently have pains in your heart and chest?			☐	☐
3. Do you often feel faint or have spells of severe dizziness			☐	☐
4. Has a doctor ever said your blood pressure was too high?			☐	☐
5. Has your doctor ever told you that you have a bone or joint problem such as arthritis that has been aggravated by exercise or might be made worse with exercise?			☐	☐
6. Is there a good physical reason not mentioned here why you should not follow an exercise program even if you wanted to?			☐	☐
7. Are you over age 65 and not accustomed to vigorous exercise?			☐	☐
Signed Consent and Release Form	☐	☐ →	☐	☐
OBSERVATIONS				
Pregnancy – ask all females			☐	☐
Difficulty breathing at rest			☐	☐
Persistent cough			☐	☐
Lower extremity swelling			☐	☐
Currently on medication			☐	☐
Followed preliminary instructions	☐	☐ →	☐	☐

APPENDIX B

Grip Strength Testing Procedure

4.5.1 Grip Strength

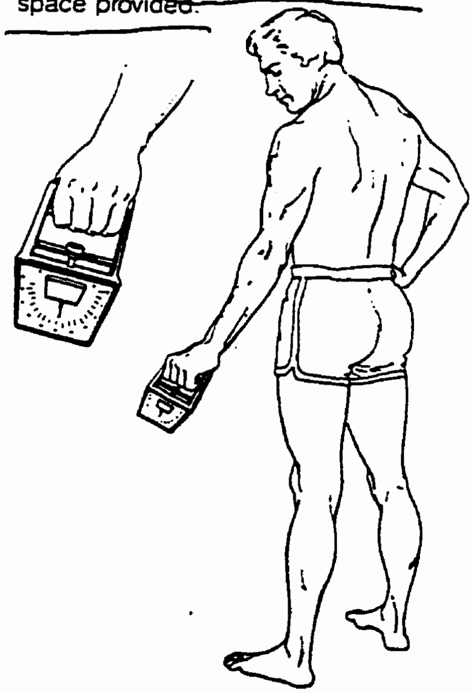
Equipment: Hand dynamometer

Procedure

Have the participant grasp the dynamometer in the appropriate hand. The grip is taken between the fingers and the palm at the base of the thumb. Adjust the grip of the dynamometer so the second joint of the fingers fits snugly under the handle and takes the weight of the instrument. Lock the grip in place. The participant holds the dynamometer in line with the forearm at the level of the thigh. The dynamometer is then squeezed vigorously so as to exert maximum force.

Have the participant exhale while squeezing (to avoid build-up of intra-thoracic pressure).

During the test neither the hand nor the dynamometer should touch the body or any other object. Measure both hands alternatively allowing two trials per hand. Record the scores for each hand to the nearest kilogram. Combine the maximum score for each hand and record in the space provided.



Appendix I: Table 6

Norms and Percentiles by Age Groups and Gender for Combined Right and Left Hand Grip Strength (kg)*

Norms

Age (yrs.)	15-19		20-29		30-39		40-49		50-59		60-69	
Gender	M	F	M	F	M	F	M	F	M	F	M	F
Excellent	≥113	≥71	≥124	≥71	≥123	≥73	≥119	≥73	≥110	≥65	≥102	≥60
Above Average	103-112	64-70	113-123	65-70	113-122	66-72	110-118	65-72	102-109	59-64	93-101	54-59
Average	95-102	59-63	106-112	61-64	105-112	61-65	102-109	59-64	96-101	55-58	86-92	51-53
Below Average	84-94	54-58	97-105	55-60	97-104	56-60	94-101	55-58	87-95	51-54	79-85	48-50
Poor	≤83	≤53	≤96	≤54	≤96	≤55	≤93	≤54	≤86	≤50	≤78	≤47

Percentiles

Age (yrs)	15–19		20–29		30–39		40–49		50–59		60–69	
Gender	M	F	M	F	M	F	M	F	M	F	M	F
Percentiles												
95	125	78	136	78	135	80	128	80	119	72	111	67
90	119	74	127	74	127	76	123	76	114	69	106	62
85	113	71	124	71	123	73	119	73	110	65	102	60
80	110	69	120	70	120	71	117	71	108	63	99	58
75	108	67	118	68	117	69	115	69	105	62	96	56
70	105	65	115	67	115	68	112	67	103	60	94	55
65	103	64	113	65	113	66	110	65	102	59	93	54
60	101	63	111	64	111	65	108	64	100	58	91	53
55	99	61	109	63	109	63	106	62	99	57	89	52
50	97	60	107	62	107	62	104	61	97	56	88	52
45	95	59	106	61	105	61	102	59	96	55	86	51
40	93	58	104	59	104	60	100	58	94	54	84	50
35	90	57	102	58	101	59	98	57	92	53	82	49
30	87	56	100	56	99	58	96	56	90	53	81	49
25	84	54	97	55	97	56	94	55	87	51	79	48
20	81	53	95	53	94	55	91	53	85	50	76	47
15	77	51	91	52	91	53	89	51	83	48	73	45
10	73	49	87	50	87	51	84	49	80	46	69	43
5	67	45	81	47	81	48	76	46	74	42	62	39

*Based on data from the Canada Fitness Survey, 1981

APPENDIX C

Industrial Applications

Estimating Hand Forces and Calculating Lumbar Moments in an Industrial Setting

In order to estimate load transfer force to the hands using the SCLTF, VLTF or ELTF strategies the following steps should be carried out:

1. Obtain Equipment

You will need a portable video camera, a meter stick or length of known dimension, a goniometer or a similar device to measure angles and a hand grip dynamometer to measure subject strength if you choose to use the ELTF strategy.

2. Record Subject Information

Measure and record the height and weight of each subject. This information will be needed when calculating lumbar moments using the quasi-dynamic link segment model. If you are using the ELTF strategy, the procedure outlined in Appendix B should be followed to calculate subject strength.

3. Collect Data

In order to obtain kinematic data for input into the quasi-dynamic link segment model a portable video camera or similar filming device should be used to record the lifting task. The camera should be positioned at a right angle to the subject and motion should occur in the sagittal plane. A known length, such as a meter stick, should also be filmed in the field of motion in order to allow conversion into life size coordinates. You may also wish to place markers on the subject, at the wrist, elbow, shoulder and L4/L5 level, in order to aid in joint position detection during digitizing.

The weight of the load being lifted should also be measured and recorded.

4. Calculate SLTF

In order to calculate SLTF, load transfer time and SLOPE needs to be determined.

Load Transfer Time: The start of load transfer is defined by the video frame in which the vertical displacement of the wrist is at the lowest value after the hands have made contact with the box. The end of load transfer is defined by the video frame where separation between the floor and load being lifted can first be seen. To aid in determination you may wish to create a colour difference between the two surfaces. The number of frames between the start and end of load transfer should then be counted. This number represents load transfer time as each frame equals 0.33 seconds.

SLOPE: = Total Load / Total # of frames = kg/frame

SLTF can then be determined as SLTF = SLOPE * Frame #

5. Calculate SCLTF

Cubic SLTF can be calculated from SLTF using the following equation:

$$\textbf{Cubic SLTF} = -0.3845 + (0.4385 * SLTF) + (0.0089 * SLTF^2) - (0.00003 * SLTF^3)$$

Cubic SLTF can then be input in the following regression equation to predict SCLTF:

$$SCLTF = -0.076 + 1.001(\text{cubic } SLTF)$$

6. Record Variable Scores

Gender (G): When entering a value for gender in the regression equations MALE = 0 and FEMALE = 1.

Style (ST): The degree of knee bend as measured from video at the start of load transfer is entered into the equation to represent style.

Load (W): The load being lifted in the trial under study is entered into the regression equation.

Strength (SS): The value for subject strength, obtained using the protocol outlined in the Canadian Standardized Test of Fitness manual, is entered to represent strength in the regression equation.

7. Calculate VLTF or ELTF

Once SCLTF is known LTF can be estimating using any three equations below.

SCLTF : Enter the values for SCLTF into the following equation:

$$MLTF = -0.076 + 1.001(SCLTF)$$

VLTF: Enter the score for gender, style, load and SLTF into the following equation;

$$MLTF = -7.571 + 1.044(SCLTF) - 0.884(W) + 7.161(G) + 0.145(ST)$$

ELTF: Enter the value for gender, style, load and strength into the following equation

$$MLTF = -5.996 + 1.044(SCLTF) - .873(W) + 8.964(G) + .157(ST) - 0.066(SS)$$

8. Calculate Lumbar Moments

Enter the kinematic data, obtained for the subject during load transfer from the video, along with corresponding load transfer force data estimated using one of the strategies discussed above into the quasi-dynamic link segment model. Resultant output equals the moment at the L4/L5 level of the spine.

Example Calculation for the Estimation of Load Transfer Using the SLOPE method.

A female worker was recorded lifting 10 kg over a total of 5 video frames.

Equation: SLOPE= Total Load / Total # of frames = kg/frame

To Do

1. Calculate SLOPE
2. Calculate SLTF for each frame of load transfer

Calculations

SLOPE = Total Load / Total # of frames = kg/frame
= 10 kg / 5 Frames
= 2 kg/frame

SLTF = SLOPE * (Frame #) *(Force of gravity)
Frame 1 = 2 kg/frame * frame 1 = 2kg * 9.81 m/s/s = 19.62 N
Frame 2 = 2kg/frame * frame 2 = 4 kg * 9.81 m/s/s = 39.28 N
Frame 3 = 2kg/frame * frame 3 = 6 kg * 9.81 m/s/s = 58.86 N
Frame 4 = 2kg/frame * frame 4 = 8 kg * 9.81 m/s/s = 78.48 N
Frame 5 = 2kg/frame * frame 5 = 10 kg * 9.81 m/s/s = 98.1 N

Therefore the estimated load transfer values are as follows:

Frame 1 = 19.62 N
Frame 2 = 39.28 N
Frame 3 = 58.86 N
Frame 4 = 78.48 N
Frame 5 = 98.10 N

These values for load transfer, along with segment coordinate data, can be entered into the quasi-dynamic link segment model in order to calculate lumbar moments during load transfer.

APPENDIX D

Statistical Tables

Appendix D-1

Regression Analysis to Predict Dependent Variable MLM Using Independent Variable MLTF

Regression

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	MLTF[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: MLTM

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.903[a]	.815	.815	33.1994

a. Predictors: (Constant), MLTF

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3267907.68	1	3267907.68	2964.899	.000[a]
	Residual	741779.587	673	1102.198		
	Total	4009687.26	674			

a. Predictors: (Constant), MLTF

b. Dependent Variable: MLTM

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	132.382	1.769		74.838	.000
	MLTF	1.298	.024	.903	54.451	.000

a. Dependent Variable: MLTM

Appendix D-2

Correlation Matrix for MLTF and MLM

Correlations

		MLTM	MLTF
MLTM	Pearson Correlation	1.000	.903**
	Sig. (2-tailed)	.	.000
	N	675	675
MLTF	Pearson Correlation	.903**	1.000
	Sig. (2-tailed)	.000	.
	N	675	675

**. Correlation is significant at the 0.01 level (2-tailed).

Appendix D-3

One-Way ANOVA for RMS and Load for Female Data

female

Female RMS error between MLTF and SLTF

5kg	9 kg	13 kg	18 kg
4.851056	3.552731	2.449646	12.09522
10.11975	10.65719	5.461049	9.136434
7.173309	1.822642	27.8104	20.81381
7.495561	5.276443	12.43354	
11.26802	8.442719	14.52039	15.65527
1.915406	25.53343	16.59941	17.67824
3.434943	8.944901	9.78861	22.14778
2.962195	10.18413	9.240496	18.91287
1.748771	4.788996	4.153212	10.82566
2.692444	15.65614	10.62134	14.37706
3.455042	5.861348	11.72631	20.5512

ANOVA

To see if there is a significant difference between RMS error values for loads

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
5kg	11	57.11649	5.192408	11.04649
9 kg	11	100.7207	9.156425	44.44871
13 kg	11	124.8044	11.34586	48.29768
18 kg	10	162.1935	16.21935	20.48711

ANOVA

rce of Varia	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between G	663.6803	3	221.2268	7.058622	0.000667	2.84507
Within Gro	1222.313	39	31.34135			
Total	1885.993	42				

Appendix D-3

One-Way ANOVA for RMS and Load for Male Data

Male RMS errorbetween MLTF and SLTF

5kg	9 kg	13 kg	18 kg
1.880859	6.184436	25.02755	15.59759
4.784911	9.169498	4.547084	15.29402
3.218156	4.860208	7.638901	7.927331
2.731277	22.05136	21.68513	54.56438
1.914814	17.88085	8.987517	35.921
1.139024	3.768781	5.773672	5.773672
13.49892	18.19935	6.964374	38.21903
1.431373	2.85614	16.9373	19.34527
9.286598	3.523757	15.01546	9.148429
0.732717	3.980251	5.870008	11.0264

ANOVA

To see if there is a significant difference between RMS error values for loads

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
5kg	10	40.61865	4.061865	17.25258
9 kg	10	92.47463	9.247463	53.17965
13 kg	10	118.447	11.8447	53.56548
18 kg	10	212.8171	21.28171	261.3396

ANOVA

Source of Varia	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between G	1561.531	3	520.5102	5.403165	0.003568	2.866265
Within Gro	3468.035	36	96.33432			
Total	5029.566	39				

Appendix D-3

One-Way ANOVA of RMS Error by Method (SLOPE, POINT)

anova to show the average RMS score for SLTF
is significantly different from the average RMS
for PLTF

SLTF	PLTF
6.54	9.66
13.22	24.23
11.35	40.06
14.74	59.85
4.06	6.91
9.25	18.8
11.84	33.7
21.28	45.5

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
sltf	8	92.28	11.535	27.75006
pltf	8	238.71	29.83875	335.9364

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1340.109	1	1340.109	7.369585	0.016767	4.600111
Within Groups	2545.805	14	181.8432			
Total	3885.914	15				

Appendix D-3

One-Way ANOVA of RMS Error (MLTF vs SLTF) by Gender

MLTF values compared to SLTF values --

RMS error

ANOVA shows there isn't a significant difference by gender

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Male	40	486.6	12.165	134.9044
Female	40	411.88	10.297	47.74061

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	69.78848	1	69.78848	0.764198	0.384702	3.963464
Within Groups	7123.155	78	91.3225			
Total	7192.943	79				

Appendix D-3

One-Way ANOVA of RMS Error (MLM vs SLM) by Load

The ANOVA shows there is a ssignificant difference between loads

FEMALE

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
5kg	6	28.25731	4.709552	10.86165
9 kg	6	101.3126	16.88543	146.7156
13 kg	6	87.96802	14.66134	51.77027
18 kg	6	119.9516	19.99193	13.70538

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	785.7795	3	261.9265	4.69712	0.012191	3.098393
Within Groups	1115.264	20	55.76322			
Total	1901.044	23				

MALE

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
5kg	6	30.16026	5.026709	16.33756
9 kg	6	62.25712	10.37619	73.04608
13 kg	6	104.5807	17.43012	148.3011
18 kg	6	129.0319	21.50531	102.167

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	966.343	3	322.1143	3.791234	0.026542	3.098393
Within Groups	1699.259	20	84.96293			
Total	2665.602	23				

Appendix D-3

One-Way ANOVA of RMS Error by Method (SLM, PLM)

anova to show the average RMS score for SLM is significantly different from the RMS average for PLM

Method is significant - Female subjects

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
SLM	24	337.4894	14.06206	82.65408
PLM	24	1150.074	47.91974	1013.331

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	13756.11	1	13756.11	25.10274	8.49E-06	4.051742
Within Groups	25207.65	46	547.9925			
Total	38963.76	47				

Method is significant Male Subjects

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
SLM	24	326.03	13.58458	115.8957
PLM	24	847.1402	35.29751	1006.589

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5657.414	1	5657.414	10.08017	0.002674	4.051742
Within Groups	25817.14	46	561.2422			
Total	31474.55	47				

Appendix D-3

One-Way ANOVA of RMS Error (MLM vs SLM) by Gender

MLM values compared to SLM values RMS error

Do an ANOVA to see if there is a significant difference by gender

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
female	24	337.4894	14.06206	82.65408
male	24	326.03	13.58458	115.8957

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.73581	1	2.73581	0.027558	0.86888	4.051742
Within Groups	4566.645	46	99.2749			
Total	4569.381	47				

Therefore there is not a significant differnce between RMS error scores by gender

APPENDIX D-4

Correlation Matrix for SLTF, Gender, Strength, Load and Style

Correlations

		SLTF	GENDER	LOAD	STRENGTH	STYLE	SPEED
SLTF	Pearson Correlation	1.000	-.006	.478**	.022	-.042	.090**
	Sig. (2-tailed)	.	.837	.000	.445	.155	.002
	N	1175	1175	1175	1175	1175	1175
GENDER	Pearson Correlation	-.006	1.000	-.037	.459**	-.149**	-.001
	Sig. (2-tailed)	.837	.	.205	.000	.000	.963
	N	1175	1176	1176	1176	1176	1176
LOAD	Pearson Correlation	.478**	-.037	1.000	.011	-.054	.151**
	Sig. (2-tailed)	.000	.205	.	.700	.065	.000
	N	1175	1176	1176	1176	1176	1176
STRENGTH	Pearson Correlation	.022	.459**	.011	1.000	.075**	-.138**
	Sig. (2-tailed)	.445	.000	.700	.	.010	.000
	N	1175	1176	1176	1176	1176	1176
STYLE	Pearson Correlation	-.042	-.149**	-.054	.075**	1.000	-.264**
	Sig. (2-tailed)	.155	.000	.065	.010	.	.000
	N	1175	1176	1176	1176	1176	1176
SPEED	Pearson Correlation	.090**	-.001	.151**	-.138**	-.264**	1.000
	Sig. (2-tailed)	.002	.963	.000	.000	.000	.
	N	1175	1176	1176	1176	1176	1176

**. Correlation is significant at the 0.01 level (2-tailed).

Appendix D-5

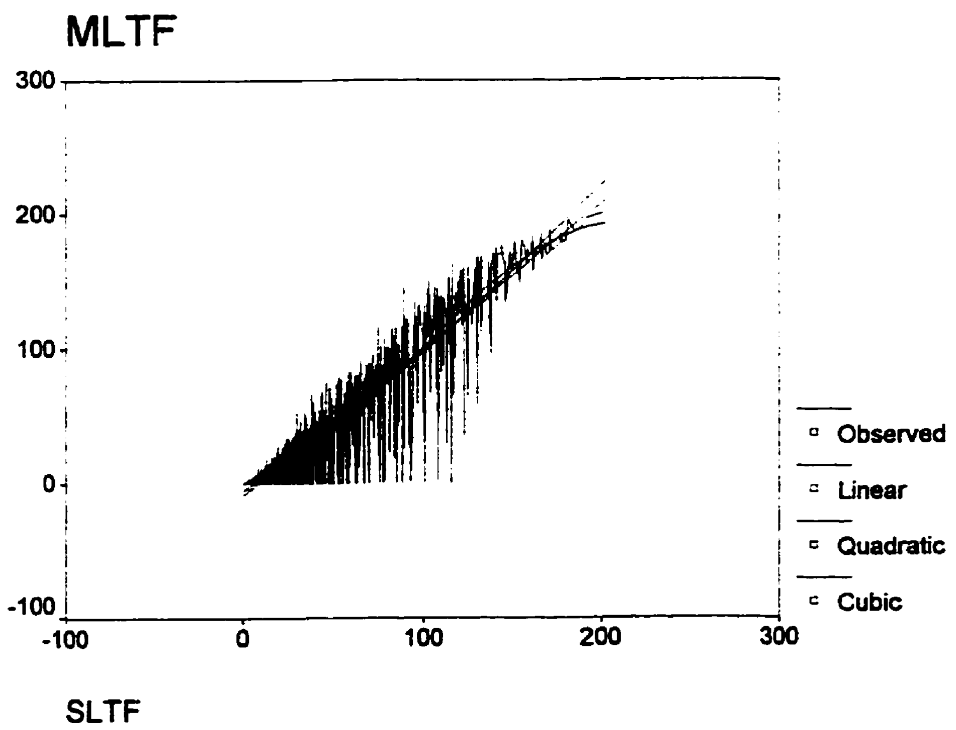
Curve Estimation

Curve Fit

```
MODEL:  MOD_3.

Independent Variable:   SLTF      Minimum value:       .00
The independent variable contains non-positive values.  Models LOGARITHMIC
and POWER cannot be calculated.

Variable:  MLTF          Minimum value:        .00
This variable contains non-positive values.  Log transform cannot be
applied.  Models COMPOUND, POWER, S, GROWTH, EXPONENTIAL and LGSTIC cannot
be calculated.

Independent:   SLTF
```

	Dependent	Mth	Rsq	d.f.	F	Sigf	b0	b1	b2	b3
	MLTF	LIN	.867	1173	7645.37	.000	-8.6900	1.0829		
12	MLTF	LOG								
	MLTF	QUA	.869	1172	3895.02	.000	-5.3526	.9225	.0011	
	MLTF	CUB	.875	1171	2724.55	.000	-.3845	.4385	.0089	-3.E-05
1	MLTF	S								

Notes:
1 Dependent variable has non-positive values; no equation estimated.
12 Independent variable has non-positive values.



Appendix D-6

Regression Analysis to Predict Dependant Variable MLTF using Independent Variables SCLTF, Gender, Load, Style and Strength

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Fit for MLTF with SLTF from CURVEFIT, MOD_2 CUBIC	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
2	LOAD	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
3	GENDER	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
4	STYLE	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
5	STRENGTH	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: MLTF

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.935[a]	.875	.875	19.3773
2	.938[b]	.880	.880	18.9906
3	.940[c]	.883	.883	18.7498
4	.942[d]	.887	.886	18.4641
5	.942[e]	.887	.887	18.3990

a. Predictors: (Constant), Fit for MLTF with SLTF from CURVEFIT, MOD_2 CUBIC

b. Predictors: (Constant), Fit for MLTF with SLTF from CURVEFIT, MOD_2 CUBIC, LOAD

c. Predictors: (Constant), Fit for MLTF with SLTF from CURVEFIT, MOD_2 CUBIC, LOAD, GENDER

d. Predictors: (Constant), Fit for MLTF with SLTF from CURVEFIT, MOD_2 CUBIC, LOAD, GENDER, STYLE

e. Predictors: (Constant), Fit for MLTF with SLTF from CURVEFIT, MOD_2 CUBIC, LOAD, GENDER, STYLE, STRENGTH

ANOVA[f]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3074423.74	1	3074423.74	8188.007	.000[a]
	Residual	440436.728	1173	375.479		
	Total	3514860.47	1174			
2	Regression	3092188.40	2	1546094.20	4287.064	.000[b]
	Residual	422672.072	1172	360.642		
	Total	3514860.47	1174			
3	Regression	3103190.55	3	1034396.85	2942.354	.000[c]
	Residual	411669.914	1171	351.554		
	Total	3514860.47	1174			
4	Regression	3115981.89	4	778995.473	2284.968	.000[d]
	Residual	398878.577	1170	340.922		
	Total	3514860.47	1174			
5	Regression	3119128.17	5	623825.634	1842.792	.000[e]
	Residual	395732.297	1169	338.522		
	Total	3514860.47	1174			

a. Predictors: (Constant), Fit for MLTF with SLTF from CURVEFIT, MOD_2 CUBIC

b. Predictors: (Constant), Fit for MLTF with SLTF from CURVEFIT, MOD_2 CUBIC, LOAD

c. Predictors: (Constant), Fit for MLTF with SLTF from CURVEFIT, MOD_2 CUBIC, LOAD, GENDER

d. Predictors: (Constant), Fit for MLTF with SLTF from CURVEFIT, MOD_2 CUBIC, LOAD, GENDER, STYLE

e. Predictors: (Constant), Fit for MLTF with SLTF from CURVEFIT, MOD_2 CUBIC, LOAD, GENDER, STYLE, STRENGTH

f. Dependent Variable: MLTF

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-7.579E-02	.814		-.093	.926
	Fit for MLTF with SLTF from CURVEFIT, MOD_2 CUBIC	1.001	.011	.935	90.488	.000
2	(Constant)	8.869	1.503		5.899	.000
	Fit for MLTF with SLTF from CURVEFIT, MOD_2 CUBIC	1.044	.012	.975	83.864	.000
	LOAD	-.948	.135	-.082	-7.018	.000
3	(Constant)	5.276	1.617		3.262	.001
	Fit for MLTF with SLTF from CURVEFIT, MOD_2 CUBIC	1.043	.012	.975	84.871	.000
	LOAD	-.921	.133	-.079	-6.898	.000
	GENDER	6.143	1.098	.056	5.594	.000
4	(Constant)	-7.571	2.634		-2.875	.004
	Fit for MLTF with SLTF from CURVEFIT, MOD_2 CUBIC	1.044	.012	.975	86.254	.000
	LOAD	-.884	.132	-.076	-6.720	.000
	GENDER	7.161	1.094	.065	6.545	.000
	STYLE	.145	.024	.061	6.125	.000
5	(Constant)	-5.996	2.675		-2.242	.025
	Fit for MLTF with SLTF from CURVEFIT, MOD_2 CUBIC	1.044	.012	.976	86.599	.000
	LOAD	-.873	.131	-.075	-6.652	.000
	GENDER	8.964	1.240	.082	7.227	.000
	STYLE	.157	.024	.066	6.566	.000
	STRENGTH	-6.551E-02	.021	-.034	-3.049	.002

a. Dependent Variable: MLTF

Excluded Variables[f]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
1	GENDER	.059[a]	5.739	.000	.165	1.000
	LOAD	-.082[a]	-7.018	.000	-.201	.759
	SPEED	-.033[a]	-3.223	.001	-.094	.992
	STRENGTH	.008[a]	.786	.432	.023	.999
	STYLE	.054[a]	5.272	.000	.152	.999
2	GENDER	.056[b]	5.594	.000	.161	.999
	SPEED	-.025[b]	-2.434	.015	-.071	.977
	STRENGTH	.008[b]	.817	.414	.024	.999
	STYLE	.051[b]	5.101	.000	.147	.997
3	SPEED	-.025[c]	-2.490	.013	-.073	.977
	STRENGTH	-.022[c]	-1.958	.050	-.057	.789
	STYLE	.061[c]	6.125	.000	.176	.974
4	SPEED	-.010[d]	-.954	.340	-.028	.910
	STRENGTH	-.034[d]	-3.049	.002	-.089	.768
5	SPEED	-.014[e]	-1.349	.178	-.039	.896

a. Predictors in the Model: (Constant), Fit for MLTF with SLTF from CURVEFIT, MOD_2 CUBIC

b. Predictors in the Model: (Constant), Fit for MLTF with SLTF from CURVEFIT, MOD_2 CUBIC, LOAD

c. Predictors in the Model: (Constant), Fit for MLTF with SLTF from CURVEFIT, MOD_2 CUBIC, LOAD, GENDER

d. Predictors in the Model: (Constant), Fit for MLTF with SLTF from CURVEFIT, MOD_2 CUBIC, LOAD, GENDER, STYLE

e. Predictors in the Model: (Constant), Fit for MLTF with SLTF from CURVEFIT, MOD_2 CUBIC, LOAD, GENDER, STYLE, STRENGTH

f. Dependent Variable: MLTF

APPENDIX D-7

Results of Test Statistic

TEST STATISTIC

The test statistic can be used to test the significance of different regression models.

$$\text{Test Statistic} = \sqrt{\frac{(\text{New \% Fit} - \text{Old \% Fit})\ (\text{degrees of freedom})}{(100\ \%\ \text{Fit} - \text{New \% Fit})}}$$

Where

Degrees of Freedom = n-k-1
n= the number of values
k= the number of independent variables in the equation

A) Test to determine if SCLTF results in a significant improvement over SLTF.

$$\text{Test Statistic} = \sqrt{\frac{(87.5 - 86.7)\ (1173)}{(100 - 87.5)}}$$

$$= 8.66$$

The critical value from the two-sided t-table with 1173 degrees of freedom

1.960 at 0.05 significance level
2.576 at 0.01 significance level

Therefore the cube model significantly improved the prediction of MLTF when compared to SLTF.

APPENDIX D-7

Results of Test Statistic

B) Test to determine if VLTF results in a significant improvement over SCLTF.

$$\text{Test Statistic} = \sqrt{\frac{(88.65 - 87.47)(1170)}{(100 - 88.65)}}$$

$$= 11.03$$

The critical value from the two-sided t-table with 1173 degrees of freedom

1.960 at 0.05 significance level
2.576 at 0.01 significance level

Therefore the VLTF significantly improved the prediction of MLTF when compared to SCLTF.

C) Test to determine if ELTF results in a significant improvement over VLTF.

$$\text{Test Statistic} = \sqrt{\frac{(88.74 - 88.65)(1169)}{(100 - 88.74)}}$$

$$= 3.06$$

The critical value from the two-sided t-table with 1173 degrees of freedom

1.960 at 0.05 significance level
2.576 at 0.01 significance level

Therefore the ELTF significantly improved the prediction of MLTF when compared to VLTF.

Appendix D-8

Correlation Matrix for MLTF, SLTF, SCLTF, VLTF and ELTF

Correlations

		MLTF	SLTF	SCLTF	VLTF	ELTF
MLTF	Pearson Correlation	1.000	.931**	.935**	.943**	.943**
	Sig. (2-tailed)	.	.000	.000	.000	.000
	N	1175	1175	1175	1175	1175
SLTF	Pearson Correlation	.931**	1.000	.995**	.989**	.989**
	Sig. (2-tailed)	.000	.	.000	.000	.000
	N	1175	1175	1175	1175	1175
SLTFC	Pearson Correlation	.935**	.995**	1.000	.994**	.994**
	Sig. (2-tailed)	.000	.000	.	.000	.000
	N	1175	1175	1175	1175	1175
VLTF	Pearson Correlation	.943**	.989**	.994**	1.000	1.000**
	Sig. (2-tailed)	.000	.000	.000	.	.000
	N	1175	1175	1175	1175	1175
ELTF	Pearson Correlation	.943**	.989**	.994**	1.000**	1.000
	Sig. (2-tailed)	.000	.000	.000	.000	.
	N	1175	1175	1175	1175	1175

**. Correlation is significant at the 0.01 level (2-tailed).

APPENDIX E

Raw Data from Force Plate

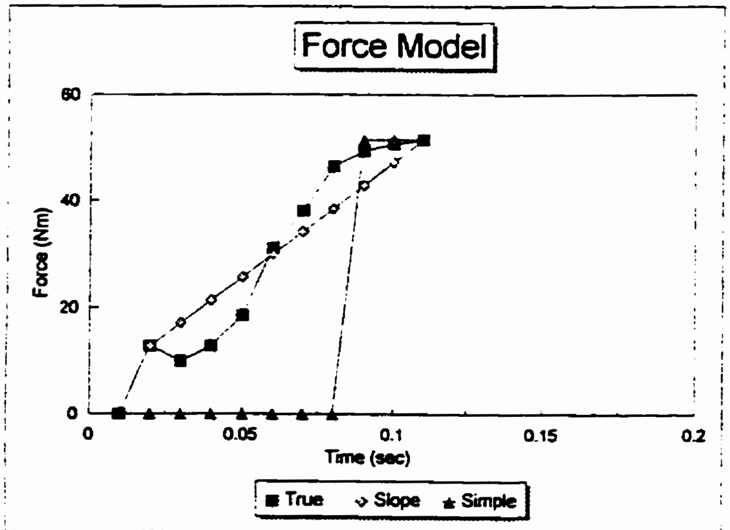
Legend

True – Measured load transfer force
Slope – Slope load transfer force
Simple – Point load transfer force

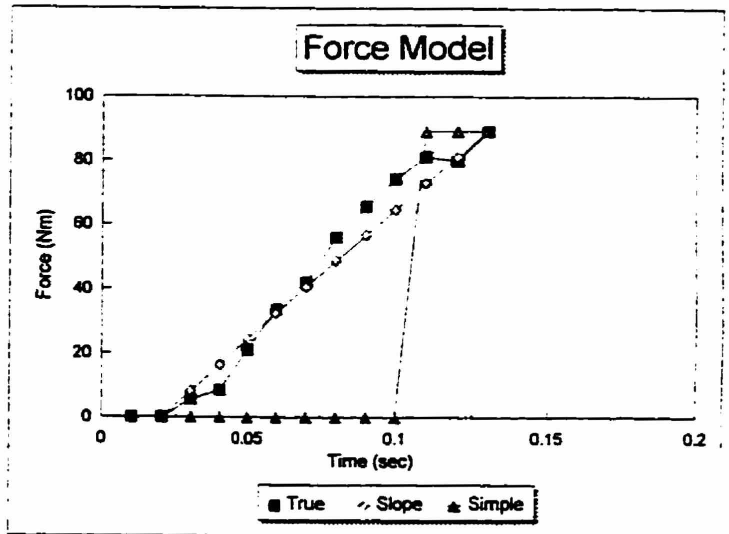
Load Transfer Data
TRUE load transfer
SLOPE estimation of the load transfer force
INSTANT estimation of the load transfer force

Subject 1

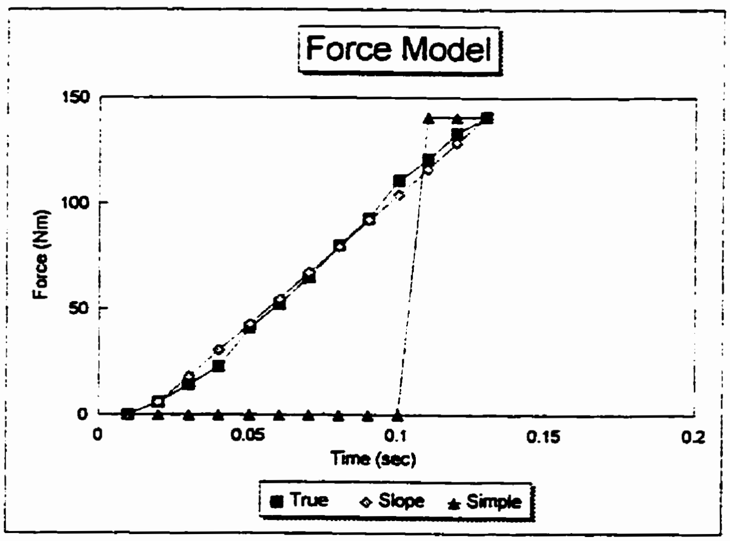
5 kg s1-t8



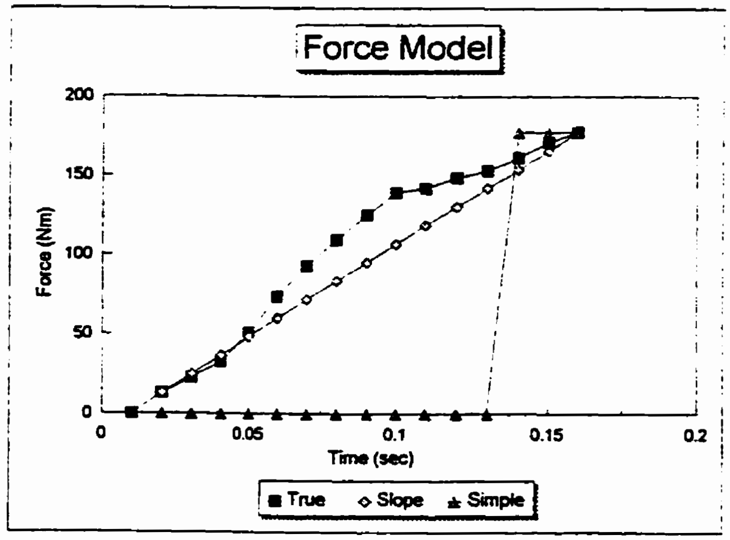
9 kg s1-t2



13 kg s1-t18



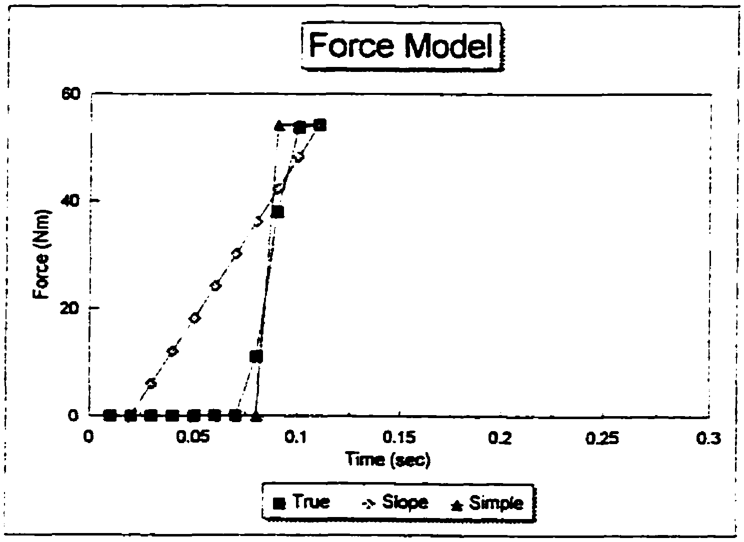
18 kg s1-t13



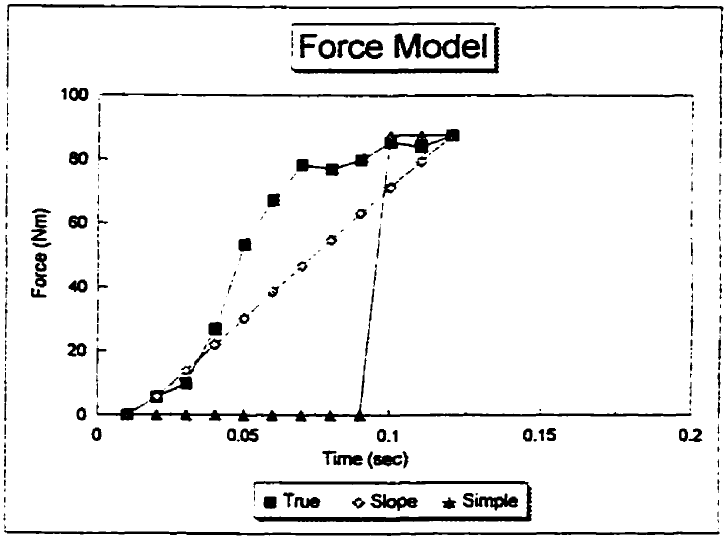
Load Transfer Data
TRUE load transfer
SLOPE estimation of the load transfer force
INSTANT estimation of the load transfer force

Subject 2

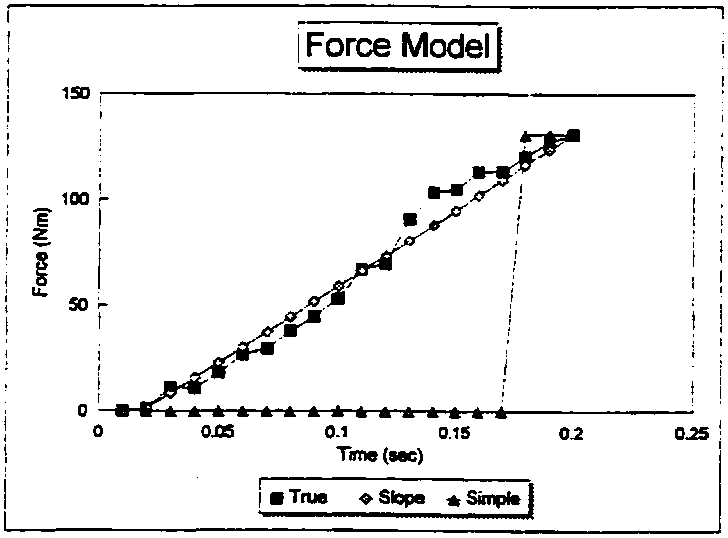
5 kg s2-t8



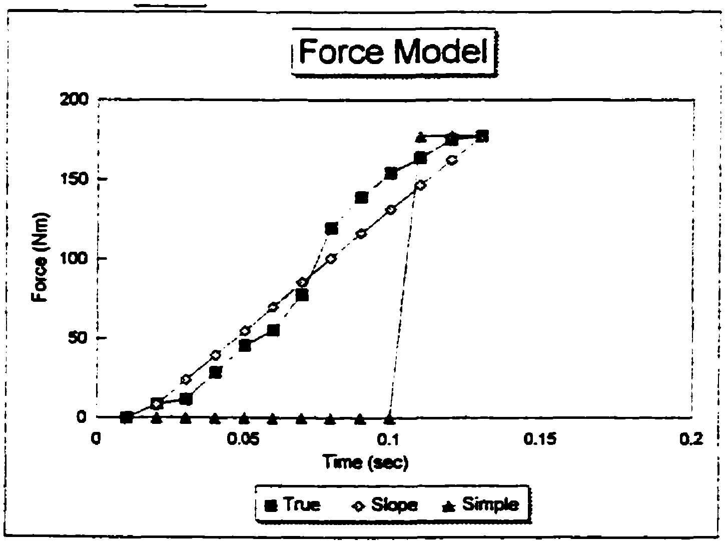
9 kg s2-t18



13 kg s2-t3



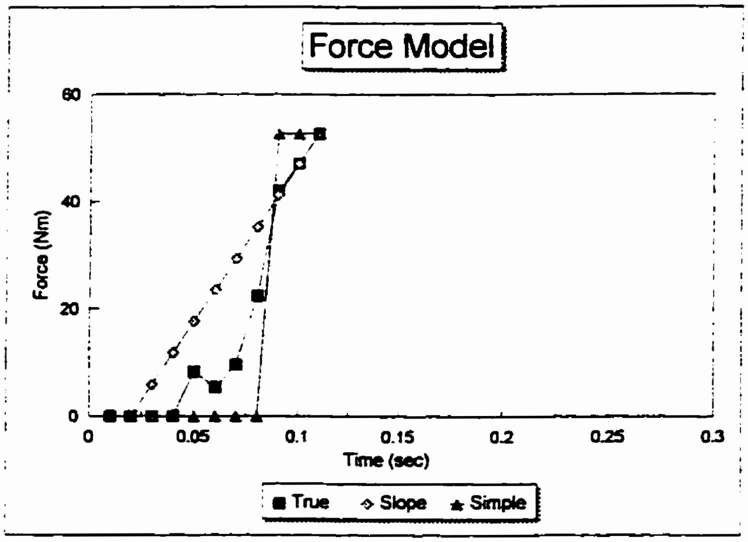
18 kg s2-t13



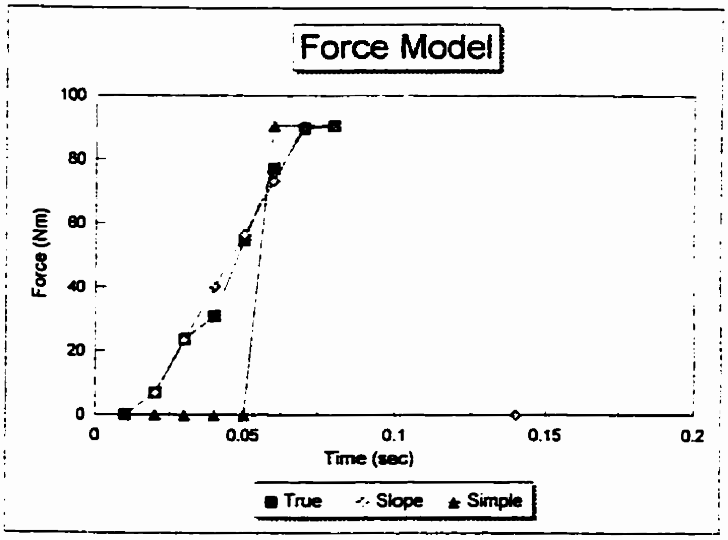
Load Transfer Data
TRUE load transfer
SLOPE estimation of the load transfer force
INSTANT estimation of the load transfer force

Subject 3

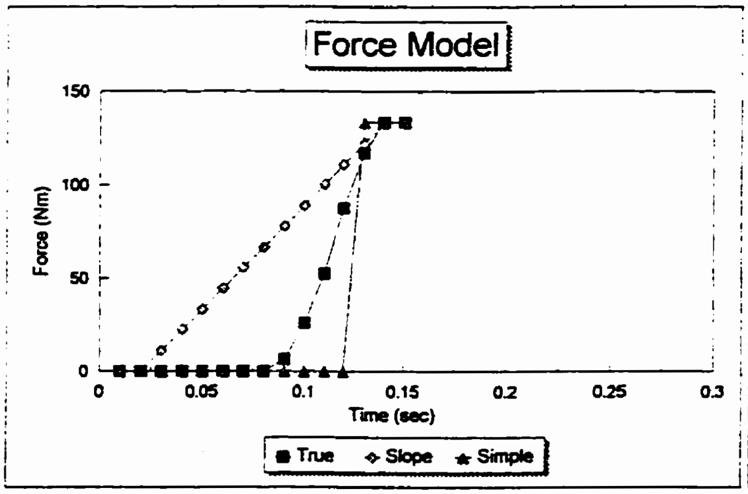
5 kg s3-t13



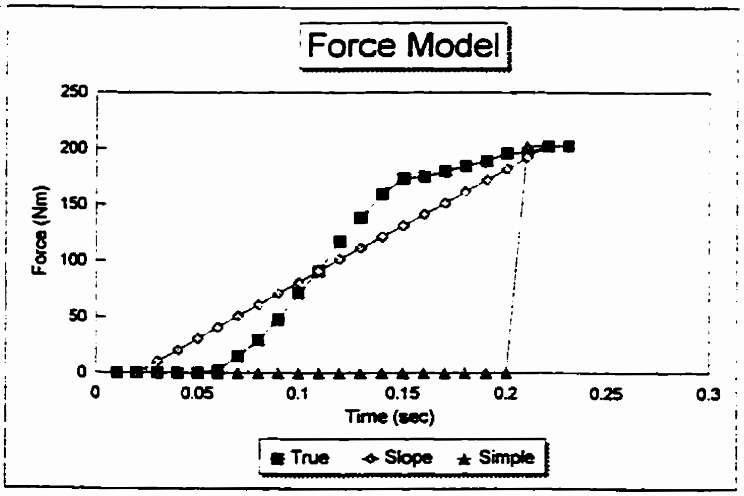
9 kg s3-t8



13 kg s3-t18



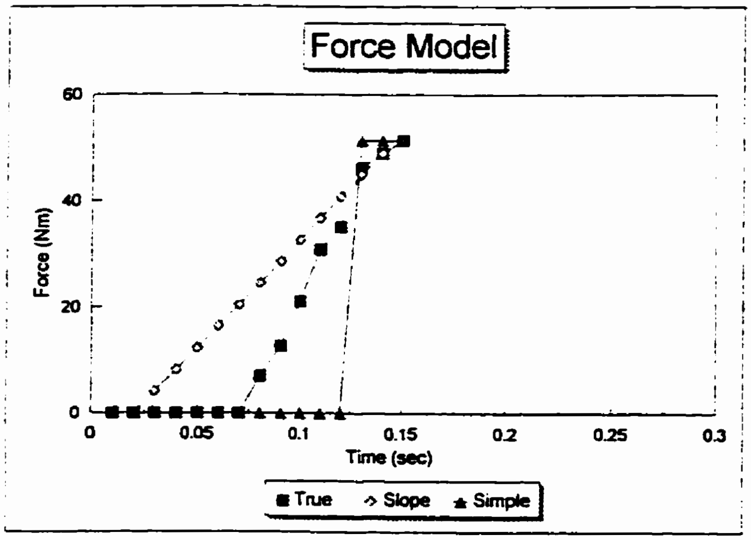
18 kg s3-t2



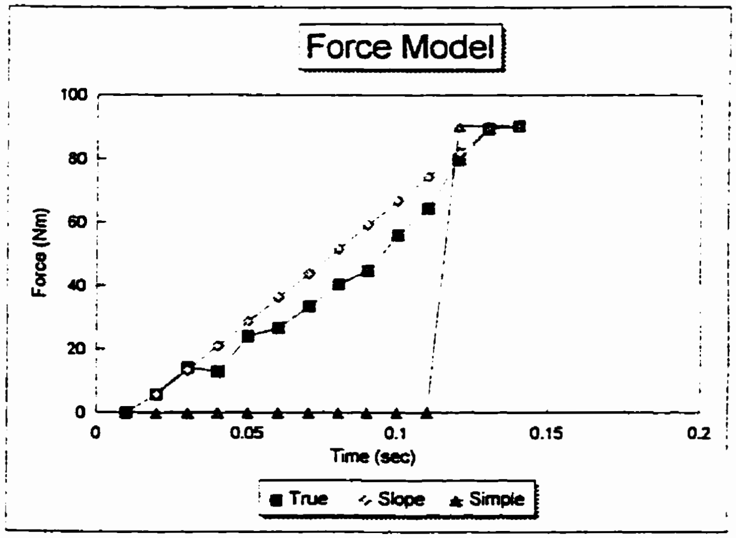
Load Transfer Data
TRUE load transfer
SLOPE estimation of the load transfer force
INSTANT estimation of the load transfer force

Subject 4

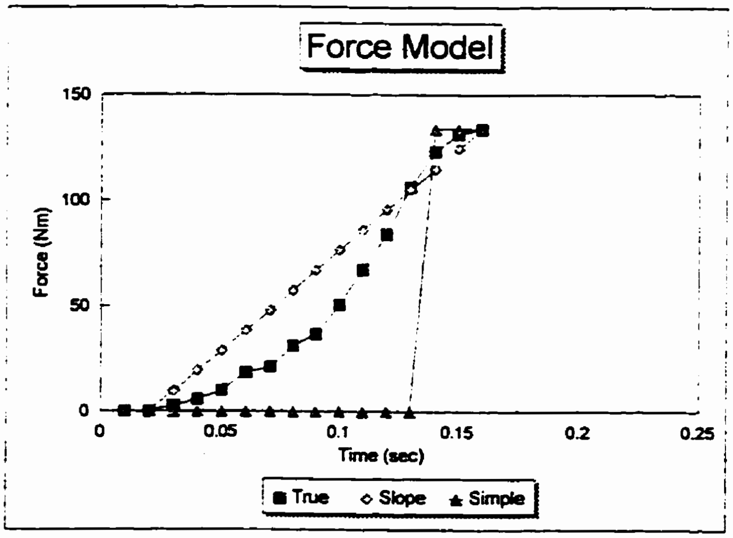
5 kg s4-t18



9 kg s4-t3



13 kg s4-t13

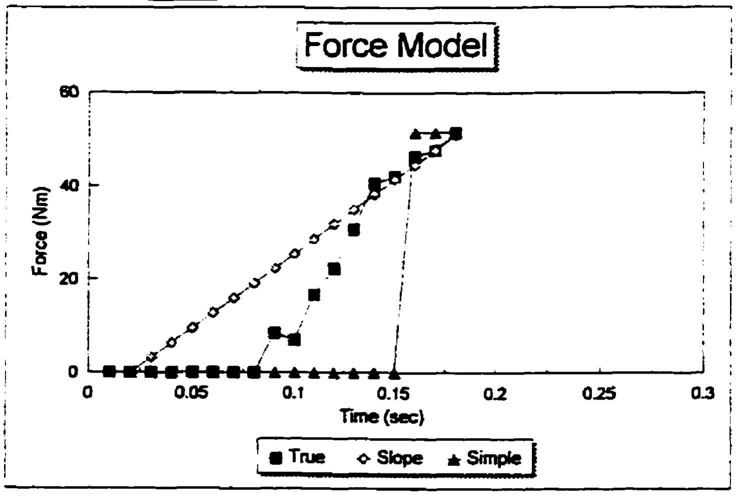


18 kg

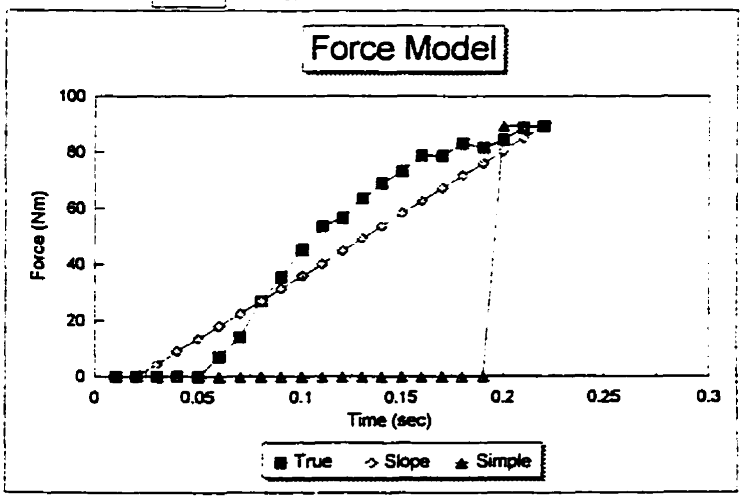
Load Transfer Data
TRUE load transfer
SLOPE estimation of the load transfer force
INSTANT estimation of the load transfer force

Subject 5

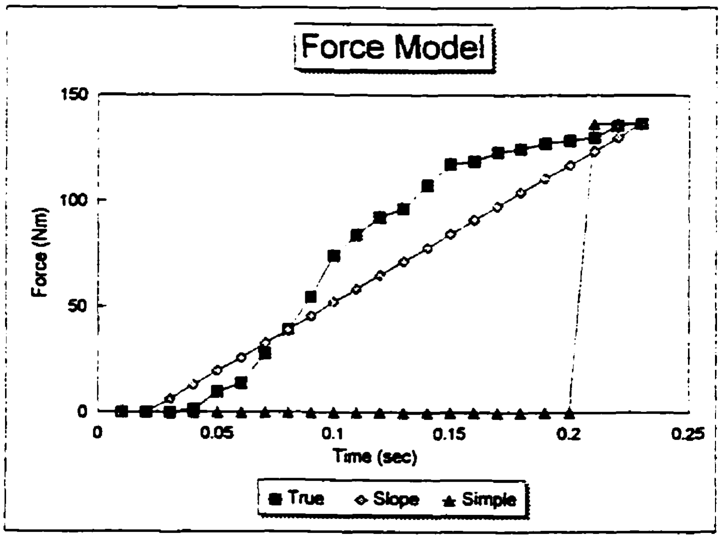
5 kg s5-t18



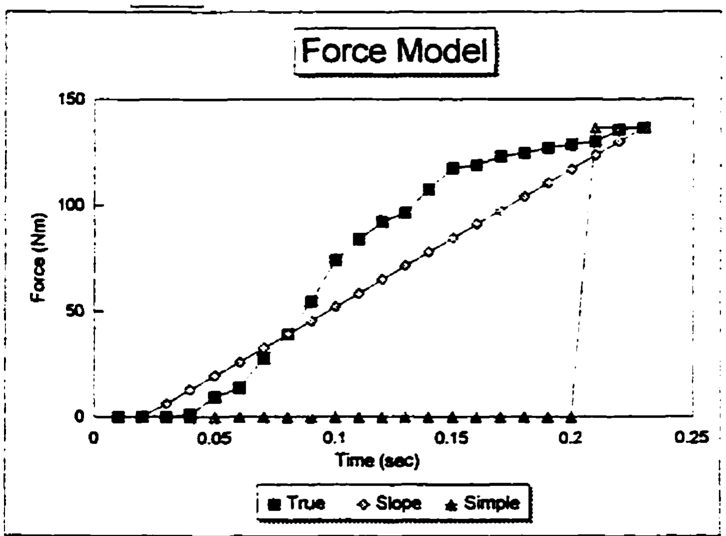
9 kg s5-t3



13 kg s5-t13



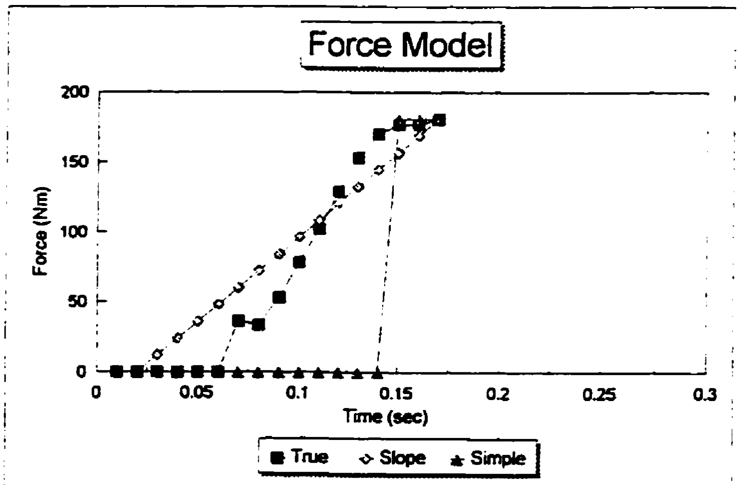
18 kg s5-t8



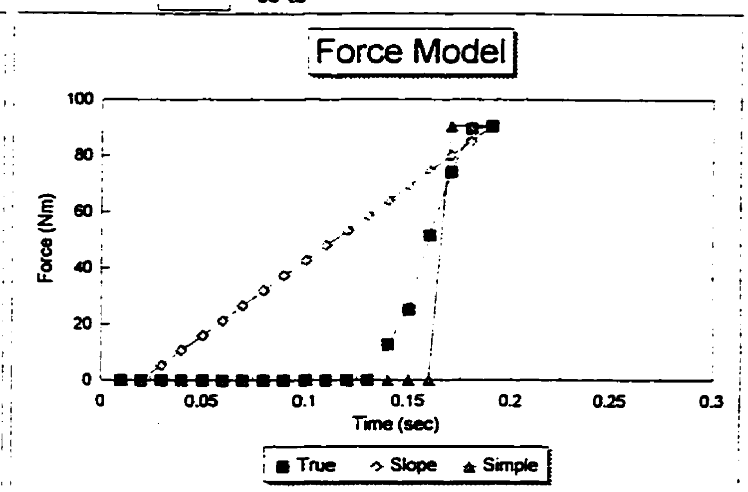
Load Transfer Data
TRUE load transfer
SLOPE estimation of the load transfer force
INSTANT estimation of the load transfer force

Subject 6

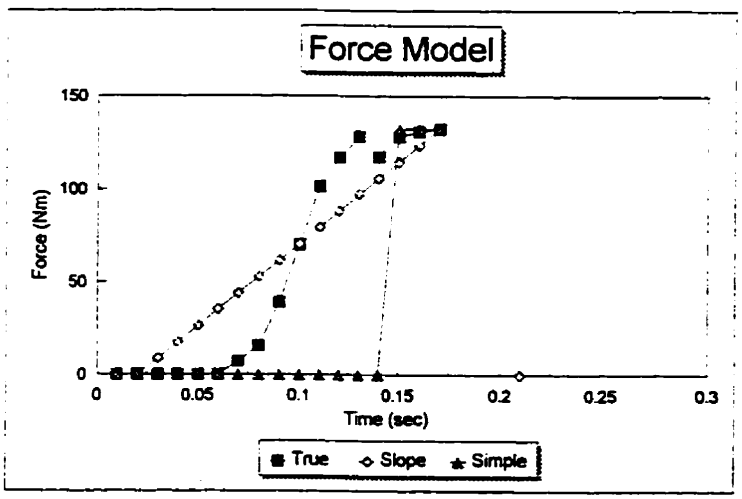
5 kg s6-t13



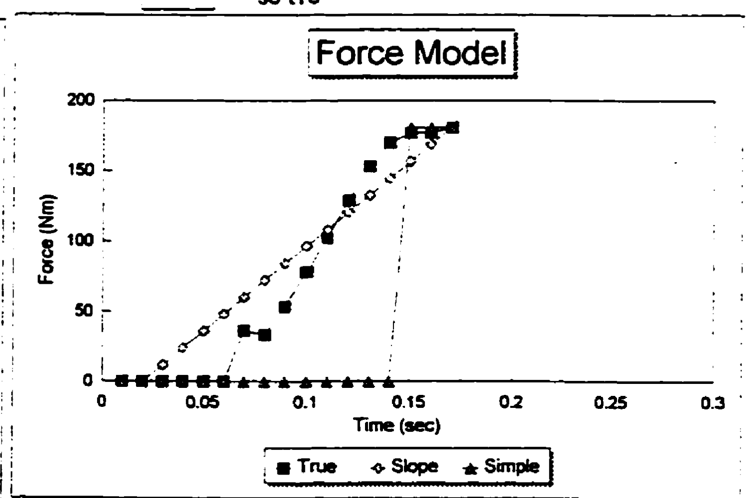
9 kg s6-t3



13 kg



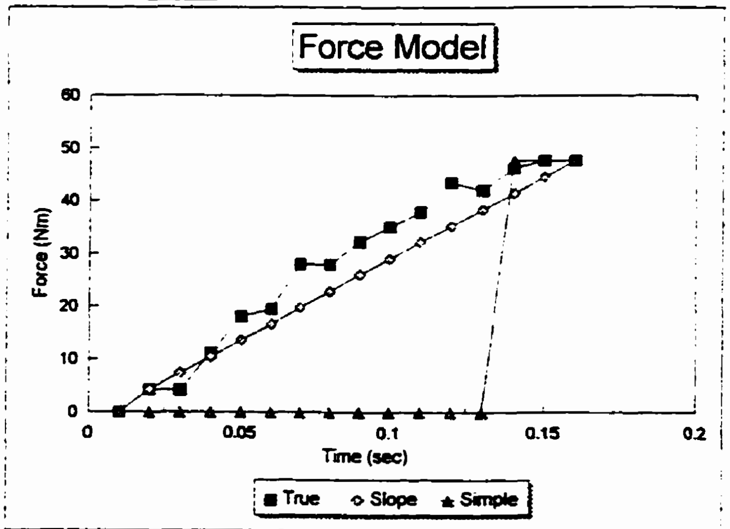
18 kg s6-t18



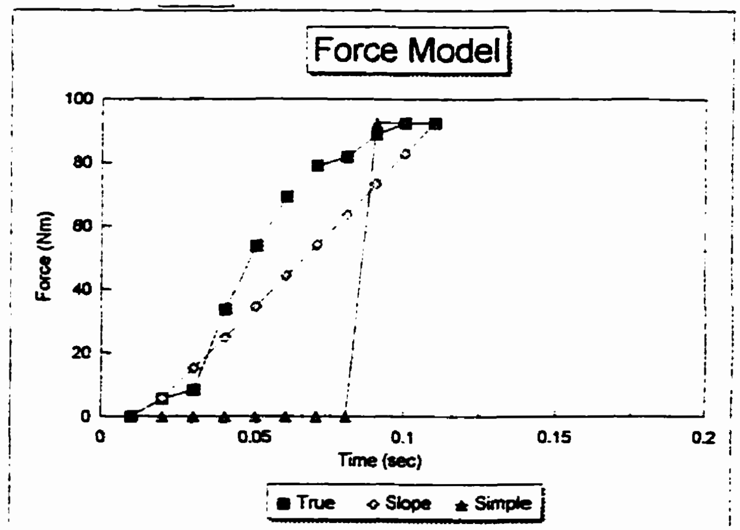
Load Transfer Data
TRUE load transfer
SLOPE estimation of the load transfer force
INSTANT estimation of the load transfer force

Subject 7

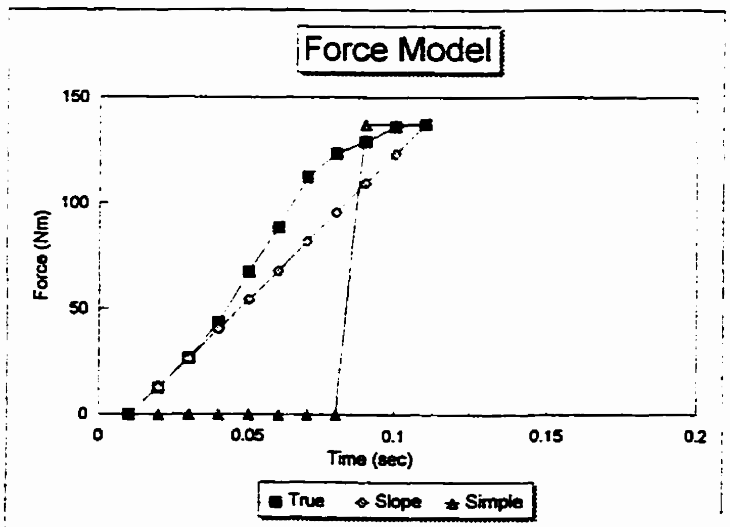
5 kg s7-t3



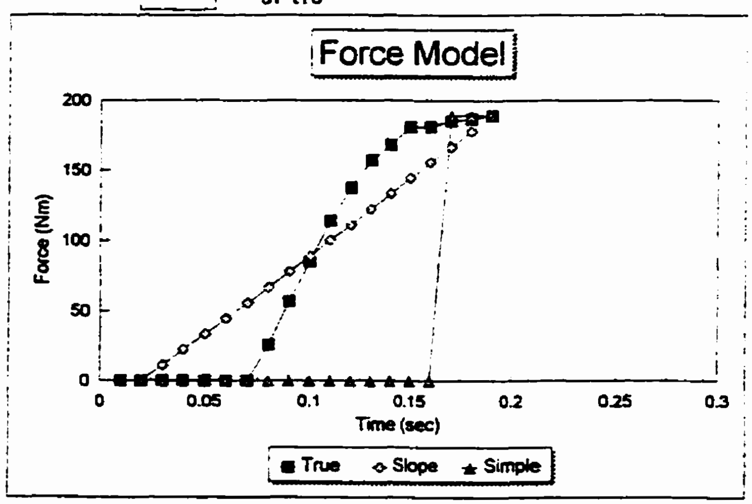
9 kg s7-t13



13 kg s7-t8



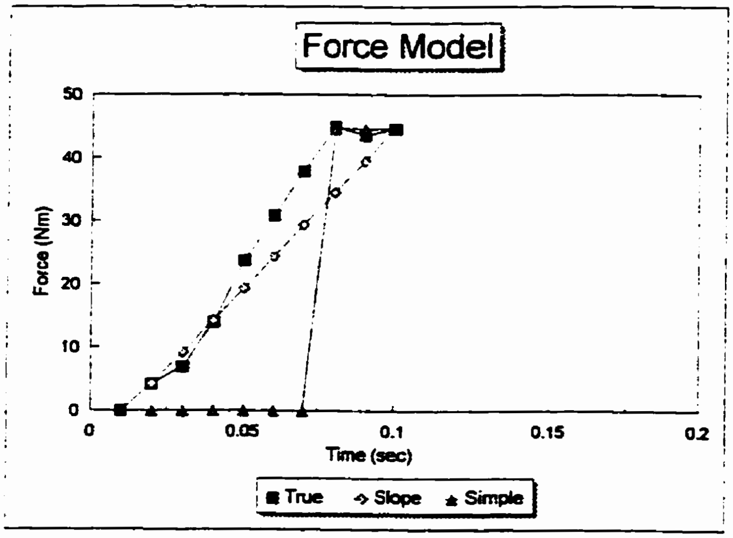
18 kg s7-t18



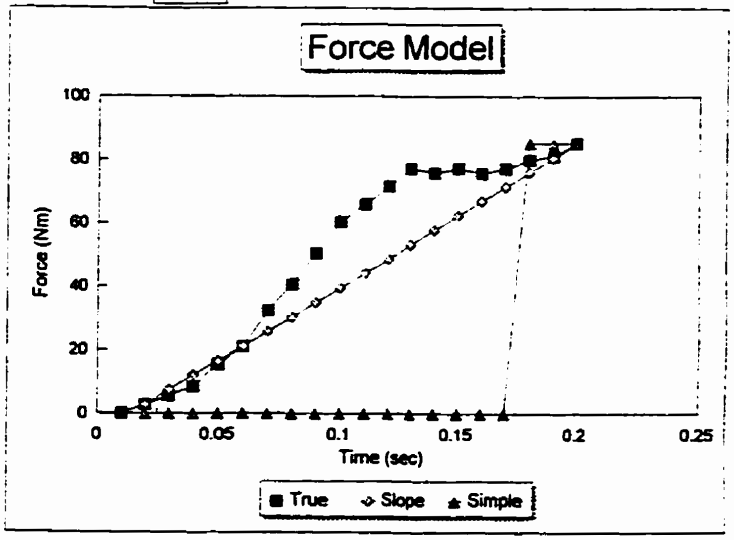
Load Transfer Data
TRUE load transfer
SLOPE estimation of the load transfer force
INSTANT estimation of the load transfer force

Subject 8

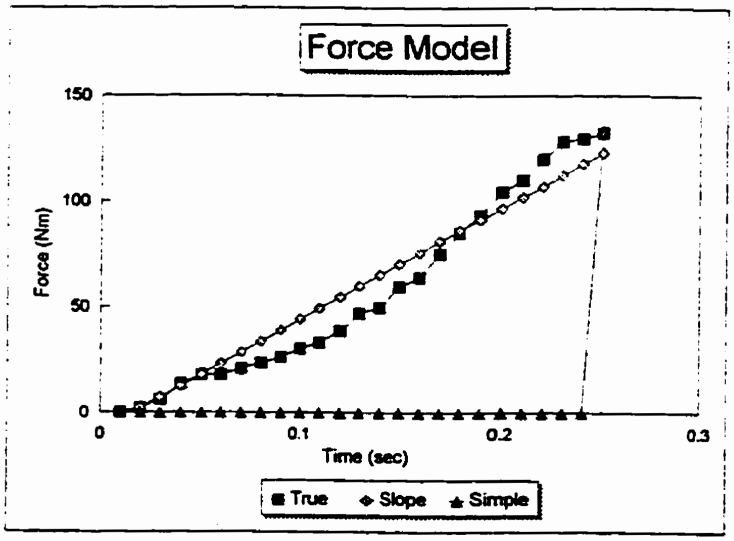
5 kg s8-t8



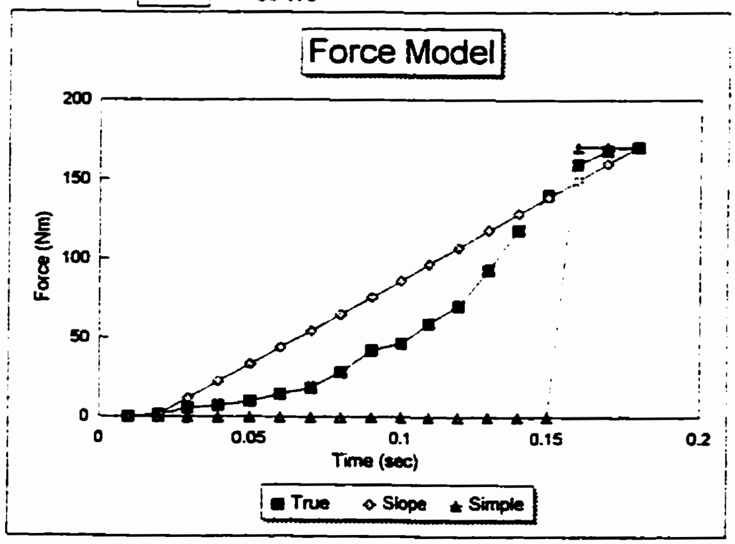
9 kg s8-t13



13 kg s8-t3



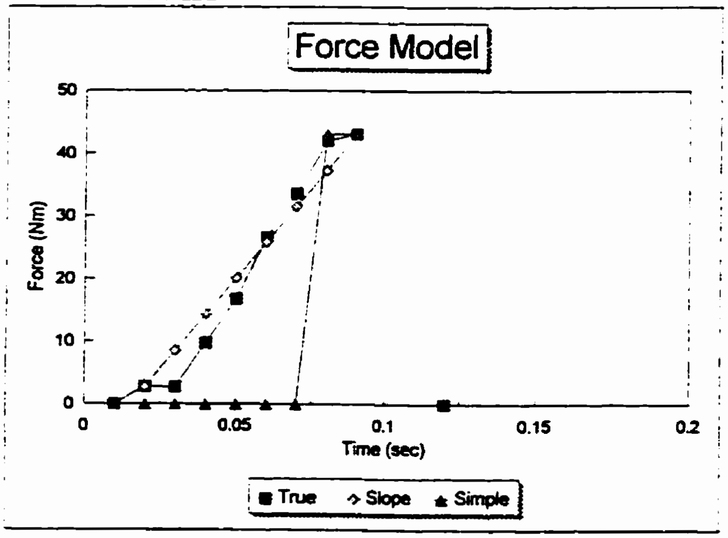
18 kg s8-t18



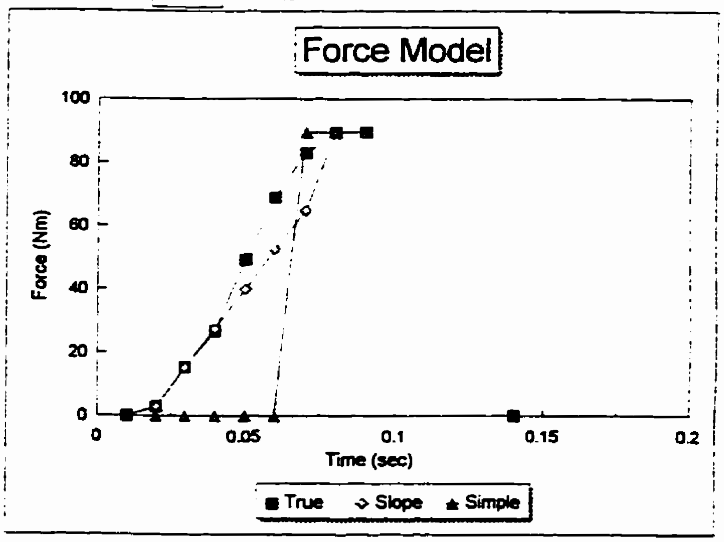
Load Transfer Data
TRUE load transfer
SLOPE estimation of the load transfer force
INSTANT estimation of the load transfer force

Subject 9

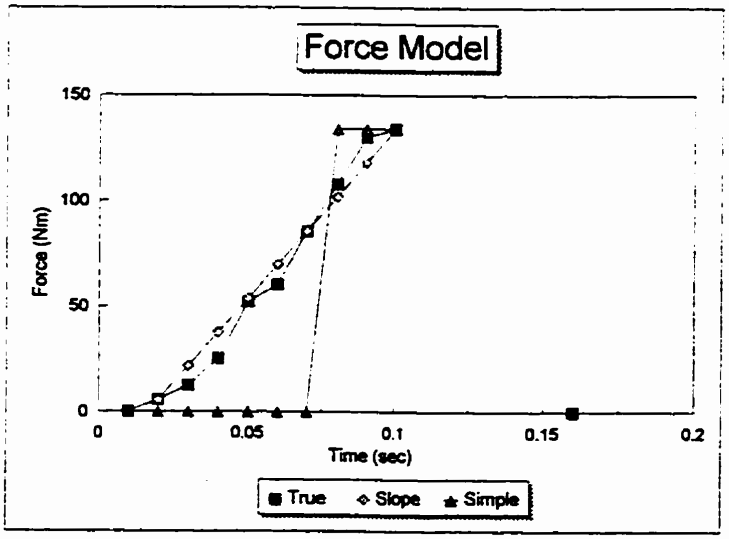
5 kg s9-t13



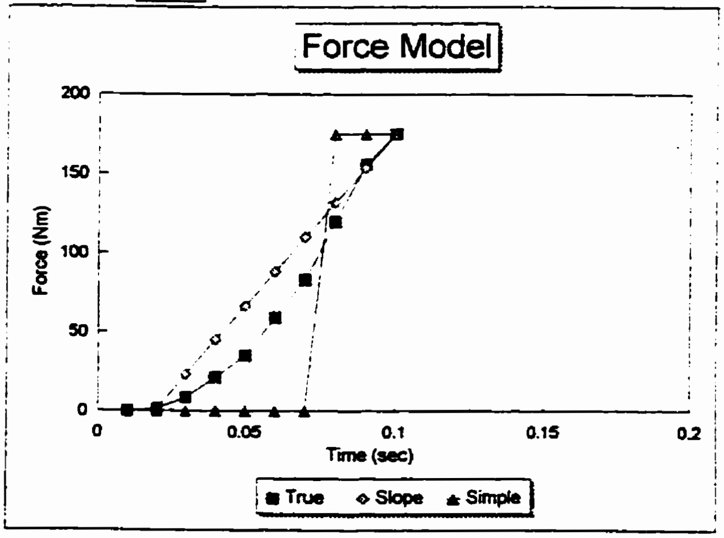
9 kg s9-t3



13 kg s9-t8



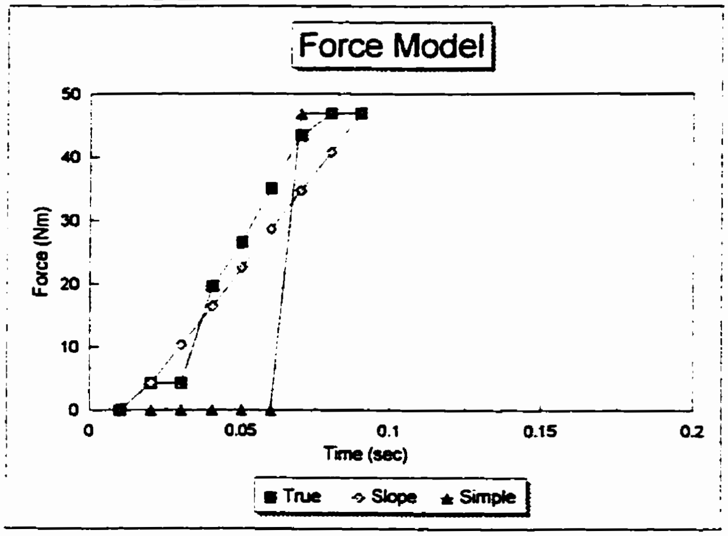
18 kg s9-t18



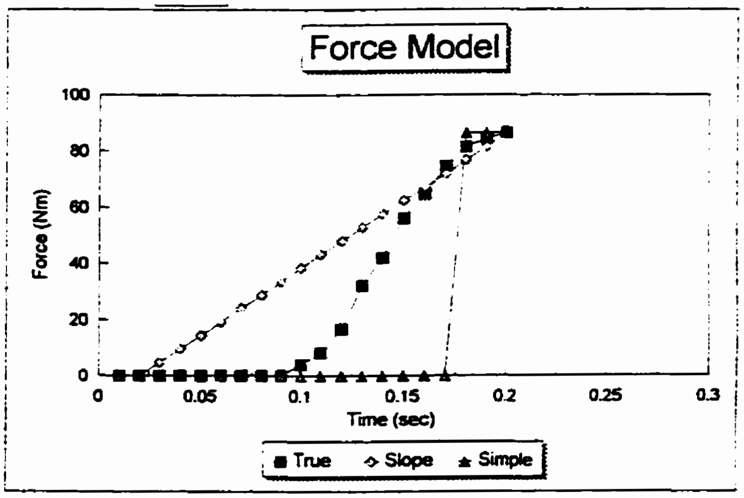
Load Transfer Data
TRUE load transfer
SLOPE estimation of the load transfer force
INSTANT estimation of the load transfer force

Subject 12

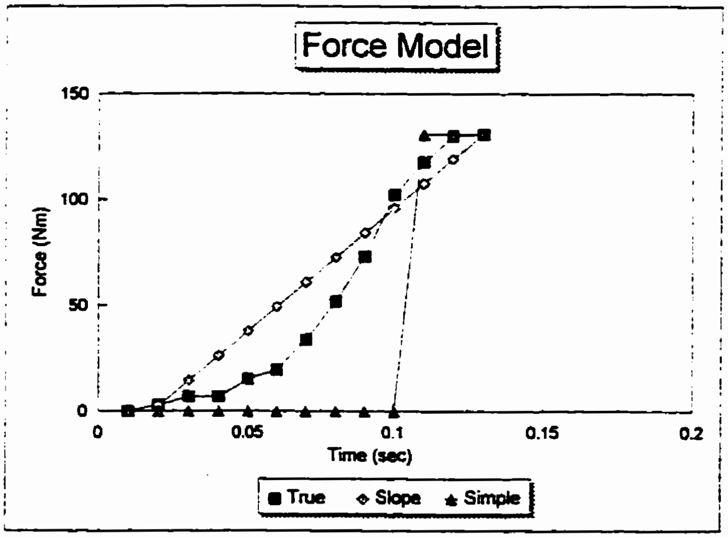
5 kg s12-t13



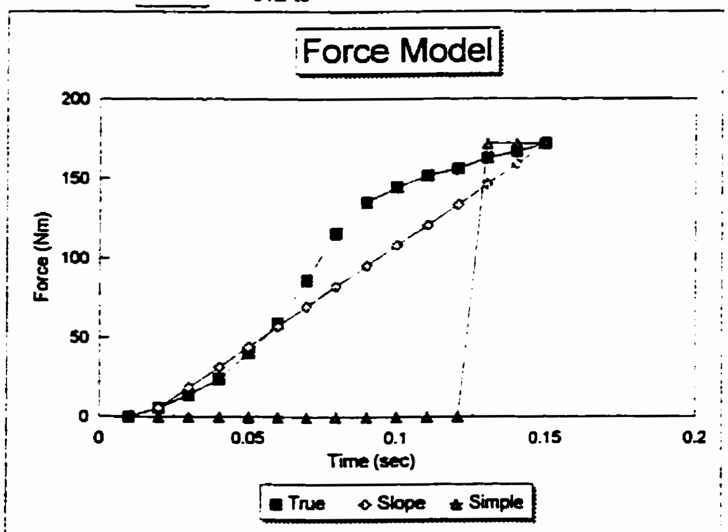
9 kg s12-t8



13 kg s12-t18



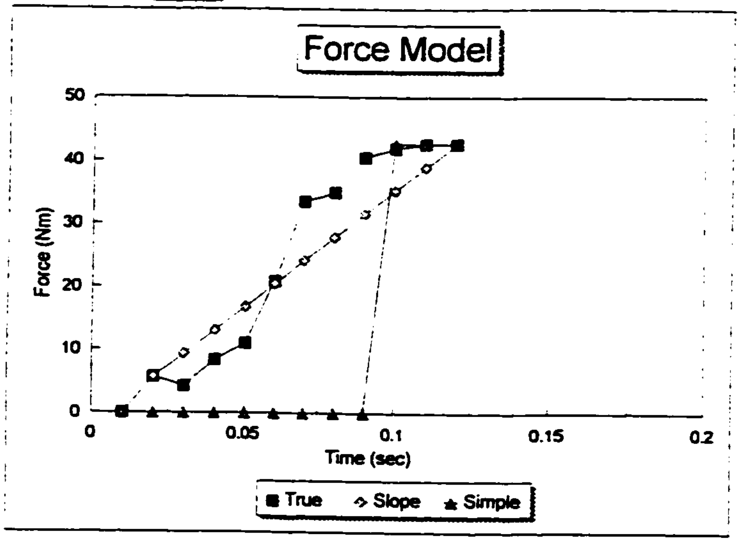
18 kg s12-t3



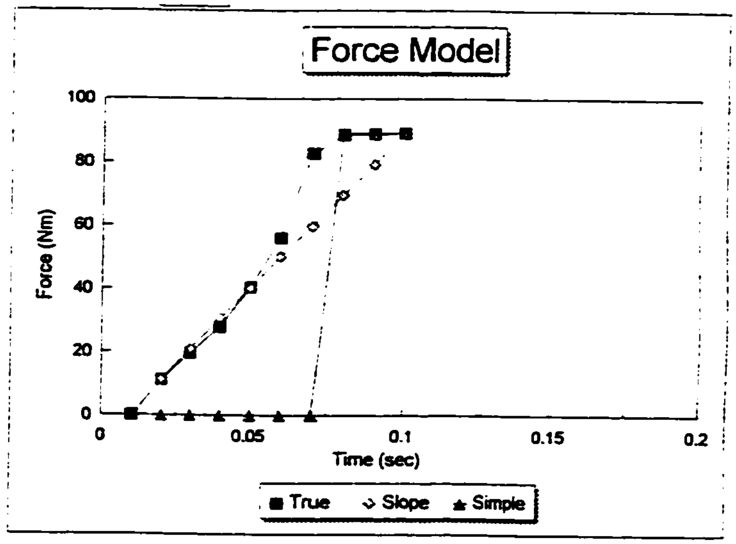
Load Transfer Data
TRUE load transfer
SLOPE estimation of the load transfer force
INSTANT estimation of the load transfer force

Subject 16

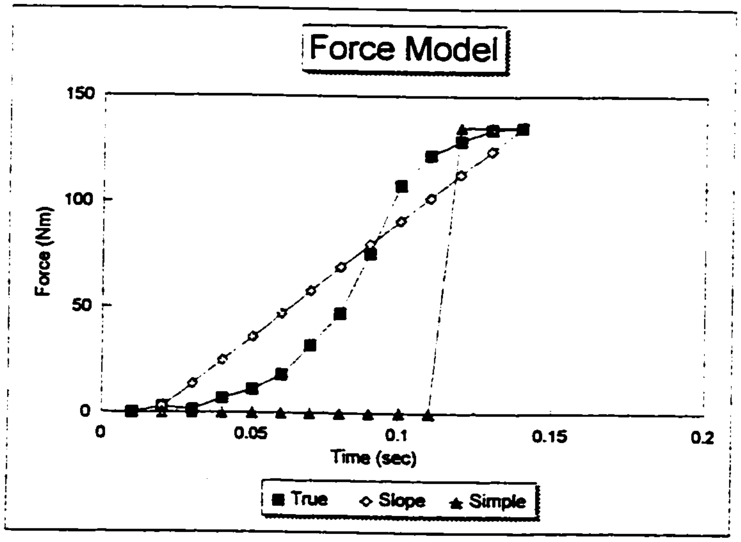
5 kg s16-t3



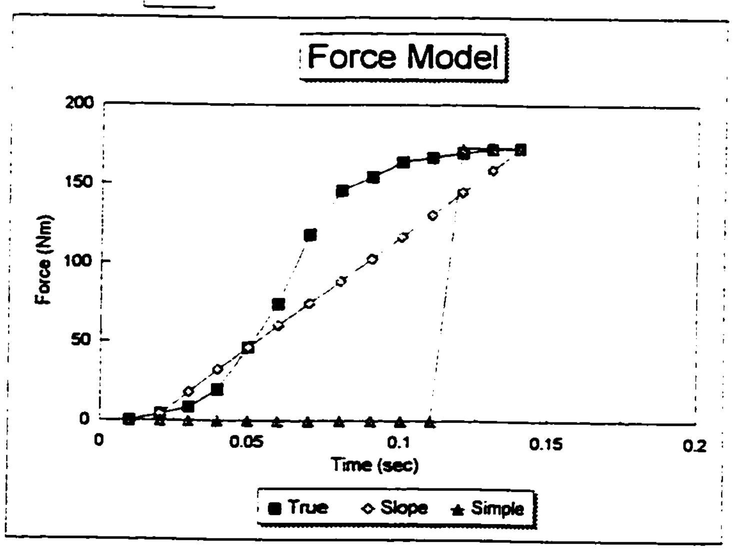
9 kg s16-t18



13 kg s16-t13



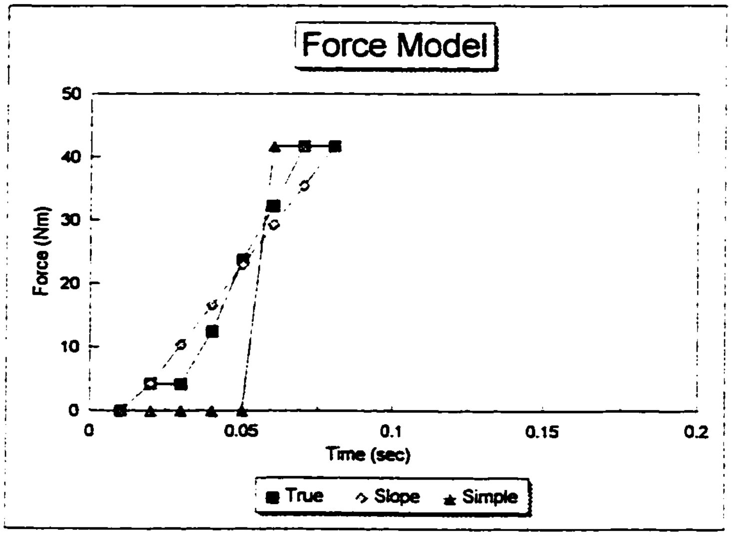
18 kg s16-t8



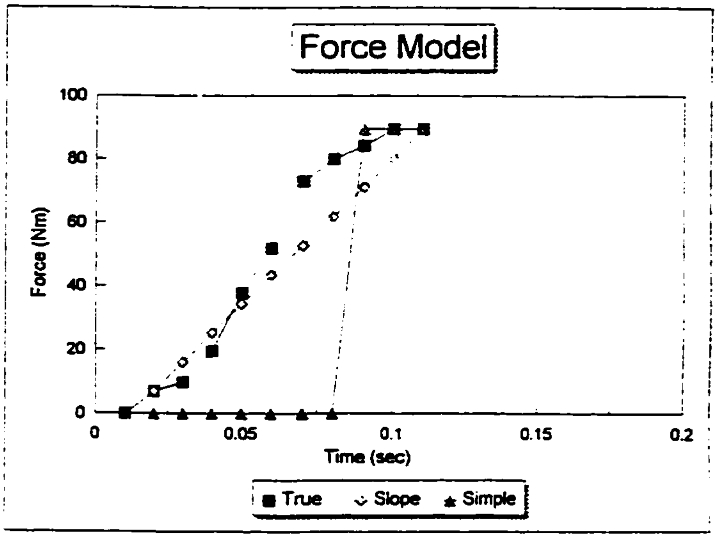
Load Transfer Data
TRUE load transfer
SLOPE estimation of the load transfer force
INSTANT estimation of the load transfer force

Subject 10

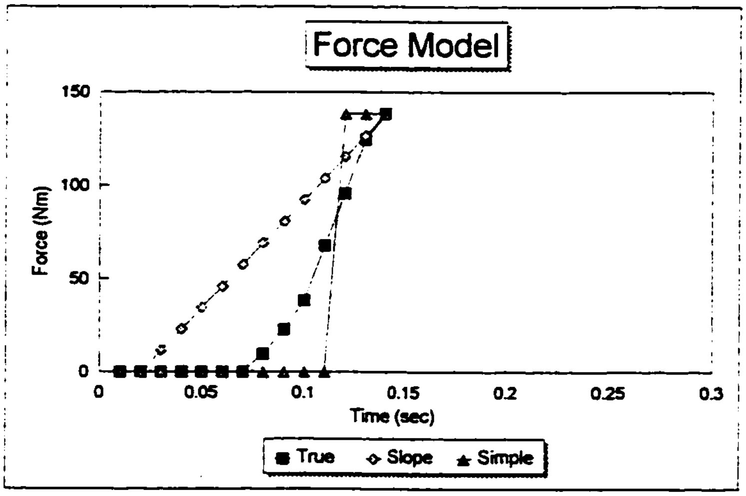
5 kg s10-t18



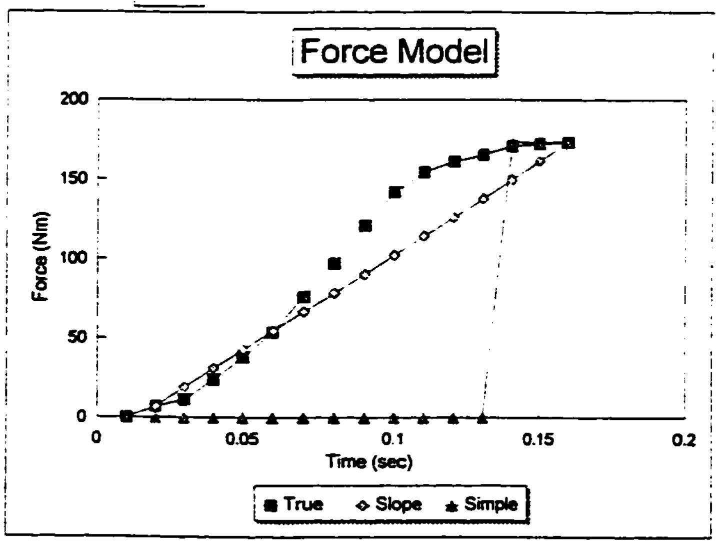
9 kg s10-t8



13 kg s10-t13



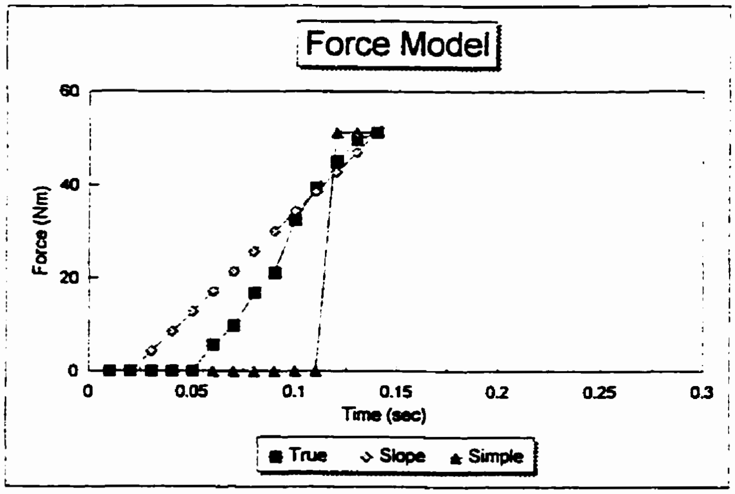
18 kg



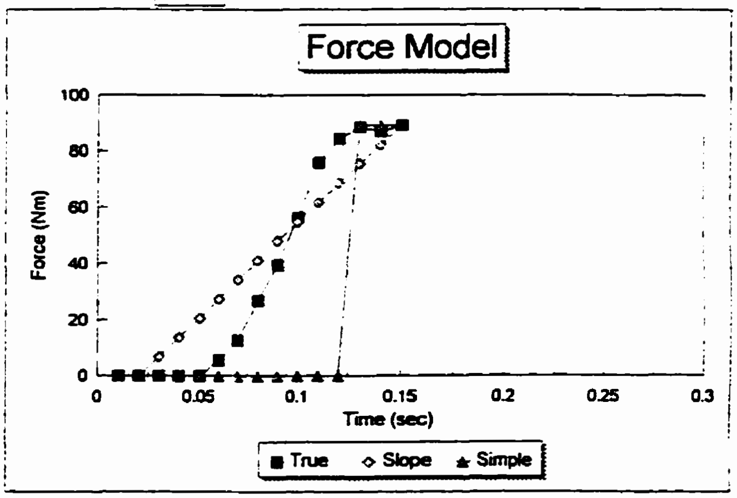
Load Transfer Data
TRUE load transfer
SLOPE estimation of the load transfer force
INSTANT estimation of the load transfer force

Subject 11

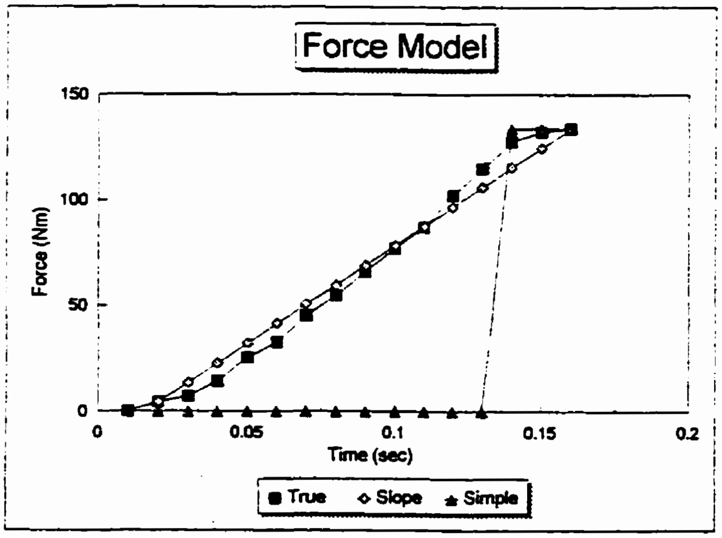
5 kg s11-t8



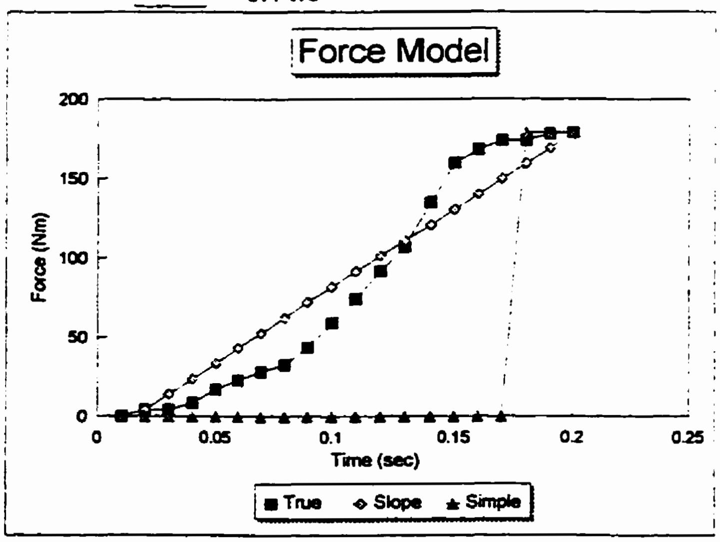
9 kg s11-t13



13 kg s11-t3



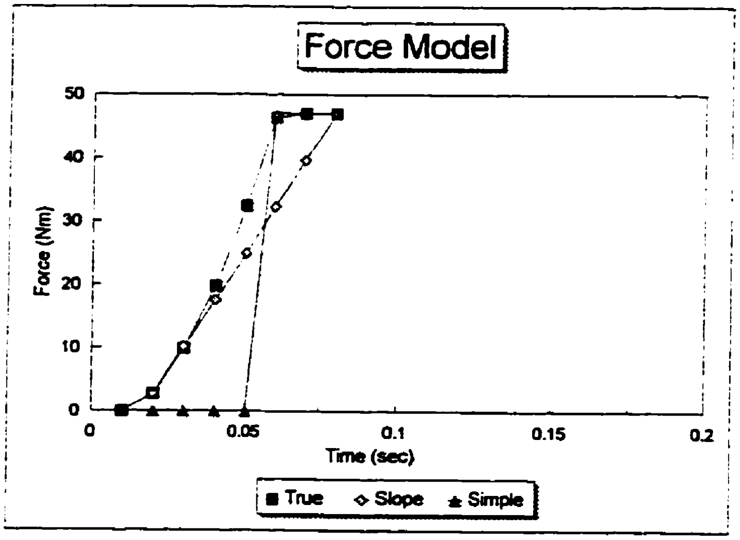
18 kg s11-t18



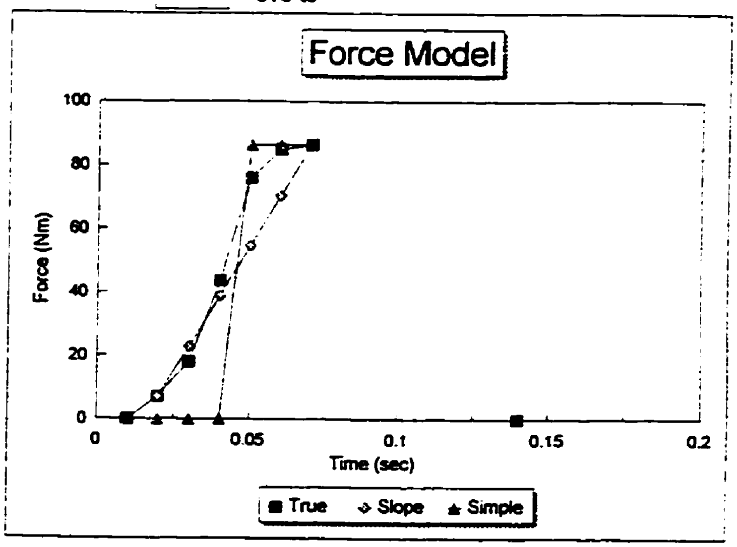
Load Transfer Data
TRUE load transfer
SLOPE estimation of the load transfer force
INSTANT estimation of the load transfer force

Subject 13

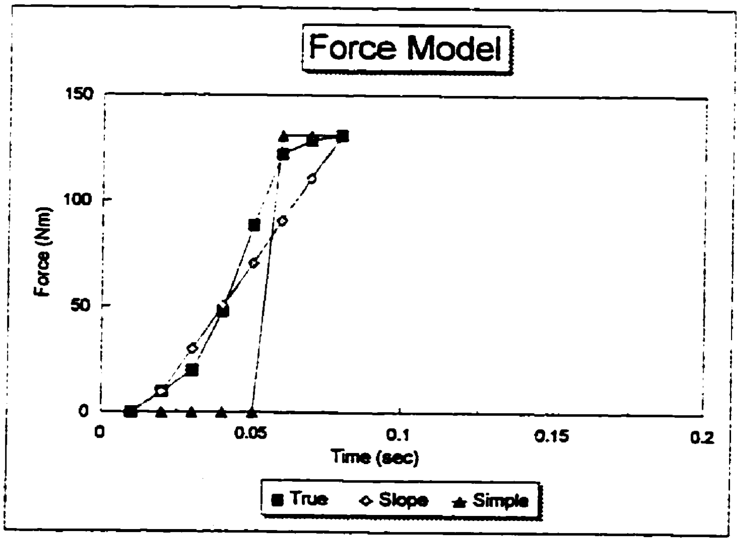
5 kg s13-t8



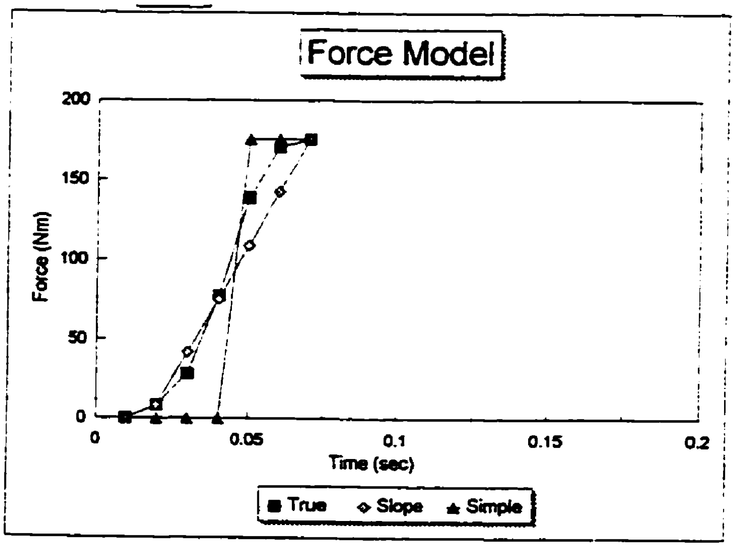
9 kg s13-t3



13 kg s13-t13



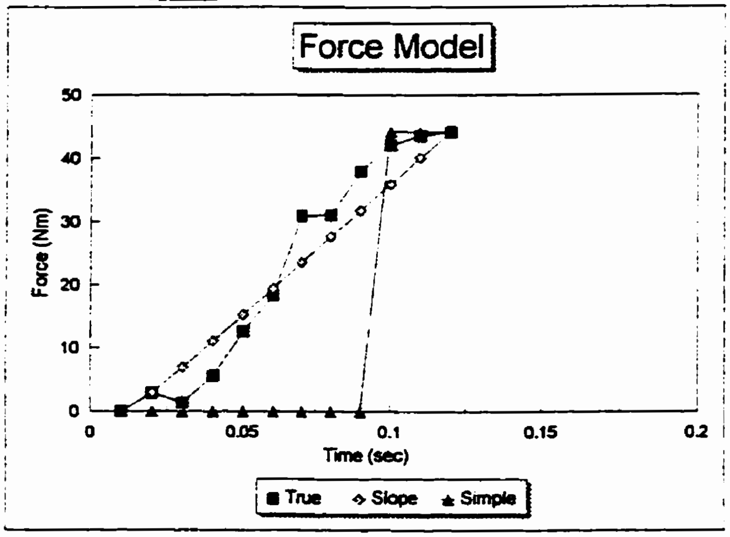
18 kg s13-t18



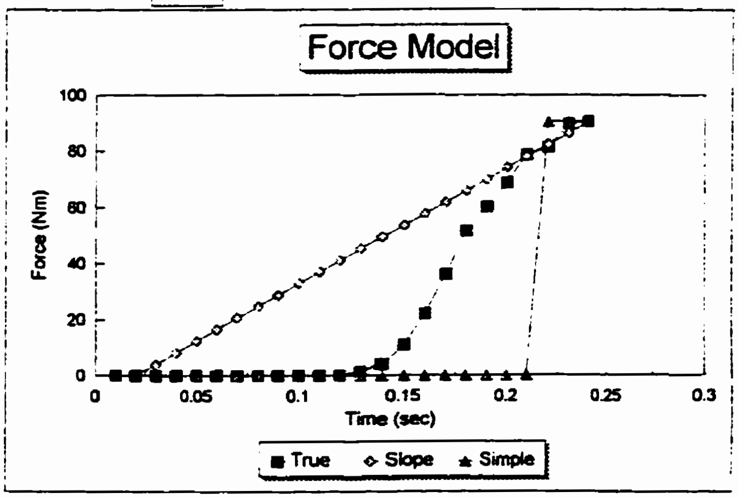
Load Transfer Data
TRUE load transfer
SLOPE estimation of the load transfer force
INSTANT estimation of the load transfer force

Subject 14

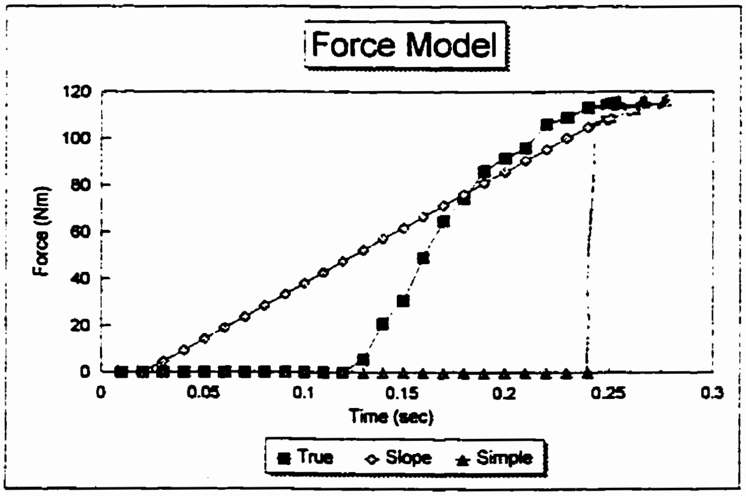
5 kg s14-t3



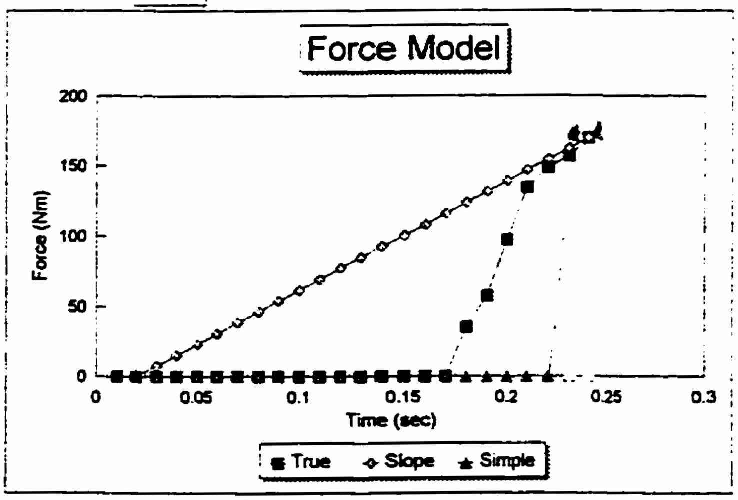
9 kg s14-t18



13 kg s14-t8



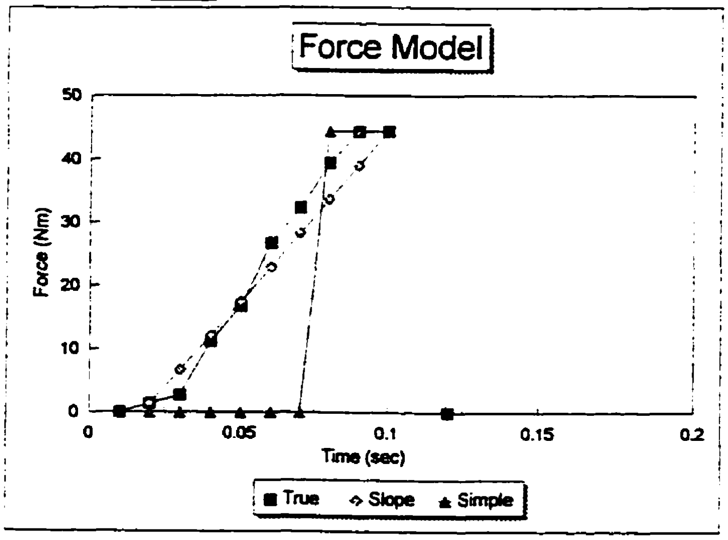
18 kg s14-t13



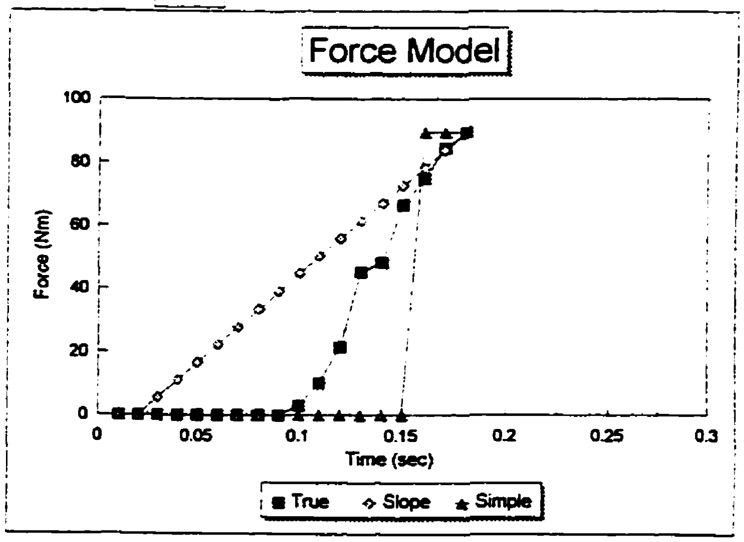
Load Transfer Data
TRUE load transfer
SLOPE estimation of the load transfer force
INSTANT estimation of the load transfer force

Subject 15

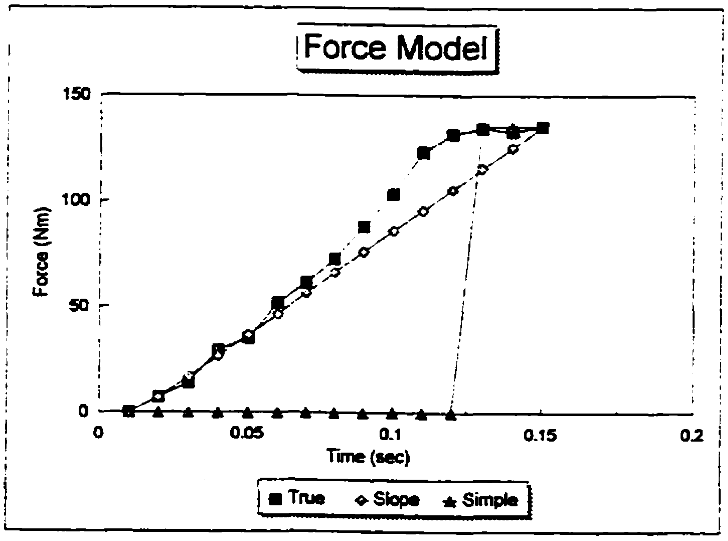
5 kg s15-t3



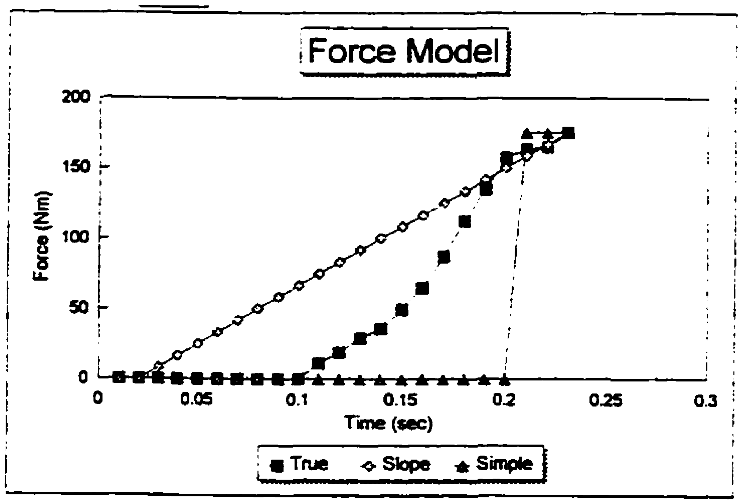
9 kg s15-t18



13 kg s15-t13



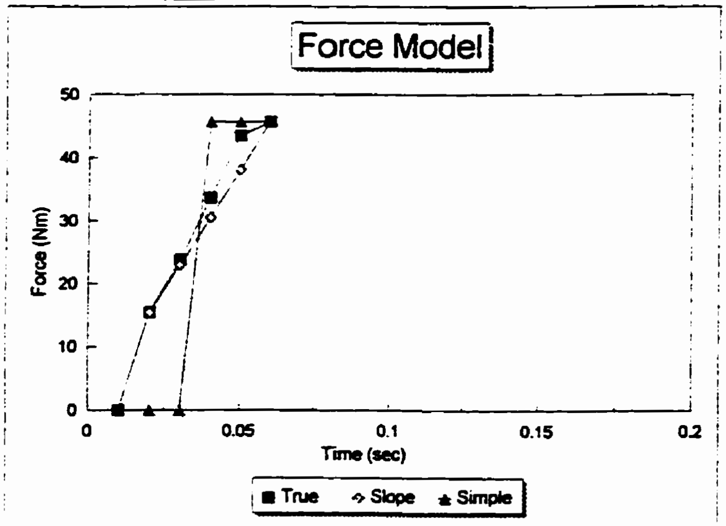
18 kg s15-t8



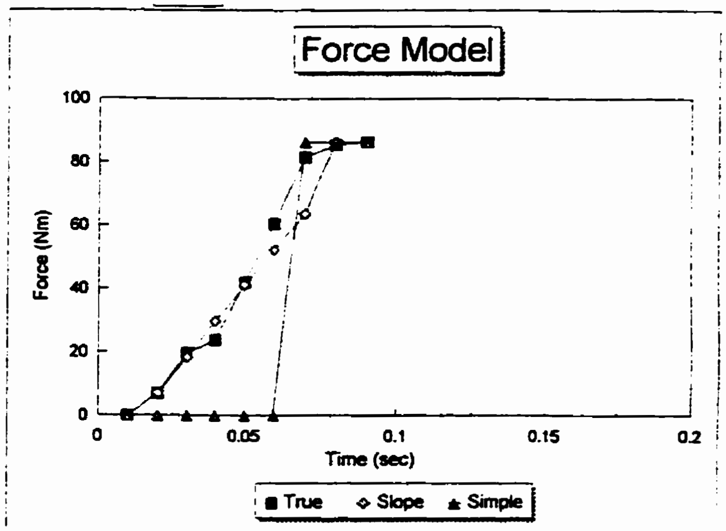
Load Transfer Data
TRUE load transfer
SLOPE estimation of the load transfer force
INSTANT estimation of the load transfer force

Subject 17

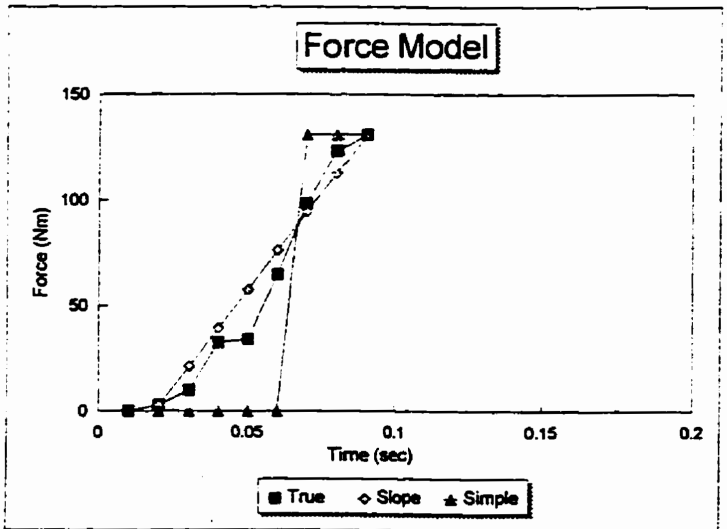
5 kg s17-t8



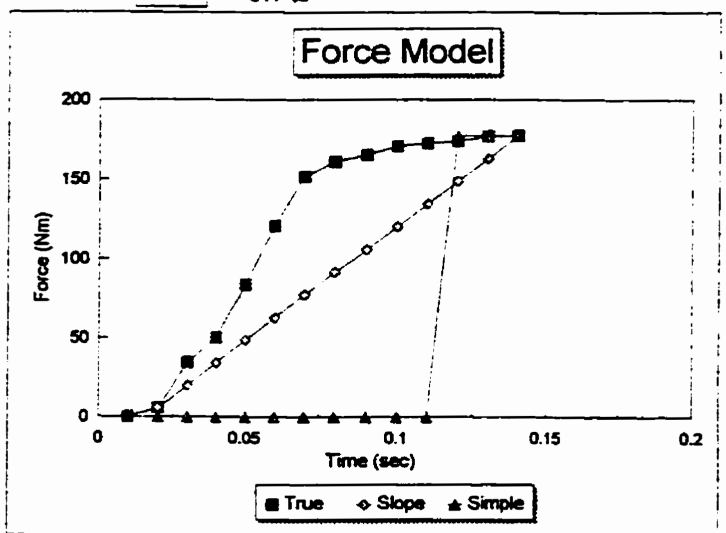
9 kg s17-t13



13 kg s17-t18



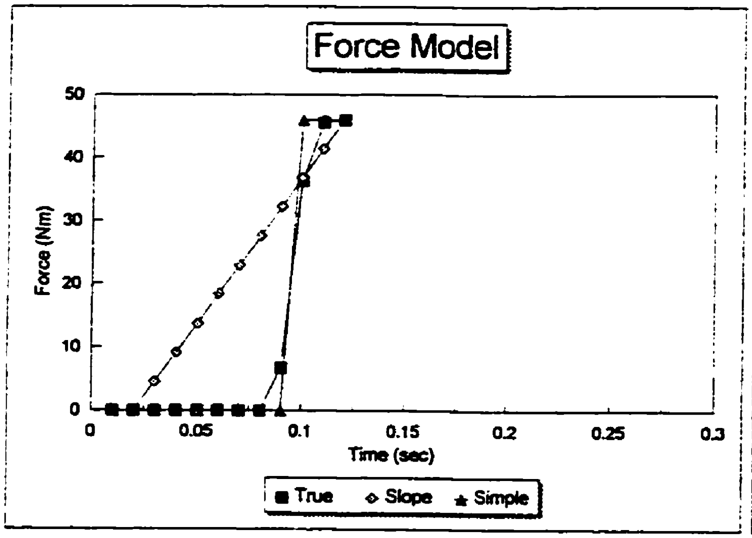
18 kg s17-t3



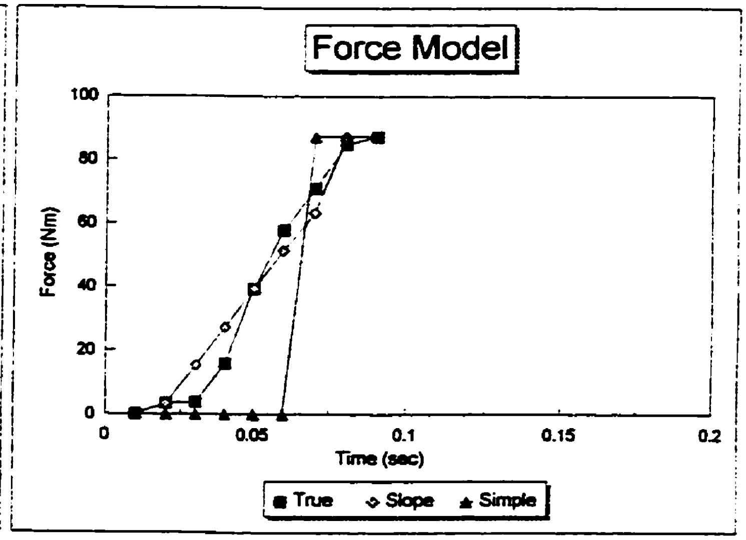
Load Transfer Data
TRUE load transfer
SLOPE estimation of the load transfer force
INSTANT estimation of the load transfer force

Subject 20

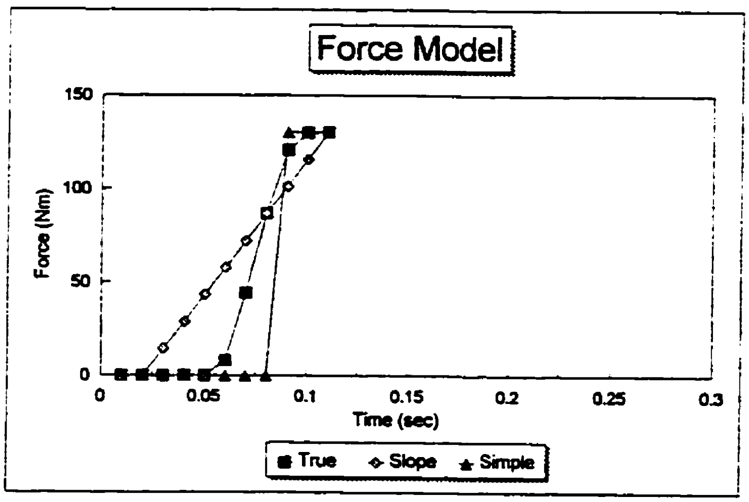
5 kg s20-t13



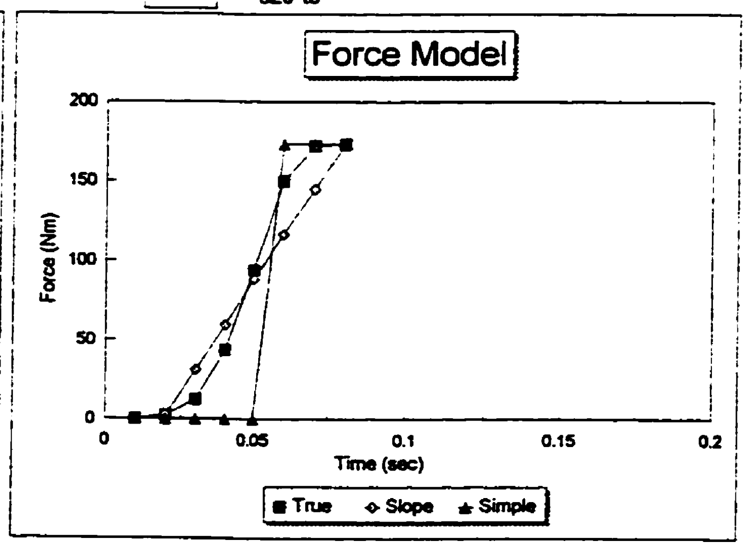
9 kg s20-t18



13 kg s20-t8



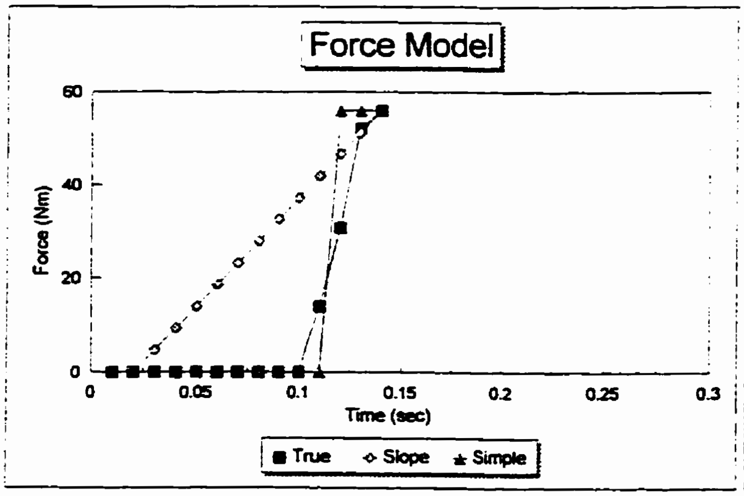
18 kg s20-t3



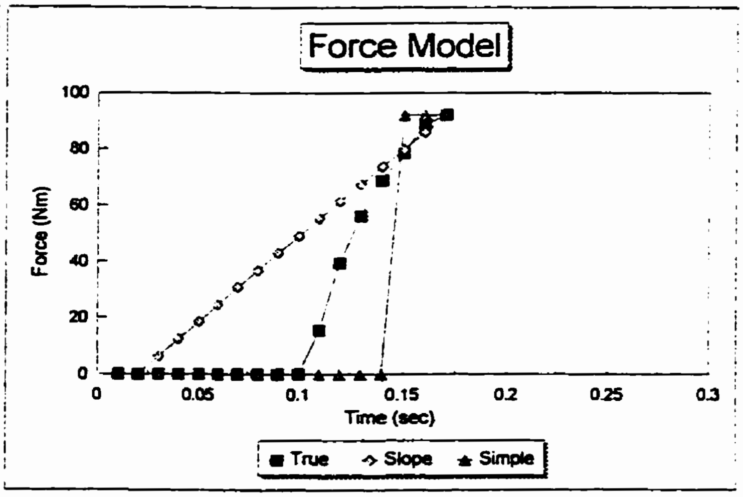
Load Transfer Data
TRUE load transfer
SLOPE estimation of the load transfer force
INSTANT estimation of the load transfer force

Subject 18

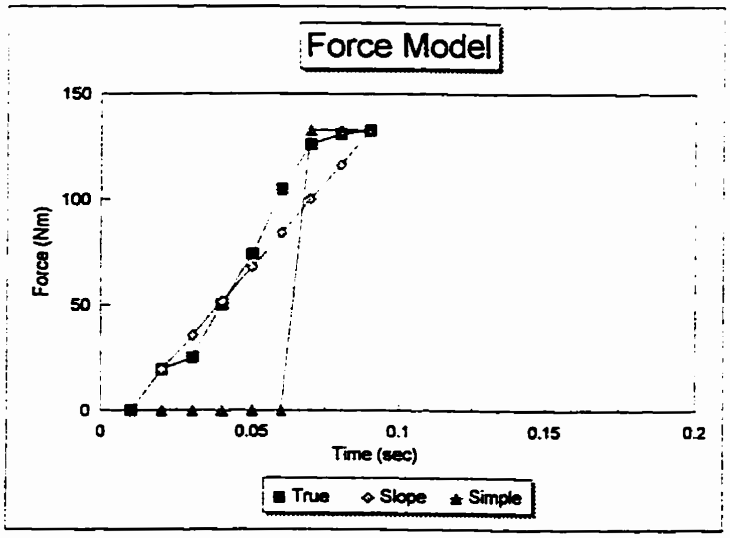
5 kg s18-t3



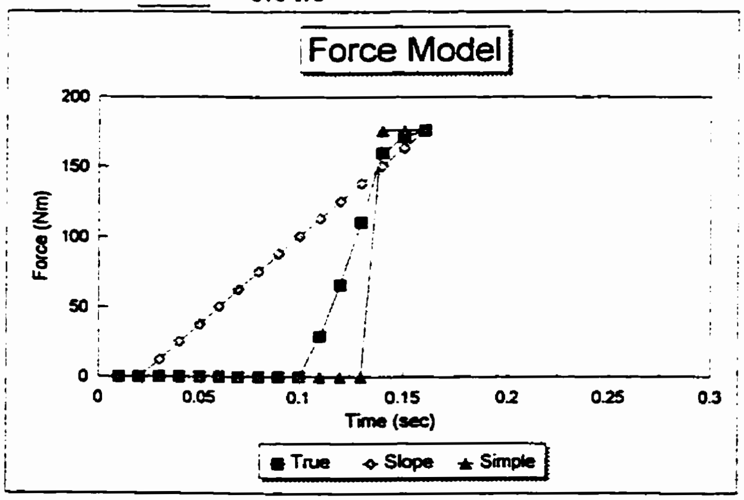
9 kg s18-t18



13 kg s18-t8



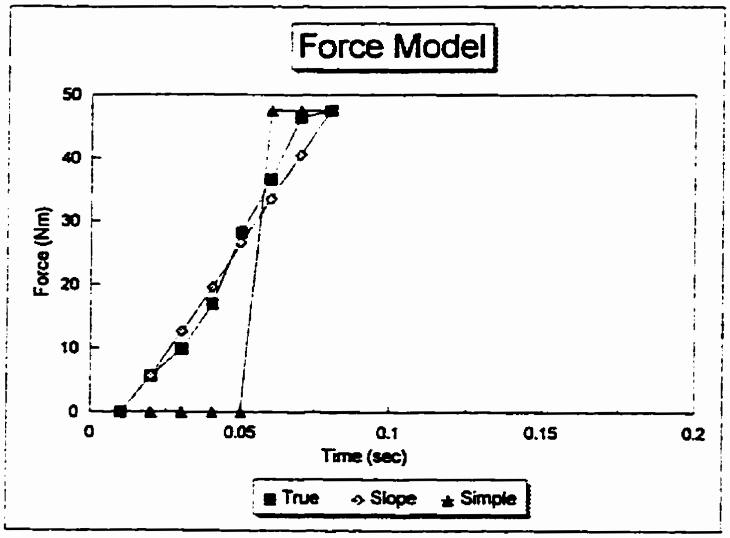
18 kg s18-t13



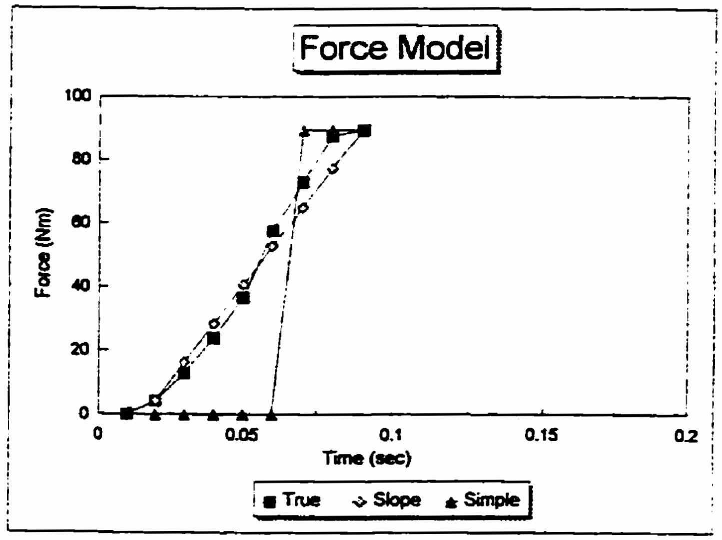
Load Transfer Data
TRUE load transfer
SLOPE estimation of the load transfer force
INSTANT estimation of the load transfer force

Subject 19

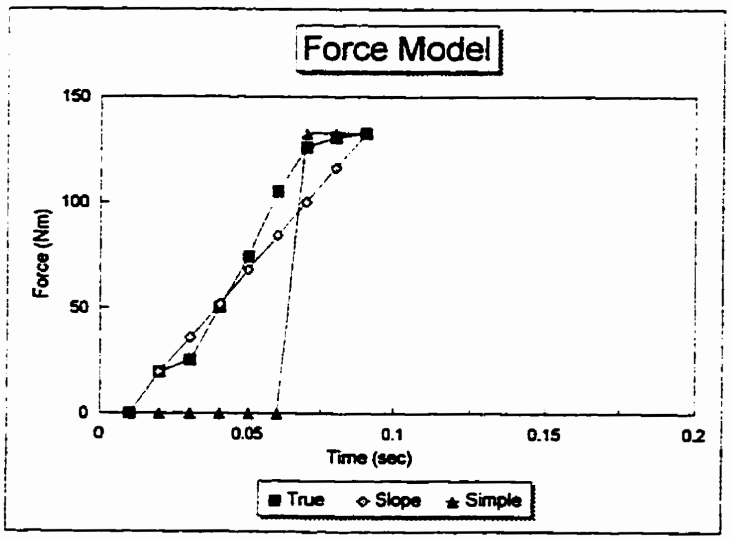
5 kg s19-t13



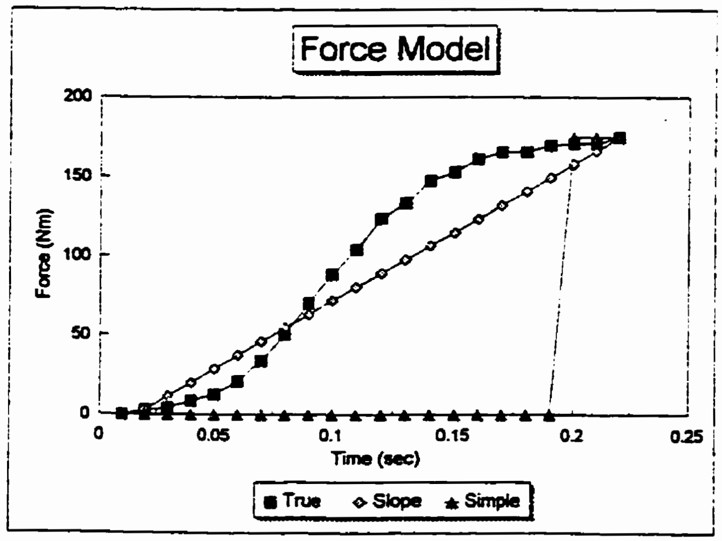
9 kg s19-t3



13 kg s19-t8



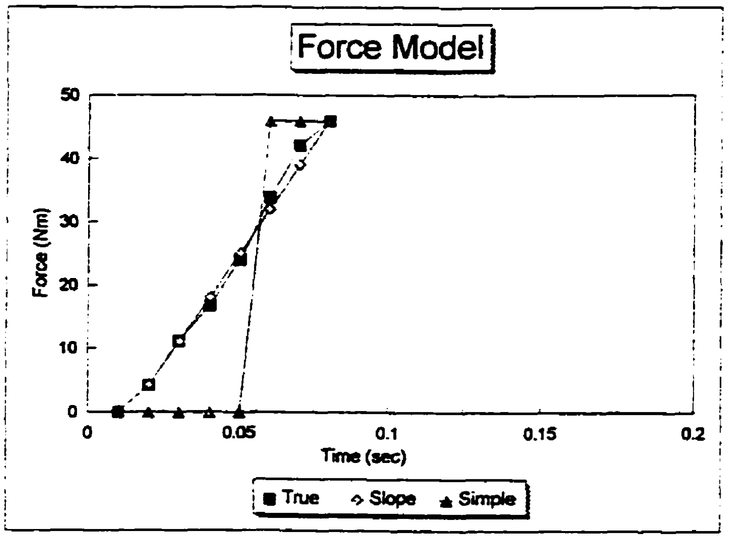
18 kg s19-t18



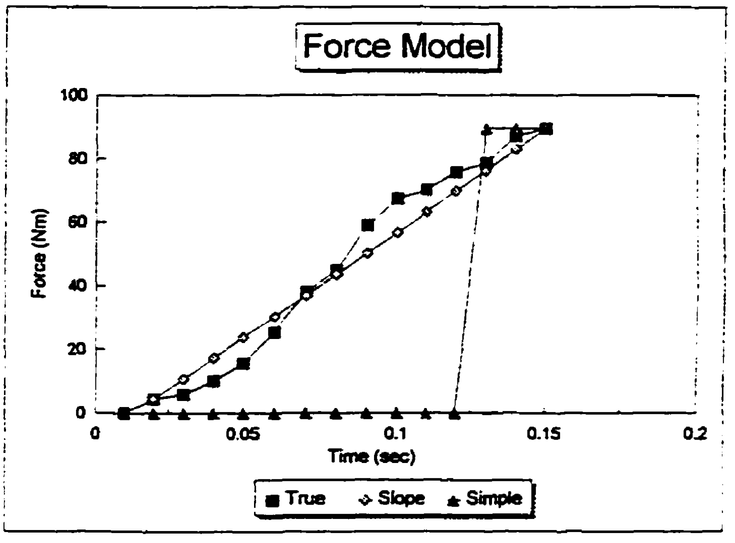
Load Transfer Data
TRUE load transfer
SLOPE estimation of the load transfer force
INSTANT estimation of the load transfer force

Subject 21

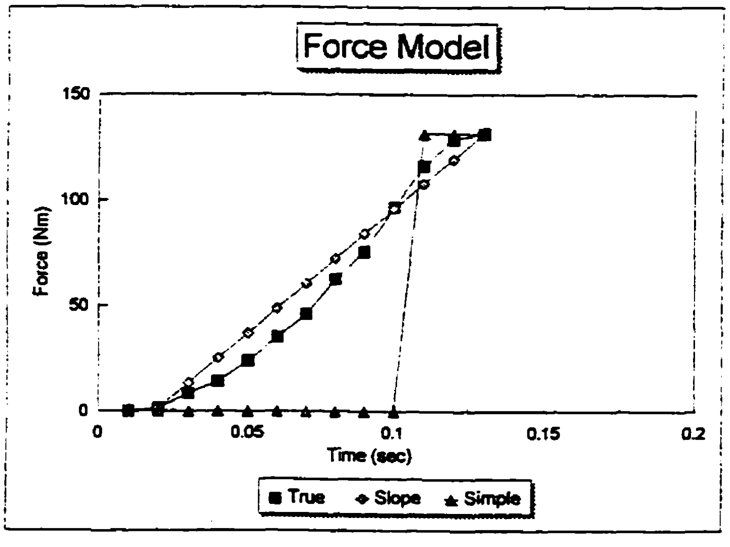
5 kg s21-t18



9 kg s21-t13



13 kg s21-t8



18 kg s21-t3

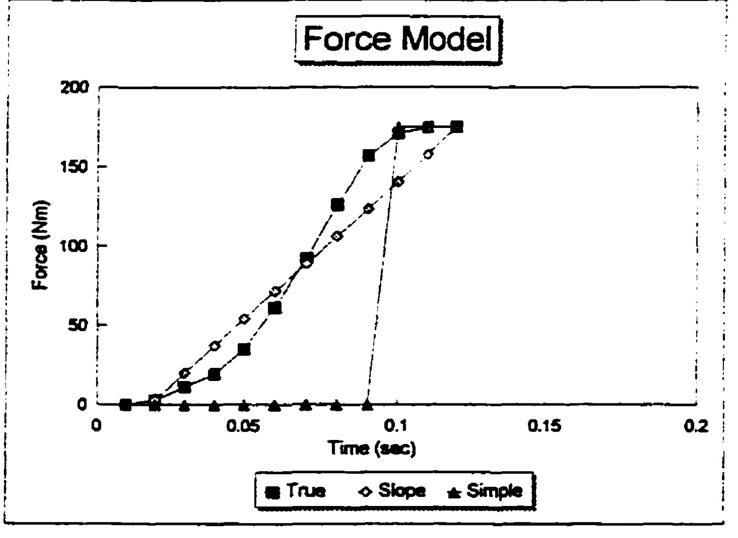
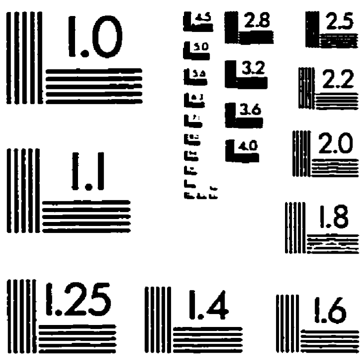
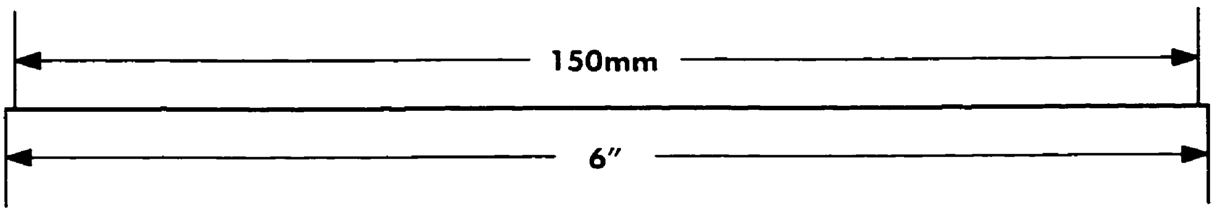


IMAGE EVALUATION TEST TARGET (QA-3)





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