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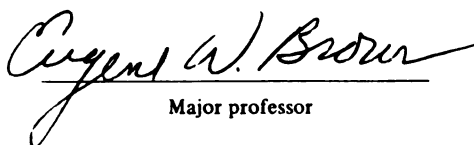
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EVALUATION OF A KINEMATIC MODEL FOR
KINETIC ANALYSIS OF THE DEAD LIFT

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EVALUATION OF A KINEMATIC MODEL FOR
KINETIC ANALYSIS OF THE DEAD LIFT

By

Daniel Michael Gibson

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
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1985

APPROVED: Eugene W. Brown
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ABSTRACT

EVALUATION OF A KINEMATIC MODEL FOR KINETIC ANALYSIS OF THE DEAD LIFT

By

Daniel Michael Gibson

This study tested the concurrent validity of a kinematic model for calculating the vertical joint reaction forces in the right ankle and the intersegmental resultant moments in the right shank during the dead lift. A kinetic model which utilized force platform data was used as a criterion measure. Kinematic data was obtained by filming three college-age, male power lifters, each performing one dead lift. The results of the study revealed that the force and moment values obtained from the kinematic model were not concurrently valid with the values obtained from the kinetic model at the ankle and shank. Individual differences in the symmetry of forces and moments acting on the ankles and shanks were found, and suggested as a possible cause of the lack of concurrent validity. Additional causality resulted from the kinematic model not being responsive to the dynamic changes in the forces and moments occurring throughout the dead lift.

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Mostly, I would like to thank my wife, Lori, and my daughter, Megan, whose help and support made completion of this study possible.

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TABLE OF CONTENTS

	Page
ACKNOWLEDGMENTS	iii
LIST OF TABLES.	vi
LIST OF FIGURES	vii
Chapter	
1. INTRODUCTION	1
Statement of the Problem	3
Need for the Study	4
Limitations of the Study	5
Definition of Terms.	7
2. REVIEW OF RELATED LITERATURE	8
3. PROCEDURES	15
Procedures for Filming	15
Procedures for Obtaining Force Records.	18
Procedures for Analysis of Data.	21
Procedures for Testing the Kinematic Model.	24
Testing symmetry	24
Testing responsiveness	26
4. RESULTS AND DISCUSSION	27
Degree of Smoothing.	27
Concurrent Validity of the Kinematic Model.	28

Chapter	Page
Joint reaction forces	29
Intersegmental resultant moments . . .	29
Evaluation of Symmetry	32
Joint reaction forces	32
Intersegmental resultant moments . . .	33
Effects of asymmetry	36
Evaluating the Dynamics of the Kinematic Model.	39
Vertical joint reaction forces	39
Intersegmental resultant moments . . .	44
5. SUMMARY AND CONCLUSIONS.	49
APPENDIXES.	55
A. THE DEAD LIFT.	56
B. WRITTEN CONSENT FORM	58
C. PERSONAL DATA FORM	60
D. RAW DATA	62
BIBLIOGRAPHY.	69

LIST OF TABLES

Table	Page
1. Summary of the Personal Characteristics of the Subjects	16
2. Distribution of Mass on the Bar	21
3. Mean Differences in Body Segment Orientations Found Through Repeated Digitization	28
4. Comparison of Kinematic and Kinetic Models for Calculating Vertical Joint Reaction Forces of the Right Ankle	30
5. Comparison of Kinematic and Kinetic Models for Calculating Intersegmental Resultant Moments of the Right Shank. . .	31
6. Vertical Joint Reaction Force Differences Experienced by the Dominant and Non-dominant Ankles.	34
7. Intersegmental Resultant Moment Differences Experienced by the Dominant and Non-dominant Shanks.	35
8. Comparison of Mean Differences Between Kinematic and Kinetic Models for Vertical Joint Reaction Forces.	37
9. Comparison of Mean Differences Between Kinematic and Kinetic Models for Intersegmental Resultant Moments	38
10. Correlations of Vertical Joint Reaction Force and Intersegmental Resultant Moment Values Between the Kinematic and Kinetic Models.	43

LIST OF FIGURES

Figure	Page
1. Values used in calculating the joint reaction forces and intersegmental resultant moments of a sample segment	10
2. Experimental setting.	17
3. Vertical joint reaction forces in the ankles of subject 1.	40
4. Vertical joint reaction forces in the ankles of subject 2...	41
5. Vertical joint reaction forces in the ankles of subject 3.	42
6. Intersegmental resultant moments in the shanks of subject 1.	45
7. Intersegmental resultant moments in the shanks of subject 2.	46
8. Intersegmental resultant moments in the shanks of subject 3.	47

Chapter 1

INTRODUCTION

Researchers, who have studied the dynamics of weightlifting, have calculated the joint reaction forces and intersegmental resultant moments solely from kinematic data. Crowninshield and Brand (1981) summarized methods of calculating these parameters through the simultaneous collection of kinematic data obtained from cinematographic images and kinetic data obtained from ground reaction forces via a force platform.

There are two situations in which joint reaction forces and intersegmental resultant moments must be determined indirectly from acceleration parameters derived from kinematic data. These are (a) a movement to be analyzed occurs during competition in which a force platform is not part of the setting, and (b) the surface area of a standard force platform cannot accommodate the entire movement.

Several researchers have developed kinematic models (see Definition of Terms) for the analysis of the kinematics and kinetics of powerlifting (see Definition of Terms). G. B. Ariel (1974); McLaughlin, Lardner, and Dillman (1978); and Hay, Andrews, and Vaughan (1980) have all developed kinematic models for the analysis of the parallel squat. Brown and Abani (in press) have developed a similar

model for analysis of the dead lift. In all of these studies, the joint reaction forces and intersegmental resultant moments were calculated solely from kinematic data obtained from cinematographic images.

Three assumptions regarding symmetry (see Definition of Terms) were made in the development of each of these kinematic models. First, one half of the force attributed to the mass and acceleration of the weighted bar acted equally on each side of the body. Second, accelerations of segments on one side of the body were symmetric to movements by the opposite side. Third, all movement occurred in a sagittal plane. These assumptions were necessary in order for these authors to determine kinetic parameters from two-dimensional cinematographic data.

Evidence, however, suggests that asymmetry between the right and left sides of the body may exist in both posture and strength. Carlsoo (1964) found, that when standing at rest, ten of fifteen subjects put more weight on their right leg than their left leg. Galloway (1973) found that the dominant leg in athletes is an average of 15.1 percent stronger than the non-dominant leg. White (1968) found that there was a significant difference in strength between the right and left sides of the body in wrist dorsiflexion and shoulder flexion. Thus, while the assumption of symmetry of movement is necessary for

the development of a two-dimensional kinematic model, evidence suggests that asymmetry of strength and posture exists between the dominant and non-dominant sides of the body. It is not known if asymmetry of posture and strength results in asymmetry of utilization during powerlifting. It is also not known if this possible asymmetry of utilization invalidates the two-dimensional kinematic model.

Statement of the Problem

This study was designed to test the concurrent validity of a kinematic model (Brown and Abani, in press) for analysis of the dead lift utilizing a kinetic model, which was assumed to be valid, as a criterion measure. The accuracy of the kinematic model for calculating vertical joint reaction forces of the ankle and intersegmental resultant moments of the shank was tested. The test was conducted by comparing the force and moment values obtained from the kinematic model with the same parameters obtained from the kinetic model (see Definition of Terms) which utilized ground reaction force data via two force platforms. With this as a basis, four questions were pursued:

1. Does the kinematic model result in a concurrently valid method for determining vertical joint reaction force and intersegmental resultant moment values at the ankle

and shank, respectively, when compared to the kinetic model?

2. Does asymmetry of utilization in the dominant and non-dominant sides of the body exist during the dead lift?

3. If asymmetry exists, what effect does it have on the force and moment values obtained from the kinematic model?

4. Is the kinematic model responsive to the dynamic changes in the forces and moments occurring throughout the lift?

Need for the Study

In order to calculate joint reaction forces and intersegmental resultant moments, it is desirable to obtain both kinematic data from cinematographic images and ground reaction force data from a force platform. Practically, this is not always possible. If the movement occurs during an athletic competition, or if the movement cannot be confined to a standard force platform, the ground reaction force data will not be available. In these instances, the joint reaction forces and intersegmental resultant moments have to be calculated solely from kinematic and anthropometric data. The accuracy of these procedures needs to be verified. Assumptions regarding symmetry are necessary to develop kinematic models used to find the joint reaction forces and intersegmental resultant moments. The validity of these assumptions

needs to be established. If the procedure of finding joint reaction forces and intersegmental resultant moments from kinematic and anthropometric data can be verified, future research, in which force platform data is not obtainable, may be conducted with greater confidence.

Limitations of the Study

The amount of data available for comparison of the kinematic and kinetic models was limited by the number of subjects used in the study, and the digitization process, in which every tenth frame of film was digitized. Digitizing every tenth frame was deemed necessary so that the movement of the projected image of the body parts was greater than the inherent error in the digitization process.

This study was limited to testing the concurrent validity of the kinematic model with the kinetic model utilized as a criterion measure. In order to determine the true accuracy of the kinematic model, the actual values for the joint reaction forces and intersegmental resultant moments are required. Although it is not possible and/or permissible to use human subjects to obtain the actual values for these parameters, it was assumed that the kinetic model produced accurate approximations, and was therefore, used as the criterion measure.

The concurrent validity of the kinematic model for

calculating the vertical joint reaction forces and intersegmental resultant moments was tested only at the ankle and shank. Calculations of force and moment values through the kinematic model originate at the weighted bar, and proceed through a series of links representing the body segments. The forces and moments calculated for the segments more proximal to the bar have a direct influence on the force and moment values calculated for the more distal body segments. The ankle and shank are the most distal joint and segment about which these calculations are made, and are therefore, subject to the greatest perturbations, due to the sequential interactions between segments. Exclusive of the foot, the ankle and shank are also the most proximal joint and segment to the force platform. Therefore, the most accurate calculation of force and moment values through the kinetic model likely occurs at the ankle and shank, respectively. Since the kinetic model was the criterion measure for testing the concurrent validity of the kinematic model, the most accurate possible values from the kinetic model were required. If the kinematic model was found concurrently valid with the kinetic model at the ankle and shank, it would be assumed that force and moment values from the two models at the other joints and segments are equipollent, because they are based on the same mass and kinematic data.

Definition of Terms

Kinematic model: A process for calculating vertical joint reaction forces and intersegmental resultant moments from a description of movement, subject mass parameter data, and the mass of a weighted bar.

Kinetic model: A process for calculating vertical joint reaction forces and intersegmental resultant moments from subject mass parameters and vertical ground reaction force platform data. For this study, this model was used as a criterion measure for testing the concurrent validity of the kinematic model.

Symmetry: The bilateral similarity of kinetic and kinematic parameters, within a subject, during the performance of the dead lift.

Powerlifting: A form of weightlifting consisting of three individual lifts- the dead lift, the bench press, and the parallel squat.

Static model: A process for calculating vertical joint reaction forces and intersegmental resultant moments utilizing a description of movement, subject mass parameter data, and the mass of a weighted bar, assuming constant linear and angular velocity. This results in constant vertical joint reaction forces and intersegmental resultant moments which fluctuate only as a result of changes in body segment orientations.

Chapter 2

REVIEW OF RELATED LITERATURE

In the past, two general approaches have been used in obtaining joint reaction forces and intersegmental resultant moments in human movement. Crowminshield and Brand (1981) have summarized methods for calculating these parameters. The first approach is based solely on kinematic and anthropometric data, and the second approach additionally utilizes external forces imposed upon the human. Often the external forces have been measured by a force platform. Human movement, however, does not always occur on, or cannot always be limited to, movement on a force platform. Brown and Abani (1984) state that,

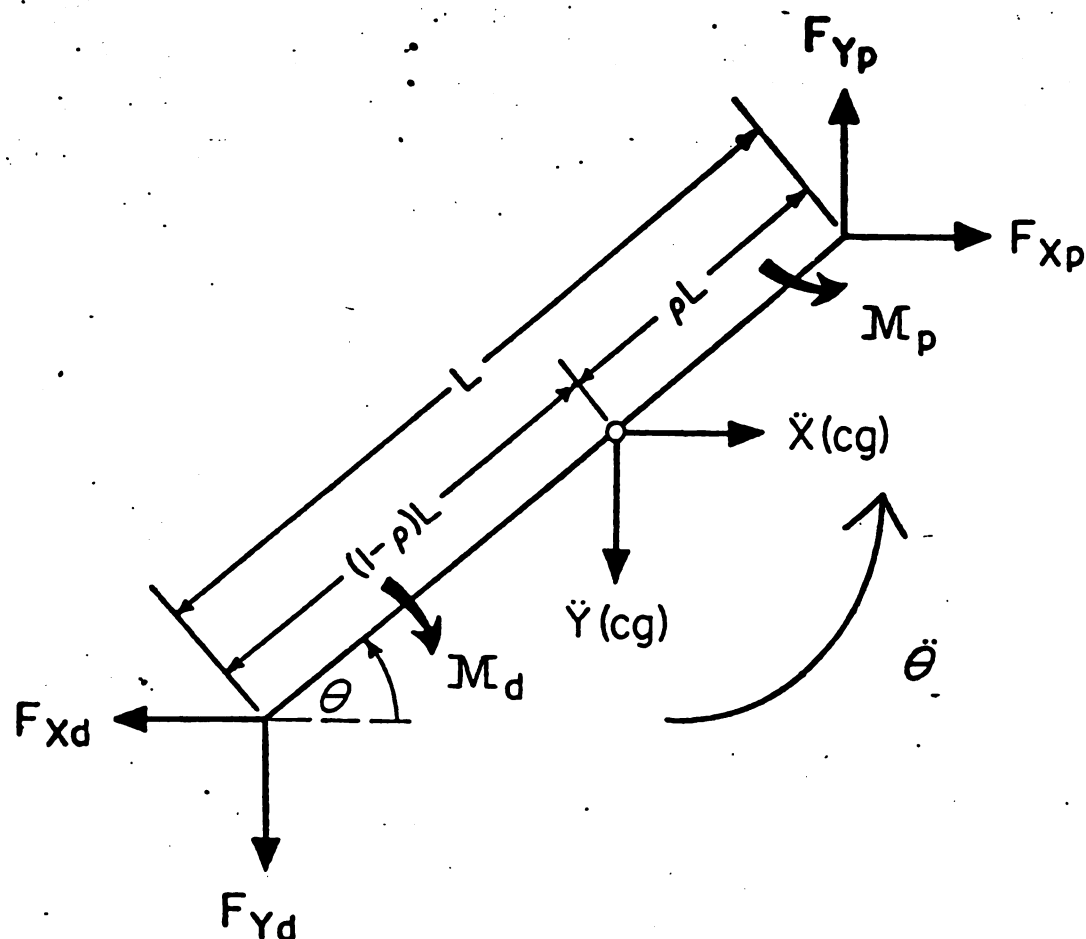
If data collection occurs during a competition, joint reaction forces and intersegmental resultant moments must be determined solely from a model based upon the kinematic characteristics of the body segment masses.

A two-dimensional kinematic model for calculating the joint reaction forces and intersegmental resultant moments in the sagittal plane, experienced during the dead lift, has been developed by Brown and Abani (in press). This model utilizes the mass of the weighted bar, human anthropometric data, and positional data, obtained through cinematography, to calculate the forces and moments acting on the joints and segments. In the

design of the kinematic model the body was divided into a series of rigid segments linked at the joints. The links included the forearm, arm, a massless segment joining the arm and trunk, trunk, head, thigh, and shank. Linear accelerations were determined from angular position, velocity, and acceleration values that were obtained from the location of the end points of each segment.

In their model, the following values were used when calculating the joint reaction forces and intersegmental resultant moments occurring in each joint and segment: (a) the gravitational force, (b) the joint reaction force from the previous joint, (c) the intersegmental resultant moment from the previous segment, (d) the angular and linear accelerations of the segment, (e) the location of the center of mass of each segment, and (f) the orientation of the body segment (Figure 1).

The calculation of joint reaction forces began at the wrist and proceeded sequentially to the elbow, shoulder, neck, hip, knee, and ankle, while the calculation of the intersegmental resultant moments began at the forearm and proceeded sequentially to the arm, head, trunk, thigh, and shank. The hand was assumed to be a part of the weighted bar. Therefore, the calculation of force and moment parameters, for a particular joint or segment, depended not only on the positional and anthropometric



M	Torque (Nm)	X	Horizontal position (m) or direction
F	Force (N)	X-double-dot	Horizontal acceleration (m/s ²)
L	Segment length (m)	Y	Vertical position (m) or direction
p	Proximal end of segment	Y-double-dot	Vertical acceleration (m/s ²)
d	Distal end of segment	theta	Angular position (rad)
rho	Percent of segment length to center of gravity	theta-double-dot	Angular acceleration (rad/s ²)
o	Location of center of gravity (cg)		

Figure 1. Values used in calculating the joint reaction forces and intersegmental resultant moments of a sample segment.

data for that joint or segment, but also the force and moment values of the previous joint and segment.

G. B. Ariel (1974) developed a model for the analysis of the parallel squat. His kinematic model was designed to calculate the joint reaction forces on the knee and intersegmental resultant moments acting on the thigh during a deep knee bend exercise with a heavy load.

Hay, Andrews, and Vaughan (1980) have also developed a kinematic model for the analysis of the parallel squat. They developed a three segment model utilizing the shank, thigh, and trunk. This model was used to determine what influence an external load had on the moments experienced during the performance of the parallel squat.

McLaughlin, Lardner, and Dillman (1978) have developed another kinematic model for analysis of the parallel squat. Their model, which also utilized the shank, thigh, and trunk as segments, was used to analyze form during the performance of the parallel squat. They state that two assumptions must be made in the development of the kinematic model used to analyze the parallel squat. Their assumptions, based on symmetry of the right and left side of the body, are that, "...the measurements were of the left side of the body and were assumed representative of movements by the opposite side," and, "...half the weight of the bar was utilized respectively for each subject in the equations

of motion for the left side of the body."

Evidence, however, suggests that some body asymmetry exists. Carlsoo (1964) found asymmetry of posture, stating that, "When standing in a rest position ten of fifteen subjects put more weight on the right foot than the left while the remaining five put more weight on the left." Carlsoo used two force platforms to complete his study, but did not state his results quantitatively, so it is not known if the differences were statistically significant. White (1968) found that strength in some muscle groups was not symmetric between the right and left sides of the body. Cable tension was used to test the strength of various muscle groups of the two sides of the body. Although no significant differences were found between the right and left sides in elbow, knee, and hip flexion, significant differences were found in wrist dorsiflexion and shoulder flexion between the two sides of the body. The correlation coefficient of wrist dorsiflexion between the right and left sides was .585, while the correlation coefficient of shoulder flexion between the two sides was .673. Galloway (1973), completing a study of leg strength patterns as they relate to future muscle injuries, determined that the dominant leg of the athletes studied was an average of 15.1 percent stronger than the non-dominant leg. Using a tensiometer to test

the bilateral strength imbalance of athletes, he determined that the strength in the dominant leg ranged from zero to forty percent greater than in the non-dominant leg.

Thus, while two-dimensional kinematic models have been developed to determine joint reaction forces and intersegmental resultant moments, these models are based on the bilateral symmetry of the body. Studies have indicated that some asymmetry of posture and muscle strength between the right and left sides exists. It is not known if asymmetry of strength and posture leads to asymmetry of utilization, which could invalidate the assumptions of symmetry made when developing the kinematic models.

Brown and Abani (1984) have compared values obtained from a kinematic model for analysis of the dead lift with the same parameters obtained from a static model. This was done to determine what effects the accelerations of the body segments had on the forces and moments acting on the joints and segments. By comparing the two models, they determined that, for skilled subjects, the average difference in the force values at the ankle was less than 1.1 percent, while the average difference in moment values at the shank was less than 16.3 percent. They stated that the static model and the kinematic model were equipollent, but concluded,

Concurrent validity of both of these models needs to be determined by evaluating them against a model which incorporates ground reaction forces and moments from records of lifting on a calibrated force platform.

Summary

Kinematic models are currently being used for analysis of the joint reaction forces and intersegmental resultant moments experienced during weightlifting. However, the accuracy of these models remains untested. Evidence exists, regarding asymmetry of strength and posture, which indicates that some assumptions made in the development of kinematic models may not be valid.

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Chapter 3

PROCEDURES

The subjects in this study were three college-age power lifters with competitive experience in the dead lift (Appendix A). Informed consent was received in compliance with the policies of the Graduate School of Michigan State University (Appendix B). Personal data forms were completed by each subject prior to the study (Appendix C). A summary of the personal characteristics of each subject appears in Table 1.

Each subject performed one dead lift at 80 percent of his self-estimated maximum on the day that filming occurred. The subjects were instructed to perform the lift using the same style they would under competitive conditions.

Procedures for Filming

A schematic of the experimental setting is presented in Figure 2. Included in the field of view of the camera were a plumb bob for vertical reference, and timing lights, with an effective frequency of 1000 Hz, for determining film speed and synchronizing the film and force platform data. Prior to filming the subjects, a meter stick was filmed in the sagittal plane of the right side of the body as a reference measure. From the perspective of the camera, body targets were placed at the centers of

Table 1
Summary of Personal Characteristics of the Subjects

Subject	Height (cm)	Weight (kg)	Dominant side	Self-estimated		Mass		Number of		Skill level
				maximum (kg)		lifted (kg)		powerlifting contests entered		
1	177.8	95.5	Right	271.0		217.6		1		Low
2	185.4	93.8	Right	275.0		220.1		7		Medium
3	177.8	101.4	Right	309.0		246.9		15		High

Note. The basis for determining skill level was the number of competitions entered prior to the date of filming.

1. permanent overhead lights
2. portable fill lights
3. plumb bob
4. timing lights
5. meter stick
6. two force platforms
7. camera
8. subject
9. weighted bar

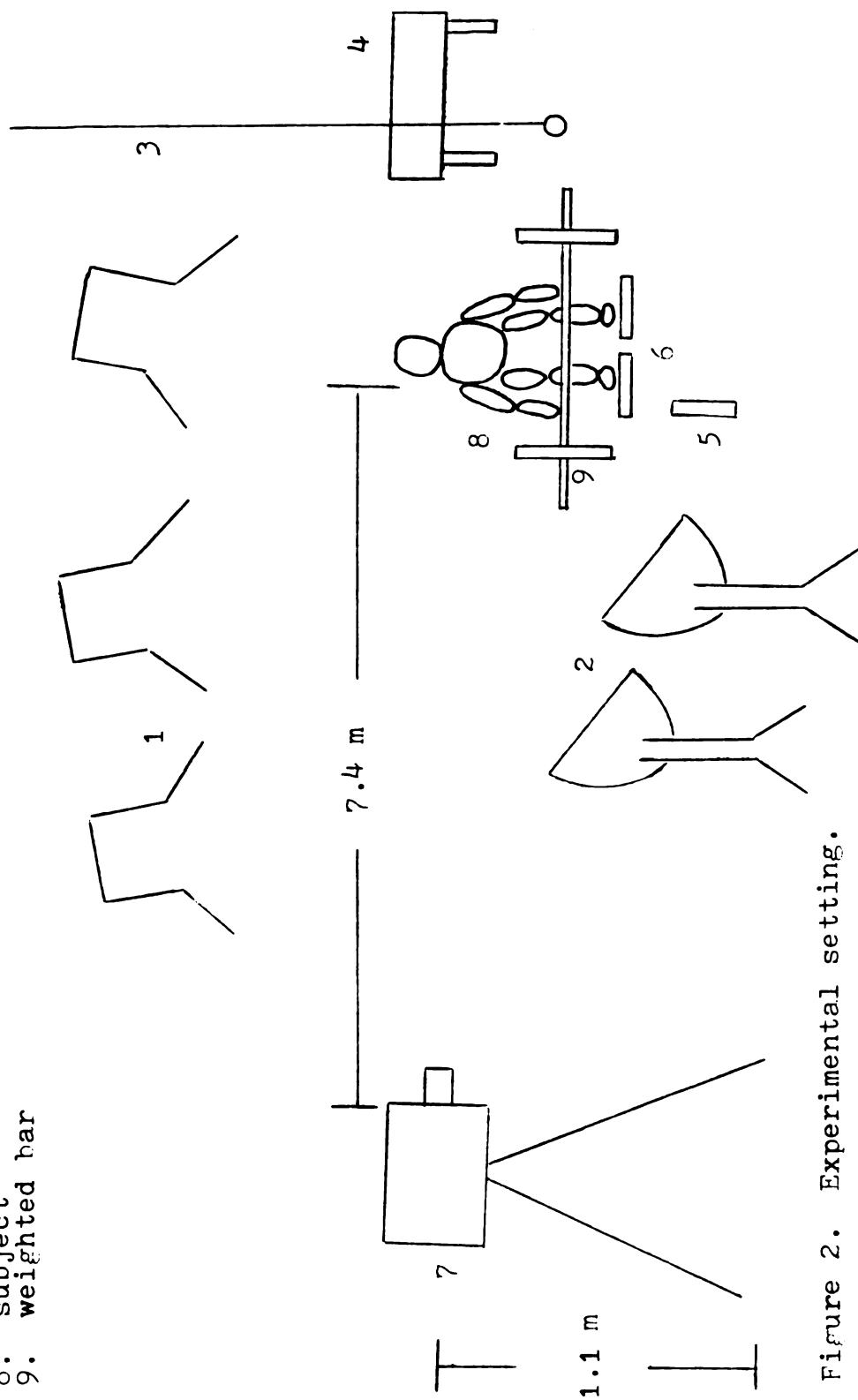


Figure 2. Experimental setting.

the right ankle, knee, hip, shoulder, elbow, and neck at the level of the seventh cervical vertebra, as well as at the end of the weighted bar used for the lifts. These targets were used as guides during the digitization of the lift.

A 16 mm LOCAM motor driven camera was positioned approximately 7.4 m from the movement plane of the right side of the body. The optic axis of the camera was perpendicular to the sagittal movement plane. The camera was leveled with its lens at a height of 1.1 m, which was approximately midway through the range of movement of each subject's lift. Permanent and portable tungsten halogen lights provided illumination for this indoor filming.

The filming rate was set at 100 frames per second, with the angle of the camera's rotation shutter set at 120 degrees, resulting in exposure of each frame for 0.03 seconds. The film used was 400 ASA Ektachrome Video News film. To allow the camera to reach the preset frame rate, filming commenced at least one full second prior to the start of each subject's lift.

Procedures for Obtaining Force Records

Simultaneous with the cinematographic record, the vertical component of the ground reaction force acting on each foot and the intersegmental resultant moment,

in the sagittal plane, about each shank, were obtained through the use of two force platforms. Two Advanced Mechanical Technologies, Incorporated (AMTI) biomechanics force platforms, model number OR6-3, were used in the study. The force platforms, housed in the Center for the Study of Human Performance at Michigan State University, have an accuracy of ± 5.0 N. On site analysis of the electronic signals from the force platforms was performed by an IBM 9000 Laboratory Computer. The two platforms were positioned adjacent to each other, approximately 8 cm apart, in the field of view of the camera. The subjects performed the dead lift while standing with one foot on each of the force platforms. Each of these lifts was filmed. The force platforms were activated by a tester approximately one second prior to signalling the lifter to commence lifting. Force platform signals were sampled at 1000 Hz.

A computer program, FPDAT, used to analyze electronic antilog signals from each of the force platforms, determined the vertical ground reaction forces and the locations of the centers of pressure on the force platform. The vertical joint reaction forces acting on each ankle were obtained by subtracting the force produced by the mass of each foot from the respective ground reaction forces. This approach was used because it was assumed that the

acceleration of each foot was zero.

The intersection of the vertical projection of the center of each ankle with the plane of the respective platform was determined. This location was measured with respect to a predetermined axis system in the plane of each force platform and entered into FPDAT to calculate the moments acting on the shank in the sagittal plane. The subjects were instructed to keep the position of their feet stationary throughout the lift. It was not thought that this procedure adversely affected their performances, as powerlifters do not normally move their feet during a dead lift.

Electronic signals from the timing lights, placed in the field of view of the camera, were also entered into the computer program. A predetermined configuration of the timing lights, occurring every second, was recorded. This allowed for synchronization of the force platform data with the cinematographic data at those time frames. The remaining time frames were synchronized by matching equal time intervals before and after the original synchronized points.

For each lift, the mass on one end of the bar was never more than 0.2 kg greater than the mass on the other end (Table 2). This was accomplished by determining the calibrated mass of each plate and attempting to minimize

differences when loading the bar.

Table 2
Distribution of Mass on the Bar

Subject	Mass (kg)		
	Left side	Right side	Bar
1	95.10	95.12	23.10
2	97.36	97.36	23.10
3	110.48	110.68	23.10

Procedures for Analysis of Data

A kinematic model developed by Brown and Abani (in press) was used to calculate kinetic parameters from kinematic data obtained from the cinematographic record. Every tenth frame of film was projected onto a screen using a Vanguard Motion Analyzer. The projected height of each subject, in the erect position, was approximately 0.35 m. A Scientific Accessories, Incorporated, L-frame sonic digitizer, with an accuracy of ± 0.01 mm, was used to digitize the cinematographic images. The digitizer was on-line to a University Cyber 750 computer in which the kinematic program was stored.

Utilizing the body targets as guides, the centers

of the right ankle, knee, hip, shoulder, elbow, and neck at the level of the seventh cervical vertebra, as well as the top of the head, and the end of the bar, were digitized to obtain the raw data arrays for analysis by the kinematic program. Digitization commenced ten time frames (note that each time frame equalled ten frames of film) prior to liftoff and concluded five time frames after the completion of the lift, in order to minimize errors in the cubic spline function associated with a zero second derivative at the endpoints of the data arrays.

The position of the ankle was determined from a time frame when it was visible, and it was assumed to remain stationary throughout the lift. When the view of the knee was obstructed by the plates on the bar, its location was determined by the intersection of two arcs drawn by compasses set at the projected length of the shank and thigh, using the position of the ankle and hip, respectively, as the centers of the arcs.

The raw data arrays were entered into the computer program, developed by Brown and Abani (in press), which calculated the body segment orientations for each frame digitized. The angles of the body segments were entered into a cubic spline function with a mean error of ± 0.02 radians, so that smooth values of body segment orientations could be obtained. The body segment orientations, along

with the time interval between frames, were used to determine angular and linear position, velocity, and acceleration values for each of the body parts. These values, along with the mass of each body segment, based on Dempster's (1955) data, mass lifted, moments of inertia of body segments, and time interval between frames, were used to calculate the joint reaction forces of the right ankle and the intersegmental resultant moments acting on the right shank.

The frame rate of the camera was determined from timing lights placed in the field of view. The time interval between frames of film was 0.0102 seconds. Since every tenth frame was digitized, the time interval between digitized frames was 0.102 seconds.

Subsequent to the digitization process, the unskilled subject's film sequence was digitized a second time in order to determine reliability. The difference in the angles of the body segments found through the two digitizations was determined for each frame. The mean differences in the angles of each body segment, as well as the mean difference in the angles of all body segments, were calculated. The mean difference in the angles of all body parts was assumed to be the inherent error in the digitization process. This value was used to determine the degree of smoothing in the cubic spline function

(McLaughlin, Dillman, and Lardner, 1978).

Procedures for Testing the Kinematic Model

Beginning at liftoff and progressing through the completion of the lift, the force and moment values obtained from the kinematic and kinetic models were compared. The absolute value of the difference between the values for the vertical joint reaction forces at the right ankle and the intersegmental resultant moments occurring in the right shank was determined. For each subject the average difference between the values obtained through the two methods of analysis was calculated for both parameters. The mean difference in the values obtained from all subjects, for each parameter, was calculated, and a one-tailed t-test ($\alpha=.05$) performed to determine if this mean difference was significantly greater than zero. One of the purposes of this study was to test the concurrent validity of the kinematic model with the kinetic model for determining the vertical joint reaction force of the right ankle and the intersegmental resultant moment of the right shank. It was assumed by the investigator that the level of significance of the t-test would indicate the degree of the concurrent validity of the kinematic model with the kinetic model.

Testing symmetry. For each subject's lift, the difference in the vertical joint reaction forces and

intersegmental resultant moments acting on the dominant and non-dominant ankle and shank, respectively, was determined through the use of force platform data, in order to evaluate symmetry. The difference in the values obtained for each parameter was found every 0.01 second. The average difference, of each parameter, for each subject, was calculated, and a one-tailed t-test ($\alpha = .05$) performed to determine if the within subject mean differences were significantly greater than zero. One of the purposes of the study was to determine if the dominant leg would experience greater vertical joint reaction forces and intersegmental resultant moments than the non-dominant leg. It was assumed by the investigator that the level of significance of the t-test would indicate the degree of asymmetry of forces and moments acting in each of the subjects. A t-test was performed for each subject so that individual differences in the symmetry of the forces and moments could be determined.

For each time interval, right and left vertical joint reaction force values, as determined from force platform data, were averaged. The absolute value of the differences between these average force values and the values obtained through the kinematic model were calculated. The mean of the differences for each subject, as well as

the mean difference for the subject population, was determined. Mean differences in the intersegmental resultant moment values within each subject, and for the subject population, were calculated through a similar process. These calculations were performed to ascertain the effect of asymmetry on the kinematic model.

Testing responsiveness. In order to determine if the kinematic model was responsive to dynamic changes in the forces and moments experienced during the dead lift, the correlation between the values for the joint reaction forces of the right ankle, obtained from the kinematic and kinetic models, was calculated for each subject. Similarly, the correlation between the intersegmental resultant moment values of the right shank, as determined from the two models, was calculated for each subject. A time interval by time interval average of the vertical joint reaction forces of the right and left ankles, as determined from the kinetic model, was correlated with the same parameters as determined from the kinematic model. Correlations for the intersegmental resultant moment values acting on the shanks were obtained through a similar process.

Chapter 4

RESULTS AND DISCUSSION

This study was designed to test the concurrent validity of the kinematic model developed by Brown and Abani (in press) for calculating the joint reaction forces and intersegmental resultant moments at the ankle and shank. The test was conducted by comparing the values obtained from the kinematic model with the same values obtained from a kinetic model which utilized force platform data. The symmetry of the forces and moments involved in each subject's lift was also investigated. This was done to ascertain what effect asymmetry might have on the values obtained from the kinematic model.

Degree of Smoothing

The inherent error in the digitization process was found to be ± 1.14 degrees ($\pm .02$ radians). This value, which was the mean difference in the angles found through two subsequent digitizations of the same lift, was used as the degree of smoothing for the cubic spline function utilized in the analysis of the cinematographic data.

A summary of the mean difference for each body segment can be found in Table 3. It should be noted that the largest mean difference occurred at the head. This was expected because it was difficult to be consistent in digitizing the location of the top of the head which

was one of the end points for determining the angle of this segment. The head was also the smallest segment, so small differences in the positions of its end points may have resulted in larger angle variances. The smallest mean difference occurred in the forearm. This was expected because the end points of this segment were the end of the bar and the elbow, which were easily identifiable.

Table 3
Mean Differences in Body Segment Orientations
Found Through Repeated Digitization

	Body Segments					
	Shank	Thigh	Trunk	Arm	Forearm	Head
Mean						
difference	0.93	1.11	1.00	1.38	0.58	1.58
(degrees)						

Concurrent Validity of the Kinematic Model

The concurrent validity of the kinematic model for calculating the joint reaction forces at the ankle and intersegmental resultant moments at the shank was tested by comparing the values obtained from the kinematic model with the same parameters obtained from a kinetic model.

Joint reaction forces. The mean of the differences in the vertical joint reaction forces, obtained from the subject population, found through the two methods of analysis was 193.6 N. A one-tailed t -test revealed that this difference was significantly greater than zero, $t(40)=8.65$, $p<.05$. A summary of the differences in the values obtained from the kinematic and kinetic models for each subject can be found in Table 4. It should be noted that the difference in the values found through the two models ranged from 3.3 N to 498.7 N. The percent differences in the vertical joint reaction forces, relative to the kinetic model, were calculated. The percent differences ranged from .21 to 22.84 percent. Therefore, it can be seen that the kinematic model did produce some values which accurately approximated the values obtained from the kinetic model.

Intersegmental resultant moments. The mean of the differences in the intersegmental resultant moments, obtained from the subject population, was found to be 48.0 N-m. A one-tailed t -test revealed that this mean difference was significantly greater than zero, $t(40)=9.35$, $p<.05$. A summary of the differences in the values obtained from the two models, for each subject, can be found in Table 5. The differences in the values found through the two methods of analysis ranged from 0.7 N-m to 158.5 N-m.

Table 4
 Comparison of Kinematic and Kinetic Models
 for Calculating Vertical Joint Reaction
 Forces of the Right Ankle

Subject	Number of frames digitized	Differences (N)		
		Minimum	Maximum	Mean
1	15	9.1	418.1	222.4
2	13	29.3	253.6	98.4
3	13	3.3	498.7	260.6
Entire population	41	3.3	498.7	193.6

Table 5
 Comparison of Kinematic and Kinetic Models
 for Calculating Intersegmental Resultant
 Moments of the Right Shank

Subject	Number of frames digitized	Differences (N-m)		
		Minimum	Maximum	Mean
1	15	11.2	158.5	59.3
2	13	0.7	65.6	37.8
3	13	1.0	111.6	44.3
Entire population	41	0.7	158.5	48.0

The percent differences in the intersegmental resultant moments, relative to the kinetic model, were calculated. These percent differences ranged from .69 to 187.2 percent.

Accurately locating the center of the ankle during the digitization process, and obtaining an accurate measure of the location of the vertical projection of the center of the ankle on the force platform, are critical in determining the intersegmental resultant moments in the shank, from the kinematic and kinetic models, respectively. Relatively small discrepancies in locating these points could have resulted in relatively large errors in calculated intersegmental resultant moment values. Large differences found between the two models, for some frames analyzed, may be the result of this problem.

Evaluation of Symmetry

Joint reaction forces. A one-tailed t -test revealed that, for two of the three subjects, the mean differences between the vertical joint reaction force values of the dominant and non-dominant ankles were significantly greater than zero: subject one, $t(160)=15.31$, $p<.05$; and subject three, $t(142)=4.23$, $p<.05$. The within subject mean differences in the joint reaction forces were 347.44 N, -81.37 N, and 69.45 N for subjects one, two, and three, respectively (Table 6). Therefore, in subjects

one and three, the dominant ankle experienced a significantly greater vertical joint reaction force than the non-dominant ankle. It should be noted that subject two had a negative mean difference, which indicates that the forces experienced in the non-dominant ankle were greater than those in the dominant ankle. It should also be observed that all three subjects experienced some time frames when the difference was less than zero.

The skill levels of subjects one and three were low and high, respectively, while subject two was classified as medium. Therefore, no pattern in the symmetry of the forces appears to emerge with respect to the skill level.

Intersegmental resultant moments. A one-tailed t -test also determined that, for two of the three subjects, the mean differences between the intersegmental resultant moment values of the dominant and non-dominant shanks were significantly greater than zero: subject two, $t(120)=24.32$, $p<.05$; and subject three, $t(142)=8.16$, $p<.05$. The within subject mean differences in the intersegmental resultant moment values were found to be 3.04 N-m, 25.38 N-m, and 6.85 N-m for subjects one, two, and three, respectively (Table 7). Therefore, the conclusion can be made that the dominant shank experienced a significantly greater intersegmental resultant moment in subjects two and three, but not in subject one.

Table 6
Vertical Joint Reaction Force Differences
Experienced by the Dominant and Non-dominant Ankles

Subject	Differences (N)			
	Minimum	Maximum	Mean	t-score
1	-63.30	988.95	347.44*	15.31
2	-334.19	250.97	-81.37	-5.46
3	-250.62	496.70	69.45*	4.23

Note. Differences represent dominant side forces less non-dominant side forces.

* $p < .05$.

Table 7
Intersegmental Resultant Moment Differences
Experienced by the Dominant and Non-dominant Shanks

Differences (N-m)				
Subject	Minimum	Maximum	Mean	<u>t</u> -score
1	-46.41	32.18	3.04	1.63
2	4.14	43.70	25.38*	24.32
3	-18.24	22.57	6.85*	8.16

Note. Differences represent dominant side moments less non-dominant side moments.

* $p < .05$.

Once again, it should be noted that subjects one and three experienced some time frames when the differences were less than zero, and therefore, the moments in the non-dominant shank were greater than those in the dominant shank. Only subject two experienced greater moments in the dominant shank throughout the lift.

Effects of asymmetry. A time frame by time frame average for the vertical joint reaction forces experienced by the right and left ankle, as determined from the kinetic model, was calculated. These average values were compared to the same parameter calculated from the kinematic model, and the differences found.

The mean difference for each subject, as well as the mean difference for the subject population, was calculated (Table 8). It was determined that, for two of the three subjects, values from the kinematic analysis of the right side more closely approximated these average values than the values obtained from the kinetic analysis of the right side.

A similar analysis of the intersegmental resultant moments revealed that, for all three subjects, values from the kinematic analysis of the right side more closely approximated the average moment values experienced by both shanks than the kinetic values for the right shank (Table 9).

Table 8
Comparison of Mean Differences Between
Kinematic and Kinetic Models for
Vertical Joint Reaction Forces

Subject	Mean differences (N)	
	Kinetic model right side	Kinetic model average value
1	222.4	152.3
2	98.4	131.6
3	260.6	178.9
Entire population	193.6	153.6

Table 9
 Comparison of Mean Differences Between
 Kinematic and Kinetic Models for
 Intersegmental Resultant Moments

Subject	Mean differences (N-m)	
	Kinetic model right side	Kinetic model average value
1	59.3	54.5
2	37.8	34.8
3	44.3	41.9
Entire population	48.0	44.5

These results suggest that the lack of concurrent validity in the kinematic model, with respect to the kinetic model, may in part be due to the asymmetry of the forces and moments experienced throughout the lift.

Evaluating the Dynamics of the Kinematic Model

Vertical joint reaction forces. Graphs of the vertical joint reaction forces experienced by each lifter appear in Figures 3-5. Included in these graphs are the vertical joint reaction forces: (a) experienced by the right ankle as calculated by the kinematic model, (b) experienced by the right ankle as calculated by the kinetic model, (c) experienced by the left ankle as calculated by the kinetic model, and (d) found through a time frame by time frame average of the force values experienced in both ankles (as determined from the kinetic model).

The correlations in the vertical joint reaction force values obtained from the kinematic and kinetic models were calculated for each subject. The correlations between the values obtained from the kinematic model and the frame by frame average values, for both ankles, were also calculated for each subject (Table 10). These correlations were calculated to determine the responsiveness of the kinematic model to changes in forces experienced,

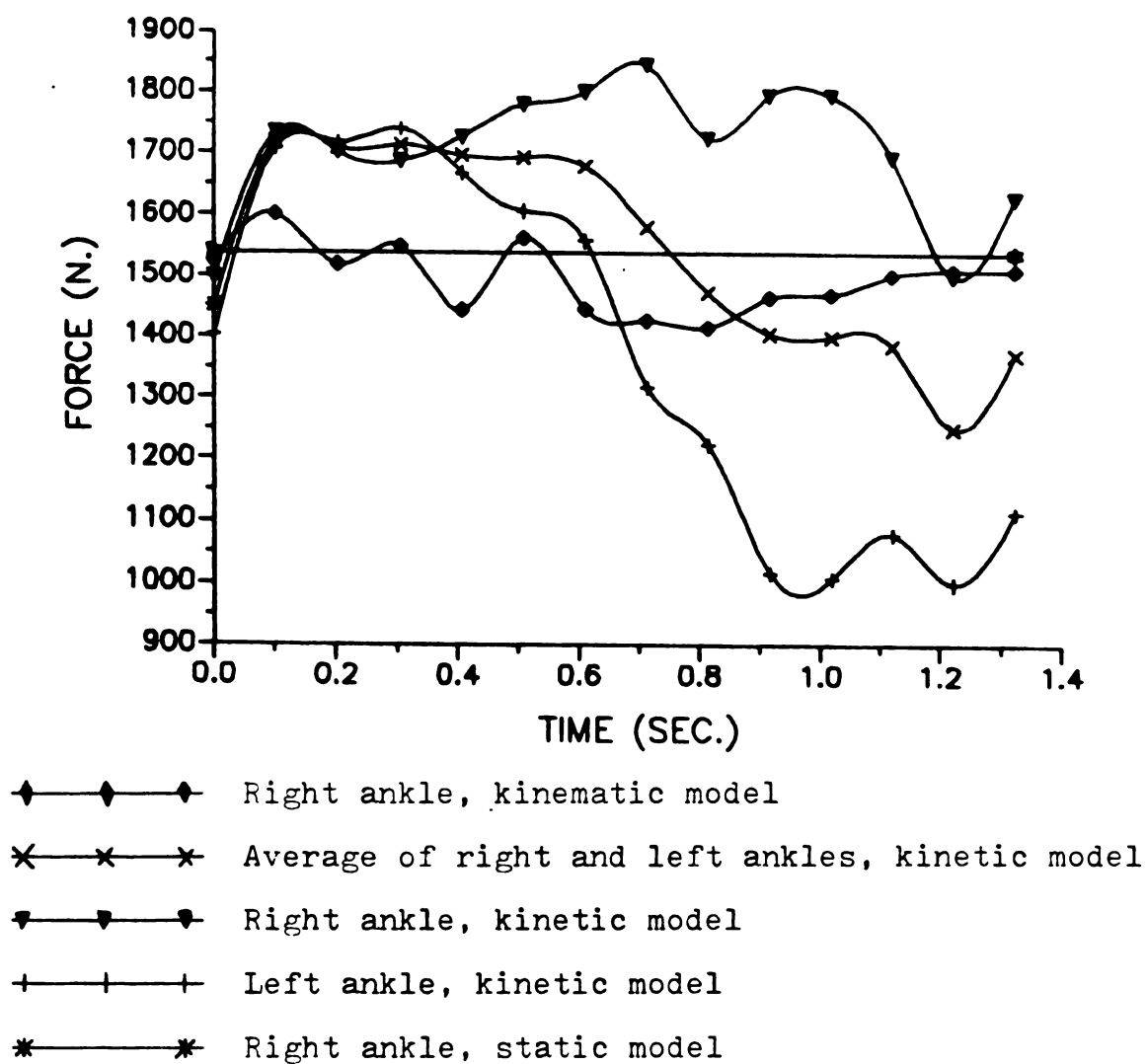


Figure 3. Vertical joint reaction forces in the ankles of subject 1.

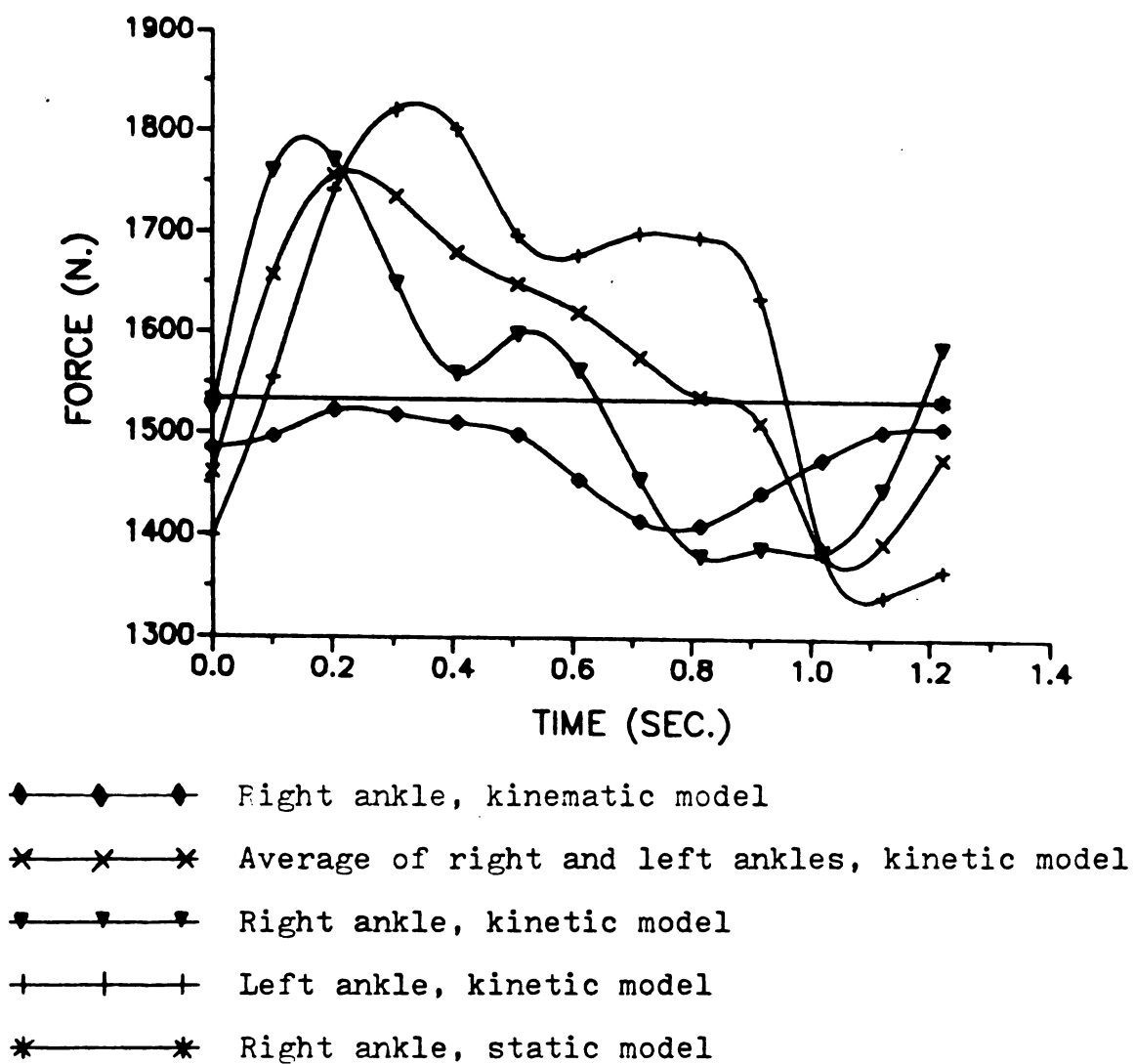


Figure 4. Vertical joint reaction forces in the ankles of subject 2.

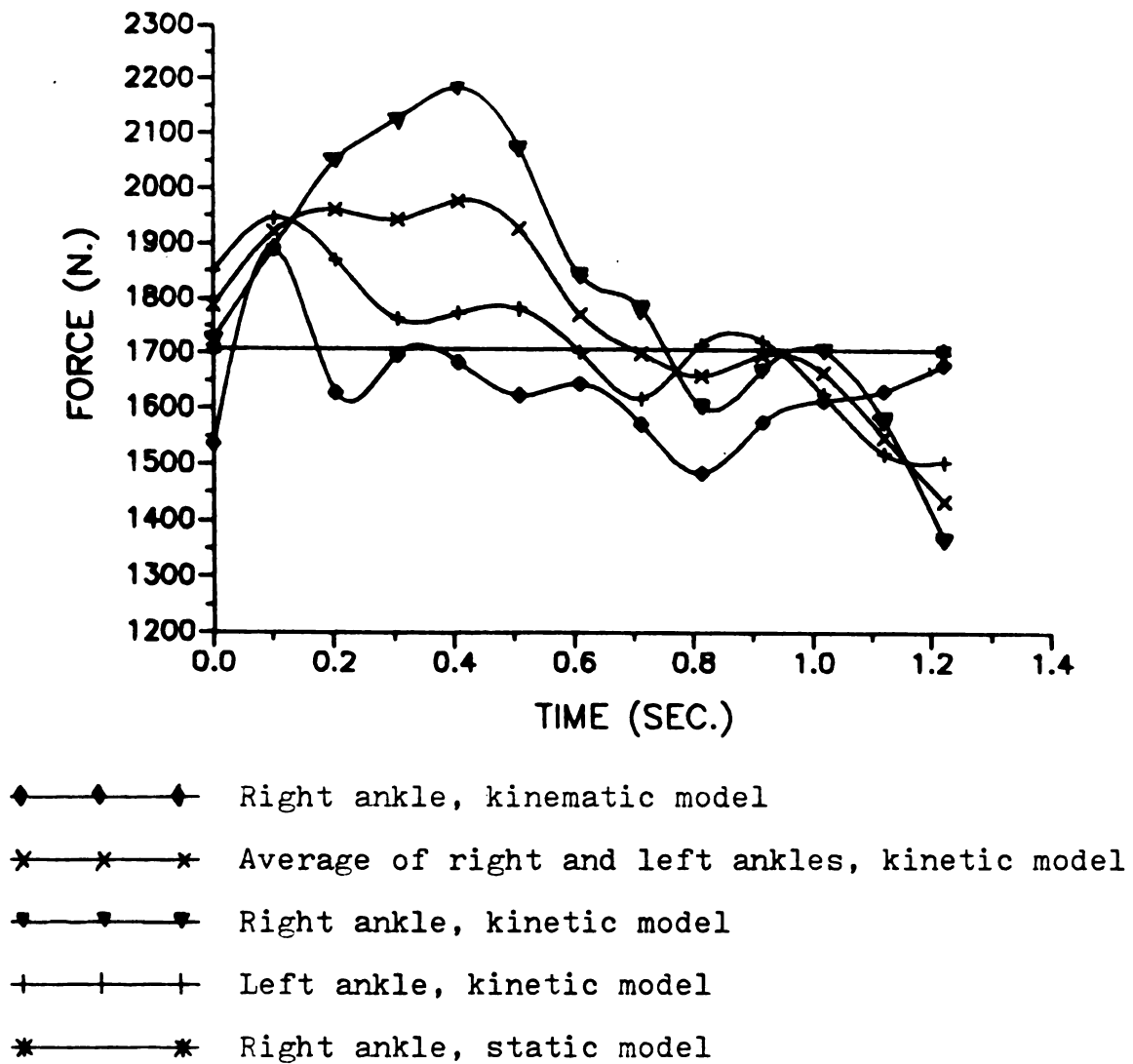


Figure 5. Vertical joint reaction forces in the ankles of subject 3.

Table 10
Correlations of Vertical Joint Reaction Force
and Intersegmental Resultant Moment Values
Between the Kinematic and Kinetic Models

Correlations		
Subject	Kinetic model	Kinetic model
	Right side	Average value
Vertical joint reaction force values		
1	-.348	.099
2	.678	.317
3	.286	.362
Intersegmental resultant moment values		
1	.462	.696
2	.646	.653
3	.381	.369

throughout the lift, by each subject. The correlations ranged from $-.348$ to $.678$. It can be seen in Figures 3-5 that the force values produced by the kinematic model were often not responsive to the dynamic changes in the forces of the lift, and often more closely approximated the forces that would be present through the use of a static model (see Definition of Terms). It is thought by the investigator that values from the kinematic model approached this static value due to the application of the cubic spline function in calculation of the acceleration parameters. It should be noted that by progressively increasing the degrees of freedom of the smoothing function, values from the kinematic model approach the static value.

Intersegmental resultant moments. Graphs of the intersegmental resultant moments experienced by each lifter appear in Figures 6-8. Included in these graphs are the intersegmental resultant moments: (a) experienced by the right shank as calculated by the kinematic model, (b) experienced by the right shank as calculated by the kinetic model, (c) experienced by the left shank as calculated by the kinetic model, and (d) found through a time frame by time frame average of the moment values experienced in both shanks (as determined from the kinetic model).

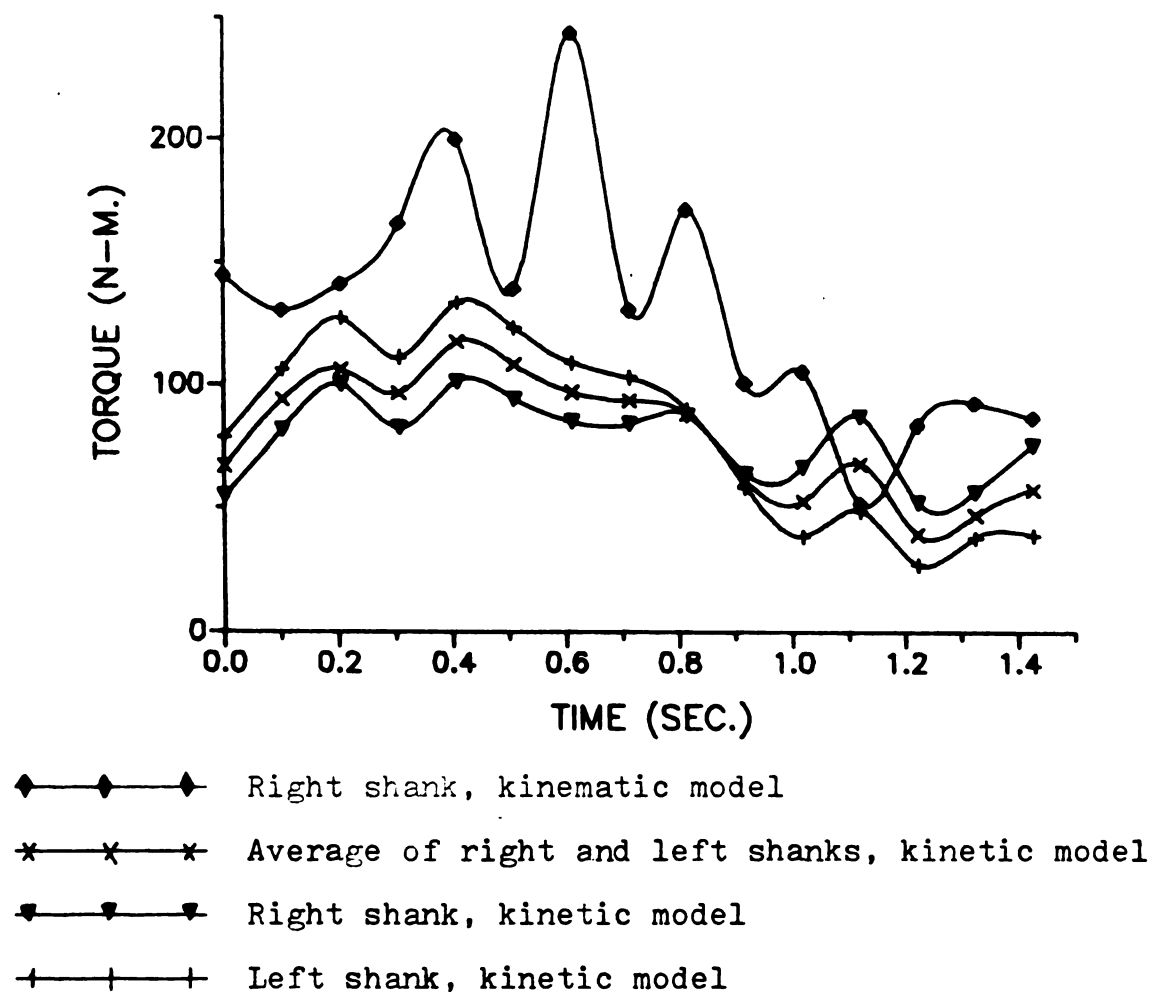


Figure 6. Intersegmental resultant moments in the shanks of subject 1.

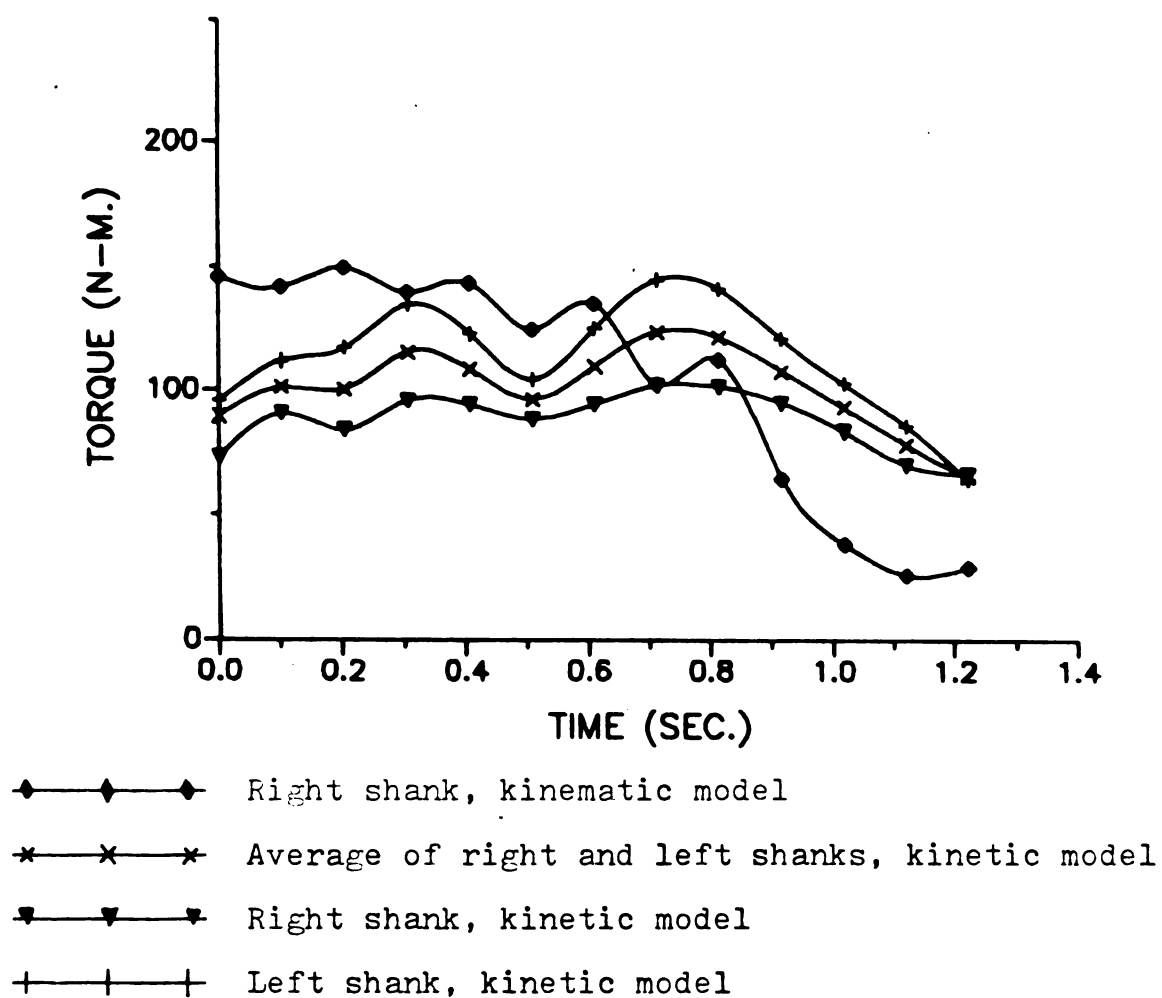


Figure 7. Intersegmental resultant moments in the shanks of subject 2.

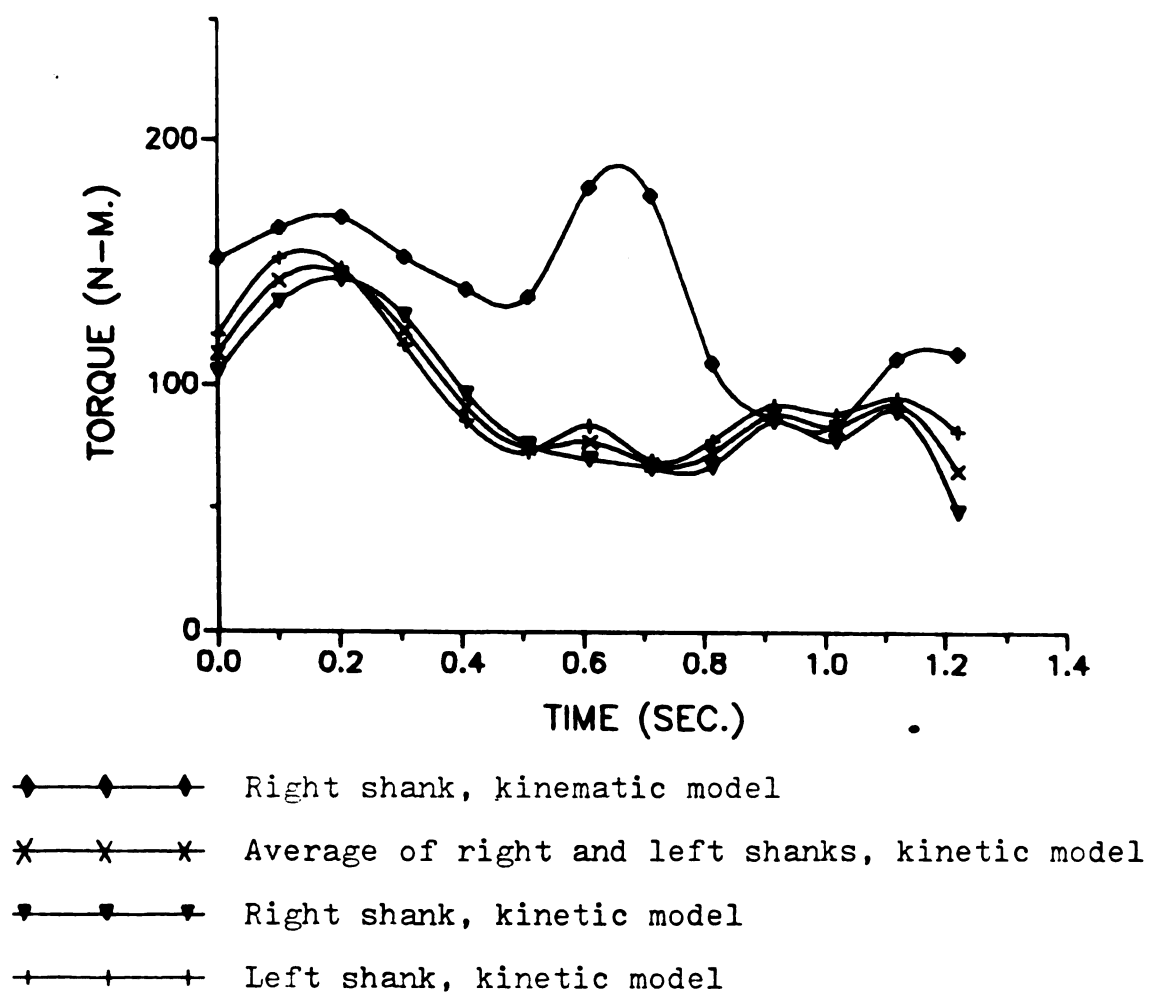


Figure 8. Intersegmental resultant moments in the shanks of subject 3.

The correlations in the intersegmental resultant moment values obtained from the kinematic and kinetic models were calculated for each subject. The correlations between the values obtained from the kinematic model and the frame by frame average values, for both shanks, were also calculated for each subject. These correlations ranged from .381 to .696. It can be seen in Table 10 that the kinematic model appears to be more responsive to the dynamic changes in the intersegmental resultant moments than the dynamic changes in the vertical joint reaction forces.

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Chapter 5

SUMMARY AND CONCLUSIONS

This study was designed to test the concurrent validity of the kinematic model developed by Brown and Abani (in press) for calculating vertical joint reaction forces and intersegmental resultant moments. Four questions were investigated.

1. Does the kinematic model produce vertical joint reaction forces at the ankle and intersegmental resultant moments at the shank that are concurrently valid with values obtained from a kinetic model?

2. Does asymmetry of utilization in the dominant and non-dominant sides of the body exist during the dead lift?

3. If asymmetry exists, what effect does it have on the force and moment values obtained from the kinematic model?

4. Is the kinematic model responsive to the dynamic changes in the forces and moments occurring throughout the lift?

The subjects were three college-age powerlifters of varying skill levels. Each subject performed the dead lift at 80 percent of his self-estimated maximum, while standing with each foot on a separate force platform. Each of the lifts was filmed.

A kinematic model developed by Brown and Abani (in press) was used to determine the vertical joint reaction forces and intersegmental resultant moments of the right ankle and shank, respectively. These same parameters were calculated from a kinetic model utilizing force platform data.

The vertical joint reaction force values obtained from the two models were compared, and the absolute values of the differences calculated. The average of the differences in the forces throughout the lift was calculated for each subject. An overall mean in the subject population was also calculated. The average in the differences of the intersegmental resultant moment values for each subject, and the overall mean in the subject population, was determined through a similar process. A one-tailed t-test was performed to determine the level of significance of the overall mean difference in the subject population for both parameters.

The symmetry of the forces and moments acting on the ankle and shank, respectively, during the dead lift, was investigated. The difference in the vertical joint reaction force values of the dominant and non-dominant ankles was calculated, and the average difference throughout the lift determined for each subject. The average difference in the intersegmental resultant moment values of the

dominant and non-dominant shanks was determined for each subject through a similar analysis. A one-tailed t-test was performed to determine if these within subject mean differences were significantly greater than zero.

The effects of asymmetry on the values obtained from the kinematic model were investigated by determining a right and left ankle time frame by time frame average value of the forces as determined from the kinetic model. These average force values were compared to the values for the right ankle obtained from the kinematic model. The mean differences in the force values were calculated for each subject and for the subject population. The mean differences in the intersegmental resultant moment values were calculated for each subject and for the subject population through a similar process.

The correlations between the vertical joint reaction force values obtained through the kinematic and kinetic models were calculated for each subject, as were correlations of the intersegmental resultant moment values obtained from the two models. This was done to test the responsiveness of the kinematic model to the dynamic changes in the forces and moments acting on the ankle and shank.

The results of this study revealed the following:

1. Values obtained from the kinematic model developed by Brown and Abani (in press) for vertical joint reaction

forces and intersegmental resultant moments at the ankle and shank, respectively, were not concurrently valid with the same parameters derived from a kinetic model, under the conditions of this present analysis.

2. Individual differences in bilateral symmetry of performance during the dead lift were found:

- a. Two of the subjects experienced significantly greater forces and moments in the dominant ankle and shank.
- b. For all three subjects, the forces experienced in the non-dominant ankle were greater than the forces experienced in the dominant ankle for some time intervals.
- c. For two of the three subjects, the moments experienced in the non-dominant shank were greater than those experienced in the dominant shank for some time intervals.

3. Values obtained for the right side of the body from the kinematic model, for vertical joint reaction forces and intersegmental resultant moments, more closely approximated the time frame by time frame average kinetic values than the kinetic values from the right side of the body.

4. The correlations between the values obtained through the two models revealed that the kinematic model

was generally not responsive to the dynamic changes in the forces and moments acting on the ankle and shank during the dead lift.

In conclusion, the findings of this study revealed that the lack of concurrent validity in the values obtained from the kinematic model was due in part to the asymmetry of the forces and moments acting on the ankle and shank. A lack of responsiveness to the dynamic changes of the lift, due to the application of the smoothing function in the calculation of acceleration parameters, was also thought to produce some of the discrepancies in the values obtained from the two models. In general, the kinematic model appears to more closely approximate the static condition than the actual dynamic changes that occur during the dead lift. Other possible sources of the discrepancies in the values obtained through the two methods include:

1. The use of Dempster's (1955) data, in the kinematic model, to represent mesomorphic weightlifters.
2. Perspective error associated with two-dimensional filming.
3. The assumption, in the kinematic model, that all body segments were rigid was obviously violated by the flexibility of the trunk during the lift.
4. The assumption, in the kinematic model, that the

end of the bar represented the location of the center of the wrist.

5. The assumption, in the kinematic model, that no torque acted on the bar.

6. The difficulty in locating the center of the ankle, which affected the intersegmental resultant moment values obtained from both models.

7. Possible instrumentation and operator errors in the conduction of the study.

Further research on the kinematic model is needed. It is recommended that future studies be conducted utilizing larger subject populations, with more lifts per subject. It is also recommended that the degree of smoothing and the number of frames digitized be varied to determine what effect changes in these parameters have on the kinematic model. A revised kinematic model for analysis of the dead lift warrants further study.

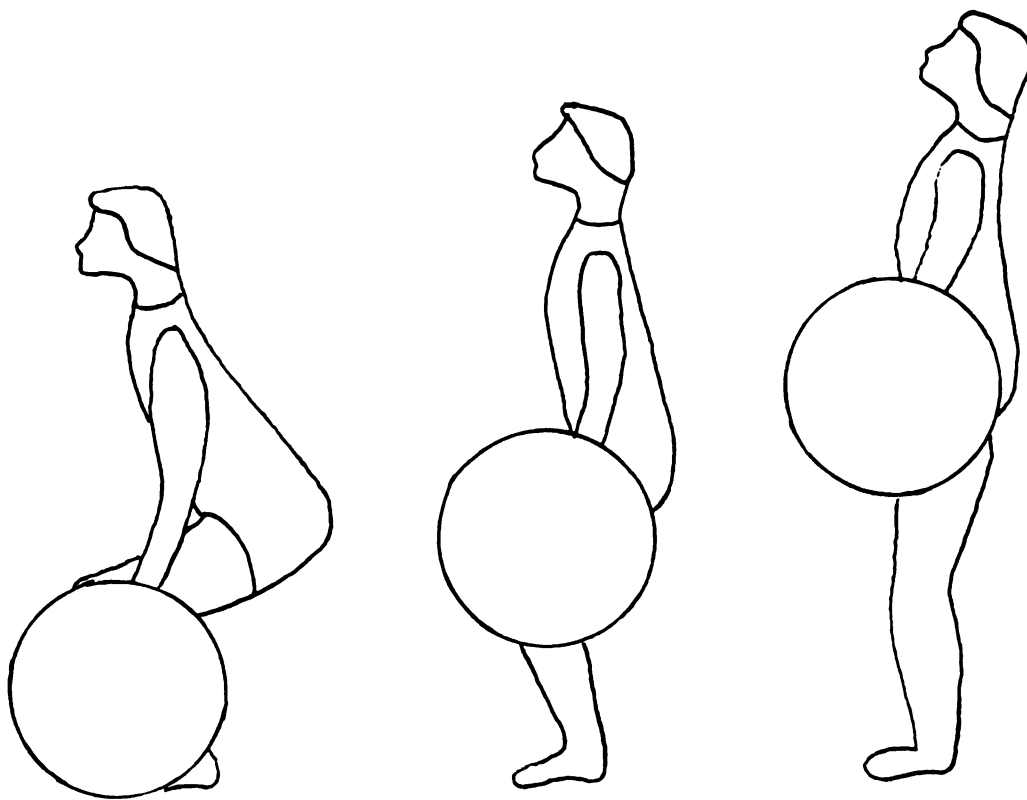
Possible changes in the kinematic model to increase the level of concurrent validity with the kinetic model include: (a) utilizing two or more body segments for the trunk, (b) differential degrees of freedom for smoothing the angles of each body part, (c) a three-dimensional kinematic model to account for asymmetry, and (d) inclusion of the possibility of torque acting on the bar.

APPENDIXES

APPENDIX A
THE DEAD LIFT

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The Dead Lift



Liftoff

Completion

APPENDIX B
WRITTEN CONSENT FORM

INFORMED WRITTEN CONSENT FORM

1. I have freely consented to take part in a scientific study being conducted for the completion of a master's degree by Daniel Gibson.
2. The study has been explained to me and I understand the explanation that has been given to me and what my participation will involve.
3. I understand that I am free to discontinue my participation in this study at any time without penalty.
4. I understand that motion pictures will be taken of my performances and that these pictures may be used for demonstrations, instructions, and study.
5. I understand that my participation in the study does not guarantee any beneficial results to me.
6. I understand that, at my request, I can receive additional explanation of the study after my participation is completed.
7. I understand that in the unlikely event of injury resulting from research procedures, Michigan State University, its agents, and employees will assume that responsibility as required by law. Emergency medical treatment for injuries or illness is available where the injury or illness is incurred in the course of an experiment. I have been advised that I should look toward my own health insurance program for payment of said medical expenses.

Signed _____

Date _____

APPENDIX C
PERSONAL DATA FORM

PERSONAL DATA FORM

Subject _____ No. _____

Ht _____ Wt _____ Dominant Hand _____

Age _____ Self-estimated maximum dead lift _____

Number of competitions _____

Weight Distribution

Left plates

Bar

Right plates

_____ Left total Right total _____

Grand total _____

APPENDIX D
RAW DATA

Vertical Joint Reaction Force Values (N)

Subject 1

Event	Kinematic Model	Kinetic model		
		Right	Left	Average
Liftoff	1530.9	1225.2	1048.6	1136.9
	1524.5	1497.7	1401.9	1449.8
	1600.6	1732.1	1706.6	1719.4
	1518.6	1701.2	1716.3	1708.8
	1548.7	1685.7	1739.4	1712.6
	1443.3	1725.0	1666.8	1695.9
	1561.6	1778.5	1605.9	1692.2
	1443.7	1798.8	1557.3	1678.1
	1425.9	1844.0	1316.9	1580.5
	1415.0	1722.6	1223.5	1473.1
	1464.3	1794.0	1015.9	1404.9
	1469.3	1794.0	1007.3	1400.6
	1501.5	1692.9	1079.0	1385.9
	1509.2	1500.1	998.9	1249.5
	1509.9	1627.4	1114.2	1370.8
Completion				

Vertical Joint Reaction Force Values (N)

Subject 2

Event	Kinematic Model	Kinetic model		
		Right	Left	Average
Liftoff	1484.4	1523.0	1398.6	1460.8
	1496.2	1759.8	1555.2	1657.5
	1522.6	1770.5	1740.9	1755.7
	1518.8	1649.1	1821.0	1735.1
	1510.6	1559.9	1801.6	1680.8
	1499.0	1599.2	1697.2	1648.2
	1454.3	1563.5	1677.8	1620.6
	1414.0	1454.5	1699.0	1577.1
	1409.5	1380.2	1696.0	1538.1
	1441.5	1388.5	1635.3	1511.9
Completion	1475.1	1383.3	1389.3	1386.6
	1503.4	1445.6	1341.5	1393.6
	1507.1	1586.1	1367.0	1476.6

Vertical Joint Reaction Force Values (N)

Subject 3

Event	Kinematic Model	Kinetic model		
		Right	Left	Average
Liftoff	1535.1	1725.4	1850.3	1787.8
	1890.1	1894.4	1947.4	1920.9
	1627.9	2051.9	1870.9	1961.2
	1697.0	2124.8	1762.9	1943.8
	1683.8	2183.5	1773.8	1978.6
	1623.7	2074.0	1782.3	1928.2
	1644.1	1843.0	1702.2	1772.7
	1571.7	1783.7	1618.4	1701.1
	1484.4	1604.0	1716.7	1660.4
	1575.9	1671.8	1724.0	1697.9
Completion	1614.2	1706.3	1626.9	1666.6
	1632.4	1579.0	1518.9	1549.0
	1681.1	1367.2	1504.3	1435.7

Intersegmental Resultant Moment Values (N-m)

Subject 1

Event	Kinematic Model	Kinetic model		
		Right	Left	Average
Liftoff	144.5	54.4	78.5	66.5
	129.9	81.5	106.3	93.9
	140.9	100.0	126.8	113.4
	165.5	82.2	111.0	96.6
	199.8	101.2	133.2	117.2
	138.9	94.2	123.0	108.6
	243.2	84.7	108.9	96.8
	130.2	83.8	102.9	93.4
	171.0	87.4	89.9	88.7
	100.6	63.7	58.1	60.9
	105.2	66.1	38.4	52.3
	51.3	86.9	48.5	67.7
	83.2	51.7	26.9	39.3
	92.4	55.9	37.9	46.9
	86.3	75.1	38.8	57.0
Completion				

Intersegmental Resultant Moment Values (N-m)

Subject 2

Event	Kinematic Model	Kinetic model		
		Right	Left	Average
Liftoff	145.6	72.9	95.3	89.2
	141.5	90.3	111.5	100.9
	149.4	83.8	116.7	100.3
	139.4	95.5	134.3	114.9
	143.0	93.9	122.2	108.1
	124.0	88.1	104.3	96.2
	134.4	94.1	124.3	109.2
	102.3	101.6	144.5	123.1
	111.9	101.2	140.7	120.9
	64.1	94.6	120.3	107.5
	38.3	83.1	102.5	92.8
	26.0	69.6	85.5	77.6
	29.1	66.0	64.0	65.0
Completion				

Intersegmental Resultant Moment Values (N-m)

Subject 3

Event	Kinematic Model	Kinetic model		
		Right	Left	Average
Liftoff	151.6	105.1	120.6	112.9
	164.0	134.0	151.8	142.9
	168.5	143.5	147.6	145.6
	152.3	129.5	116.5	122.5
	139.4	96.5	85.2	90.9
	136.2	75.8	72.6	74.2
	180.8	69.7	83.4	76.6
	177.6	66.0	69.2	67.6
	109.2	66.8	77.4	72.1
	86.3	85.3	91.8	88.6
Completion	83.7	77.5	88.6	83.1
	111.1	89.6	95.2	92.4
	113.2	48.4	81.4	64.9

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