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A CINEMATOGRAPHICAL INVESTIGATION OF THE DOUBLE KNEE BEND STYLE OF CLEAN AND JERK IN OLYMPIC WEIGHT LIFTING

by

© ALLEN G. ELLIOTT

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled....

A CINEMATOGRAPHICAL INVESTIGATION OF THE DOUBLE KNEE BEND STYLE OF CLEAN AND JERK IN OLYMPIC WEIGHT LIFTING

submitted by Allen G. Elliott....

in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Physical Education.

Supervisor

External Examiner

Date February 2 . 1979

ABSTRACT

The purpose of the investigation was to collect descriptive and kinematic information about the Olympic weightlifting event known as the clean and jerk as performed by provincial and national calibre athletes using the double knee bend style of pulling and a squat clean.

Using one camera positioned at right angles to the plane of motion and film transport speeds of 24, 30 and 50 frames per second respectively, two provincial championships and one national championship were filmed in order to obtain a record of novice and international calibre athletes. Two cameras positioned at right angles to each other were used to film the clean and jerk at a film transport speed of 100 frames per second from anterior and lateral points of view in a laboratory test session. Two athletes of international calibre and expert in the performance of the double knee bend style of lifting were used. Data collected from the films was compared to the literature in order to produce a description of the double knee bend style of lifting.

A simple model was constructed from information contained in the literature and was tested for its ability to describe the pull phase of the clean and the thrust phase of the jerk. A simplified version of the model was also tested and both utilized angular displacement-time functions for the limbs.

The most unexpected finding of the study was the variability found in both the information given in the literature and the performances of high calibre athletes in competition. The jerk, in particular, exhibited a lack of consistency from both an intra and inter individual point of view. In contrast, the performances of the two subjects used in the laboratory test session were found to be highly consistant. Bar velocities were at the lower end of the range characteristic of world class performances and the power generated by the subjects to complete the second pull and thrust phases agreed with values found in the literature.

The double knee bend technique of lifting was found to exhibit three characteristic phases to the pulling movement and these manifested themselves in distinct movement patterns at the ankle, knee and hip joints. Data taken from the film records confirmed the uniqueness of the three phases. The pulling movement was also described in term of angles at the said joints.

The simplified model predicted bar velocities which were consistent with actual measured values. The model also predicted the premature cessation of knee extension during the first pull and this was later confirmed from the film record. It was found that the model was capable of describing the double knee bend technique of lifting and that manipulation of the model could provide insights into the mechanisms involved in lifting.

It was concluded that the double knee bend technique offers a means of minimizing stress placed upon the lumbosacral joint and that it was a means by which the body segments could be manipulated in order to obtain maximum utility out of the energy expended in lifting. It was further concluded that full extension at the joints probably hinders performance as does execution of the so called top pull. Further research is required in order to determine the means by which world class weight lifters achieve high velocities of descent under the bar.

Cinematography was found to be an indispensible tool for descriptive purposes but was inadequate when a more detailed examination was required.

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CHAPTER ONE

INTRODUCTION

Purpose

The purpose of this study was to collect descriptive and kinematic information about the Olympic weightlifting event known as the clean and jerk as performed by provincial and national calibre athletes. In particular, this research paper is concerned with the double knee bend style of lifting which utilizes a squat clean.

Justification

Justification for the study lay in the lack of qualitative and quantitative information specifically related to the clean and jerk. Most of the data available was found to be descriptive and had been written prior to the decade of the sixties. Although a number of publications had been published later than this, they were largely reprints of earlier works. The books written by Hoffman (1959) and Kirkley (1957) and (1964) are typical of what is available for weightlifting and they appear to contain educated guesses, based upon years of experience, of what factors are pertinent in successful lifting. As one might expect where subjective reasoning is involved, the opinions expressed in the various publications often contradict each other. Thus, literature of a scientific nature was found to be virtually non existant with the exception of three related categories of investigations. First, a number of researchers had examined the clean and jerk, the snatch and the parallel squat as part of master of science degree programs. Second, an assortment of 'lifting' studies were found ranging from those concerned with job safety to those which dealt with anatomical investigations into the role of intra-thoracic and intra-abdominal pressure while lifting. Third, a number of researchers had investigated various aspects of the weightlifting events but non had dealt with the lifts as a whole.

In view of the fact that there are at least three basic styles of lifting, there was a need to begin to give meaning to information in the literature by viewing it in the context of one style or another. As already mentioned, this investigation is specifically concerned with the double knee bend style of lifting which utilizes a squat clean. The rebend technique came into prominence in the mid seventies. Prior to that time, a swing style or according to Garhammer (1976), a trunk extension style of pulling was used in most countries except Japan where the Frog style of lifting is used. This latter style was developed by the Japanese to suit the peculiarities of their anatomical structures.

Limitations

The scope of the analysis of the data collected was limited to describing the double knee bend technique of the clean and jerk. It was not extended to a detailed examination of the critical aspects of the event because of limitations in the experimental design.

Only two subjects were used who were expert in the style under investigation. The loss of external validity, however, is partially off set by comparison to experimental results in the literature for performances by world class athletes.

Identification of Event Under Study

Before proceeding with a description of the study and a report of the results, the reader should have a clear understanding of the movement being investigated. Figure 1 illustrates the clean and jerk. The clean is a movement designed to take the barbell from the floor to the shoulders while the jerk is a movement designed to place the barbell at arms length over head. The two distinct movements are necessary because of the magnitude of the load being lifted.

The clean is composed of three parts. The barbell is first pulled as high off the platform as possible (pictures 1-4). Second, the lifter lowers himself under the bar by squatting (picture 5) and he subsequently 'catches' the bar at the shoulders (pictures 6-8). The act of catching the bar at the shoulders is usually referred to as racking the bar.

With the bar securely racked at the shoulders while standing in an erect position, the jerk is initiated. The jerk is composed of three parts as well. First, the bar is given a vertical upward thrust (pictures 10-11). Second, the lifter becomes airborne as he descends under the bar in order to catch it at arms lenght overhead. The descent is facilitated by splitting the legs fore and aft (picture 12). Third, from a split position with the bar overhead (picture 13), the lifter recovers to a standing position (picture 15) which must be held motionless until the referee signals that the lift has ended.

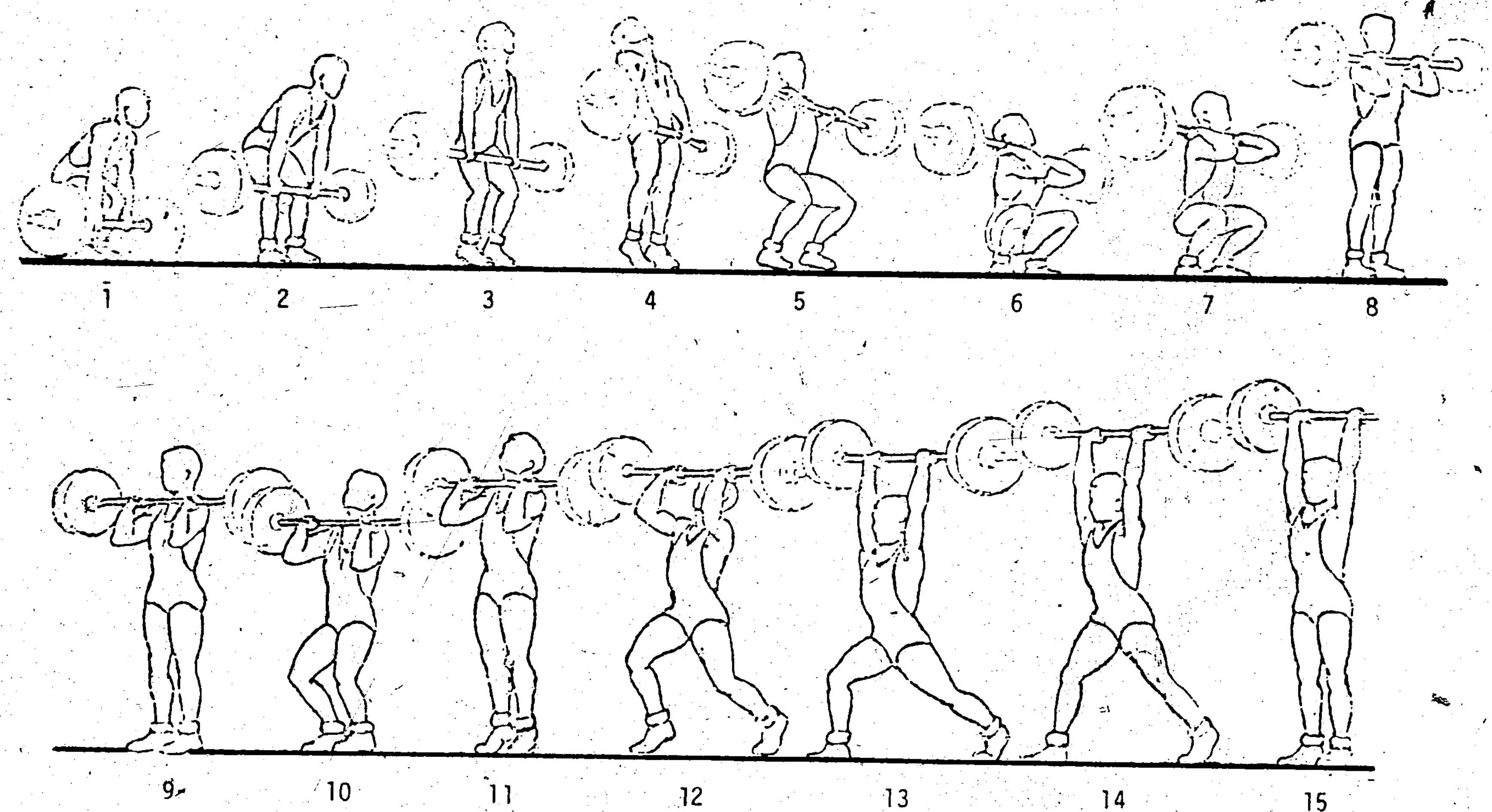
The parts just described can be broken down further into phases. It is convenient to subdivide the pull during the clean into three phases. The first pull takes place between the floor and knees (pictures 1-2). The scoop occurs when the position of the bar is between the knee and hip joints (pictures 2-3). The second pull takes place between the hips and the point where vertical force ceases to be applied to the bar (pictures 3-4).

The word 'scoop' refers to a movement which realigns the body segments into a more efficient configuration. The hips are displaced anteriorally which causes the knees to flex or rebend. The double knee bend or rebend technique derives its name from this characteristic action.

The dead lift is one of the events performed in competitive power lifting. It has a first pull in common with the clean.

Figure 1

Pictoral Representation of Clean and Jerk,



CHAPTER TWO

REVIEW OF LITERATURE

Definition of Terms

Whitcomb (1969) studied the clean and jerk from a descriptive point of view and in doing so, used fourteen headings to classify the information obtained. The same breakdown, with some modifications, deletions and additions, has been used in this report. For the purposes of this study, the clean and jerk has been divided into seven phases which contain thirteen positions of importance.

The First Pull: that part of the pulling motion during the clean which takes place between the floor and the knees. There are three positions associated with the first pull;

The Starting Position: the configuration of the body segments immediately prior to initiating the lift.

The Bar Off Floor Position: the configuration of the body segments immediately after initiating the lift.

The Knee High Position: the configuration of the body segments when the scoop commences.

The Scoop Phase: when Whitcomb conducted his study, the double knee bend technique with its scooping motion, was unheard of. He, therefore, had no term for it. The scoop phase of the lift refers to that part of the pulling motion during the clean which is characterized by a rebending or flexion of the knees.

The Second Pull: that part of the pulling motion during the clean which commences upon completion of the scoop and ends when the body begins its descent in order to rack the bar. There are three positions associated with the second pull;

The Bar On Thigh Position: the configuration of the body segments upon commencement of the second pull.

The Full Extended Position: the configuration of the body segments upon completion of the second pull.

The Bar High Position: the vertical position of the barbell relative to the lifter's body as if it was in an erect standing position upon the platform when vertical motion of the bar ceases.

The Squat Phase: refers to the movement of the body when it dips under the bar in order to rack it at the shoulders. Whitcomb defined only one position of importance for this phase of the clean. Another position, the racked position, has been added:

The Racked Position: the configuration of the body segments at the moment that the barbell has been racked upon the shoulders.

The Full Squat Position: the configuration of the body segments when the body has reached its lowest position during the squat.

The Dip Phase: refers to the descent of the body into a position from which thrust can be applied to the bar during the jerk. Two positions are associated with the dip phase of the jerk;

The Preparation for Jerk Position: the erect body segment configuration assumed while preparing for the descent to the dipped position.

The Dipped Position: the configuration of body segments from which thrust will be applied to the bar during the jerk.

The Thrust Phase: refers to the act of vigorously propelling the barbell overhead by extending the ankle and knee joints. The thrust commences from the dipped position and ends upon commencement of descent of the body under the bar. Two body positions are associated with this phase of the lift;

The Full Extended Position: the configuration of the body segments upon completion of application of thrust.

The Bar High Position: the vertical position of the barbell relative to the lifter's body as if it was in an erect standing position upon the platform when vertical motion of the bar ceases.

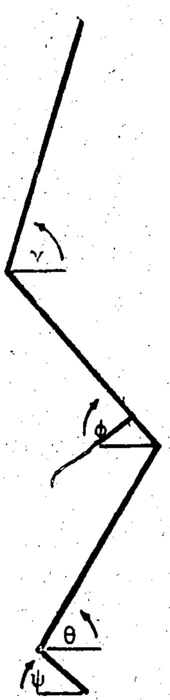
The Split Phase: refers to the fore and aft movement of the legs which permit descent of the body under the bar during the jerk in order to catch the bar at arms length overhead. The split phase also includes recovery of the athlete to an erect standing position with the bar still overhead. The split phase is characterized by one position;

<u>The Full Split Position</u>: the configuration of the body segments after the feet have been replanted upon the platform and all vertical movement has ceased.

This study will frequently refer to angles at four joints of the body, namely, the metatarso-phalangeal, ankle, knee, and hip joints. These angles have been respectively designated as ψ, θ, ϕ, and γ. All of the angles have been referenced to the horizontal (Figure 2). Theta and phi and gamma will also be respectively referred to as the angles at the ankle, knee, and hip joints.

Figure 2

Illustration of Joint Angles Frequently Referred To



Review With Regard to Phases and Positions

The literature contains considerable repetition, that is, the same points are made by many authors. The specific review to follow is, therefore, largely a collection of highlights from these writings and points where authors disagree. The reader can consult various authors for a very basic description of the clean and jerk. Kirkley is probably as good as any for that purpose.

The Starting Position:

Hoffman (1959) recommended a stance which is confortable. The bar should be close to the body and the back flat. Smithinunt (1974) further recommended a hook grip, anterior displacement of the shoulders relative to the bar, straight arms and laterally rotated elbows. Gardner (1974) was even more specific when he claimed that the best foot width is hip width. He further stated that the bar should be positioned over the metatarsal joints. He criticized the Japanese for their narrow foot placement by stating that it results in a cramped, uncomfortable starting position; yields poor lateral stability; and leads to problems for lifters who have anatomical problems such as uneven legs.

Both Webster, as reported by Whitcomb, and Whitcomb (1969) analyzed filmed international lifters and found that the width of foot placement ranged from 11.4 to 21.6 cm. Webster and Whitcomb were also in agreement with regard to the position of the back which was found to range between 25 and 35 degrees when measured from the horizontal. The line of sight was found to be downward at an angle of 45^{0}. The hips were slightly lower than the shoulders but higher than the knees. The shoulders were ahead of the bar and the hands were slightly wider than shoulder width. However, contrary to Webster, Whitcomb found the toes pointing straight ahead rather than outward.

Miller (1975) has given three reasons for commencing the lift with the thigh angled above the horizontal. First, there is a natural tendency to displace the bar posteriorally instead of upward. Second, the leverages of the joints are more efficient. Third, "the lever arm (where the bar would intersect the spine) will be decreased since the back will be lower".

The First Pull:

<u>The Bar Off Floor Position</u>:

According to Kirkley (1957), the lifter should pull the bar off the floor as quickly as possible. Massey et al (1959), on the other hand, have suggested that the initial force required to overcome the inertia of the weight, must be the result of a slow pull. Hoffman (1959) was more general in his description when he stated that the lift is commenced slowly and the velocity of the bar increases as it rises off the floor. Miller (1974a) gave reasons for pulling the bar slowly. He stated that a fast pull displaces the bar anteriorally. Further, the contractile force generated by contracting muscles decreases rapidly as the velocity of contraction increases. However, he later modified this statement somewhat by stating that the first pull should be as fast as possible having regard for the leverages present and good body position (Miller, 1975) but that there should not be any concern for lost power as a result of increased velocity of muscle contraction because the increased mechanical advantage of the lever system would more than offset the loss of contractile force. Gardner (1974) provided another reason for a slow pull when he pointed out that the rebend at the knees requires time to take place. Smithinunt (1974) has stated that the bar is not jerked from the floor and that the ensuing first pull should be both close to the shin and the result of contracting leg muscles as opposed to back extension.

Miller (1974a) has stated that the weight of the body is initially centred on the balls of the feet and is then displaced posteriorally as the lift continues to the knee high position. Confirmation of the shifting nature of the centre of pressure was found in Garhammer's force plate analysis of the snatch lift (1976). The hips move vertically upwards and the angle of the back to the horizontal remains constant.

Webster (as reported by Whitcomb) found the back to be in the same position just after the bar leaves the floor as in the starting position. Whitcomb (1969) found the same thing except the shoulders of his subjects exhibited a tendency to drop and move anteriorally while the bar was being pulled to the knee high position.

The Knee High Position:

Webster (as reported by Whitcomb) found that the primary source of vertical motion is still knee extension when the bar reaches the knee high position. There is some extension of the back and the shoulders are anterior to the bar. Whitcomb (1969) found essentially the same thing.

The Scoop Phase:

As the bar passes the knee high position, the posterior displacement of the centre of gravity of the body reaches its maximum (Miller,1974a). Commencement of the scooping motion displaces the centre of gravity back toward the balls of the feet where it resides until the lifter assumes the full extended position at the end of the second pull. The hips move forward and upward causing the knees to rebend under the bar.

The act of rebending the knees restretches the quadriceps thus enabling them to pull more powerfully (Miller, 1975). Rebending also introduces a short period during which the contracting muscles can relax because the quadriceps are eccentrically controlling the forward and downward motion of the scoop. Finally, the scoop dramatically alters the system of levers such that the increased efficiency of the system outweighs the loss of contractile force.

O'Shea (1969) has noted that every effort should be made to keep the head and shoulders ahead of the bar as the bar passes the knees.

The Second Pull:

The Bar on Thigh Position:

Whitcomb defined this position as being slightly above the knee joint. Since it is not clear whether or not his position is the same as that defined in this report, comments from his study will not be reported. The findings were suggestive of both the Knee High and the Bar on Thigh Positions.

The Full Extended Position:

All authors are in agreement that full extension is very desirable. Webster (as reported by Whitcomb) believes that the extended body should make an angle of 103 - 104° to the horizontal when measured in the same sense as θ. Whitcomb (1969) found all of his subjects extending into this range and some even exhibited hyperextension. The angle of the back (to the horizontal) ranged from 92° to 105°. The direction of vision was 45° upward and shoulder elevation was noted.

It is during this phase of the lift that the arms and shoulders exert their pulling power (Hoffman, 1959). Smithinunt (1974) found it convenient to introduce the notion of a third pull which is characterized by use of the arms and shoulders to apply force to the bar.

Movement of the body to the full extended position should be thought of as a jumping away from the platform with a weight in the hands (Miller,1974a). The second pull is initiated by an accelerated extension of the hips and knee joints and not by an extension of the back.

Miller has discussed the action of the wrists at the top of the pull. Flexion at the wrist joint not only prevents bar swing but it throws the elbows forward and laterally causing the trapezius to stretch and therefore, contract more powerfully. Further, placement of the elbows forward facilitates execution of an upright rowing motion which causes the trapezius to pull vertically and raise the scapula maximally upon the ribs. If the elbows were positioned posteriorally, the rhomboids will assume a dominant roll and the result will be displacement of the scapula resulting in a reduction of pulling power.

The Bar High Position:

Webster (as reported by Whitcomb) found an approximate one-third split between those whose bar high position was above, level and below the belt. He also found that the bar continued to rise after the lifter had commenced his descent into the squat. Whitcomb (1969) found the same thing. In addition, he found that the feet had already re-established contact with the platform when the bar high position had been reached. The shoulders were abducted and the back was near the vertical. The back angle ranged from 85^{0} to 102^{0}.

The Squat Phase:

From the full extended position, the lifter descends into the full squat position, O'Shea (1969) produced time/displacement data for what he classifies as good and champion lifters. The author produced figures for the velocity of shoulder drop in the vertical plane during the squatting motion. Table 1 summarizes the findings:

TABLE 1

Shoulder Drop Velocity During the Squat (cm/sec.)

Subject	Good Lifter	Champion
1	195.1	237.7
2	179.8	277.4
3	185.9	274.3
4	149.3	222.5
Average	176.9	253.0

The total elapsed time for the descent was .24 seconds and it is clear from the data that the champion performer is able to get under the bar much faster than the good lifter.

An interesting comparison can be made of the above findings to the characteristics of the clean by Rigert (Shakirzianov, 1974). Rigert took between 0.2 and 0.22 seconds to descend into the full squat position and of this time, between 0.05 and 0.07 seconds was spent in free fall motion. Since the total distance dropped was 59 cm, the average drop velocity was 287.8 cm/sec. Both the time of descent and the velocity of descent agree with the data presented by O'Shea.

Gardner (1974) has claimed that the descent to the full squat position at such a high velocity can only be accounted for by the ability of the lifter to pull himself under the bar.

The Full Squat Position:

Webster (as reported by Whitcomb) has stated that the back should be at an angle of 60 - 70° to the horizontal. Whitcomb (1969) found the angle to range from 68 - 82°. In addition, foot placement was slightly wider than shoulder width and the knees were anterior and lateral to the feet. The upper arms were at an angle of 45° to the horizontal and vision was straight ahead.

The Dip Phase:

The Preparation for Jerk Position:

Whitcomb (1969) found foot placement to be slightly narrower than shoulder width. The bar was held on the clavicles and the elbows were directed anteriorally.

Hise (1974) warned lifters against rushing the jerk and allowing the bar to slide off the sternum or deltoids. He then outlined three basic positions for holding the bar in the preparation for jerk position.

1. The bar is held well back on the deltoids and sternum at a position where the bar touches the neck. The elbows are high with the upper arms parallel to the floor.

2. The bar is held in the middle of the deltoids so that it is touching the sternum and the forearms are 30° off the perpendicular.

3. The bar is held at the front of the deltoids and upper chest with the forearms perpendicular to the floor.

Hise felt that the position described in (2) is optimum for most lifters. He pointed out that, as a general rule, the magnitude of the dip and the extent of the split are inversely related. This relationship follows from the belief that the magnitude of the thrust, which can be imparted to the bar, is directly related to the depth of the dip.

The Dipped Position:

Kirkley (1957, 1974) stated that the dipping movement is effected by a fairly rapid bending of the knees to a maximum depth of 4 to 6 inches and that the trunk must be displaced absolutely vertically if the ensuing thrust is to be vertical as well. The split commences when the bar is at the top of the head and the arms apply thrust in order to vigorously propel the barbell to the overhead position. O'Shea (1969) believes that the dip should be short while Hoffman (1959) recommended a moderate dip 'with a jerk or a jolt'. If the dip is too low, the body will have a tendency to be displaced forward. Smithinunt (1974) recommended a dip which was 15 cm in depth and Hise (1974) cautioned against dipping too slowly. He agreed, however, that the dip is as vertical as possible.

The Thrust Phase:

At maximum depth in the dip, the legs are extended. Near the end of extension, the body rises onto the toes in order to achieve maximum height before splitting (Kirkley, 1974; Murray and Karpovich, 1956). O'Shea (1966) believes that thrust comes from extension of the arms and legs while Gardner (1974) claimed that an overlooked source of thrusting power is elevation of the shoulders. Hoffman (1959) has stated that the weight achieves a height not much greater than the shoulders during the jerk movement and the key, therefore, is to dip under and catch the bar at arms length before it has had an opportunity to drop.

Webster (as reported by Whitcomb) found that the split commences as the bar leaves the shoulders. Whitcomb's analysis was more precise. The feet are planted when the bar is an inch off the shoulders.

The Split:

Commencement of the splitting motion of the feet causes the body to lose support upon the platform and the body thereupon descends to the full split position. Smithinunt (1974) seemed to recommend a hard push against the bar with the arms after the splitting movement has begun. Gardner (1974) claimed that the arms exert such a thrust.

The rear foot leaves the platform before the front and the bar is at the top of the head when the feet lose contact with the ground (Whitcomb, 1969). Hise (1974) advised lifters to allow the back foot to re-establish contact with the platform before the front when splitting.

The Full Split Position:

This position incorporates the 'feet on floor position' of Whitcomb. Whitcomb (1969) found the bar to be 15 cm. above the head at the moment contact is made with the platform. The body continues to lower itself into a full split position. The front foot often points medially and recovery is initiated by moving the front leg back one step while the rear leg remains stationary. The rear leg is then brought forward. According to Hise (1974), 95% of all top lifters recover in this manner.

According to Kirkley (1957), vision should be directed straight ahead and a vertical line should fall through the bar, head, shoulders and hip. The legs should be almost equally displaced fore and aft.

Paths of the Barbell, Hip and Shoulder and Their Relationship

The means to completion of a successful maximal lift is the efficient application of force in the vertical direction. A measure of efficiency may be obtained by recording the path of the barbell throughout the lift. The path of the bar was very apparent when the swing or back extension style of lifting predominated and the literature from that era abounds with discussion about the 'S' shaped path produced and how one could eliminate it. Identification of the double knee bend as a technique has caused the attainment of a vertical path for the bar to become a theoretical possibility. As a result, increased attention is now being paid to the path of the bar.

In the past, the absence of scientific studies produced as many descriptions of the ideal path as there were writers expressing an opinion. Kirkley (1974) recommended a path which was as close as possible to the body. Murray (1956) stated that the bar should be anterior to its starting position when racked.

Whitcomb (1969) found considerable variation in the path produced among the high calibre lifters as well as among the attempts of an individual. Figure 3 is a modified reproduction of the plotted paths for the five lifters used in his study. All of the curves exhibit posterior displacement during the first pull, anterior displacement during most of the second pull and finally, posterior displacement again as the second pull nears its conclusion. Point A is the extended position in the clean and B is the bar high position. Whitcomb indicated that the squat is initiated when A is reached. Point C is the preparation for jerk position while D is the thrust position. It is interesting to note that in no case is the dip vertical while the thrust tends to be near the vertical. Although there is a pattern to the pull, there is no tendency

Figure 3

Paths of the Barbell - Lateral View
(Whitcomb, 1969)

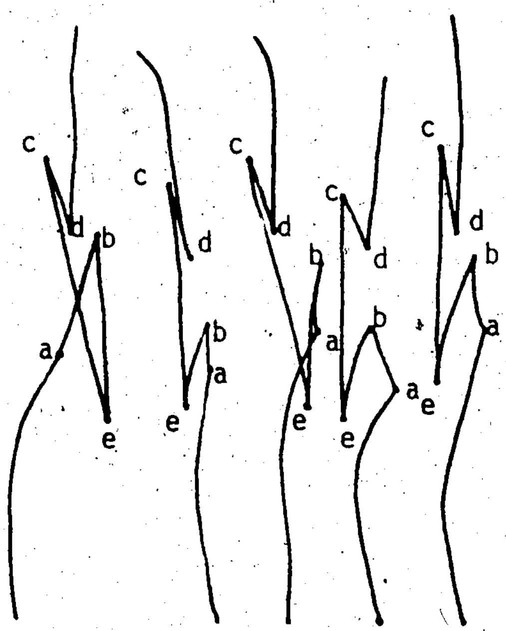
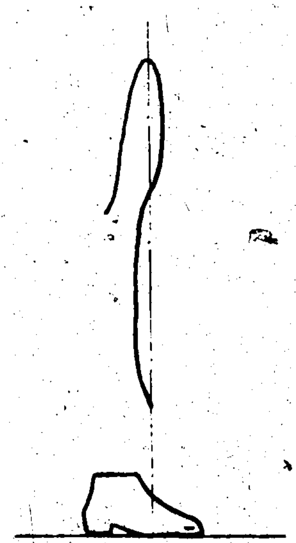


Figure 4

Trajectory of the Clean by Dave Rigert
(Shakirzianov, 1974)



shown in the jerk other than the direction is up. The dip is anteriorally displaced in every case.

It is now pertinent to compare the above curves with the path produced by the finest lifter in the world, namely, the curve of Dave Rigert (Shakirzianov, 1974). Figure 4 is the path of the bar from the starting position to the low position in the squat (to point E in Figure 3). Twenty cleans were analyzed of which seventeen were in competition and three were training lifts. The path appears to be much more vertical than those of the American lifters. The maximum horizontal displacement of the bar during the pull never exceeded 4 cm. The outstanding feature of this graph is the verticality of the pull and the apparent consistency under stressful circumstances.

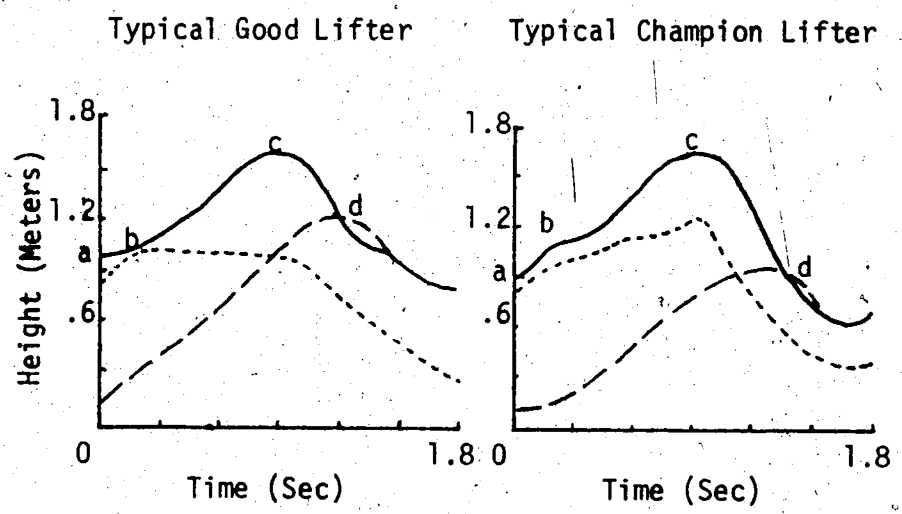
Rigert uses a double knee bend style of lifting and one can be reasonably sure that at least some of the Americans in Whitcomb's study were using the back extension style. Assuming this to be the case, the two pictoral presentations offer an interesting opportunity to compare the paths produced from both styles.

Miller (1975) has pointed out that the bar must be pulled vertically if maximum efficiency is to be achieved. In practise, according to him, this is not possible because the bar is initially placed over the metatarsals and must be brought in. However, a deviation of 5 cm from the vertical is acceptable in his opinion. He further pointed out that bringing the bar in closer to the ankles will only shift the weight of the body back upon the heels and will cause the bar to be displaced even further back.

O'Shea (1969) produced two displacement graphs which compare displacement patterns for good and champion lifters (Figure 5). The distance AB represents the first pull while BC is the second pull. Although the author did not say so, it appears that the level portion of the shoulder line at B on the 'champion' graph is probably the scooping

Figure 5

Comparison of Bar, Shoulder and Hip Movement in the Vertical Plane During the Clean



A Start of clean
B End of first pull
C End of second pull
D Shoulders meet bar

Bar — — — — —
Shoulder ————————
Hip ------------

TABLE 2

Relationship Between Hip Height and Bar High Position

Good Lifter	Hip Height (cm)	Bar Peak Height(cm)	Difference
Berger	93.3	98.7	+ 5.5
Williams	97.5	125.0	+27.4
Norton	101.5	111.2	+ 9.7
Total	292.3	335.0	
Overall Total	621.5	737.0	
Mean	103.6	122.8	+19.2
Champion Lifter			
Kono	103.0	108.8	+ 8.2
J. George	108.5	98.7	- 9.7
Shepart	106.1	98.7	- 7.3
Total	316.1	307.2	
Overall Total	721.2	726.0	
Mean	103.0	103.6	+ 0.6

action. The graph also demonstrates constant upward displacement of the hips. The hip line for the good lifter is very steep during the first pull which is indicative of the swing style. During the second pull, the hip of the good lifter falls as the back is extended. The champion lifter continues to raise his hips confirming that his lifting power is the result of knee and hip extension. Another difference is the sharp rise between A and B of the shoulders in the case of the champion. Table 2 lists some relationships between hip height and peak bar height. In the case of the champion, the maximum height of the hips at the end of the pull is higher than that for good lifters and the height to which the bar is pulled is less for the champion. Good lifters pull higher than hip height whereas the champion lifter tends to pull only to hip height or less.

A comparison with the foregoing can be made using the parameters characteristic of the clean of Rigert (Shakirzianov, 1974). The bar high position for Rigert in the clean is 97 cm. Having a stature of 173 cm, the athlete's hip height is approximately 105 cm. The difference, therefore, between the height of the bar at the bar high position and the height of the hips in a standing position is 6.7 cm; that is, Rigert pulled the bar to a height which was 6.7 cm below hip height. These figures are in agreement with the statements made by O'Shea.

O'Shea (1969) pointed out that the principle of force application suggests a delay in the use of arm and shoulder muscles until the force produced by the legs and hips has peaked at which time, the arms and shoulders can be applied effectively. In the case of the good lifter, in his study, the hips peaked too soon and weaker body segments had to somehow compensate.

Lifting Styles In Terms of Joint Angles

Lifting technique has been analyzed from the point of view of joint angles, namely, the ankle, knee and hip joints. Whitcomb (1969) reported angles for all three joints. The subjects were national calibre American lifters and at least one was ranked internationally. Miller (1974a) has also reported joint angles for the same three joints. Table 3 summarizes these results.

Alterations have been made to the original data reported by these authors in order to make the information directly comparable. The definitions of the angles used in this report were reported in the introduction.

TABLE 3

Comparison of Joint Angles For The Clean
(Degrees)

	POSITIONS			
	Starting	Knee High	On Thigh	Extension
Ankle (θ)				
Miller (Double Knee Bend)	71	95	80	92
Whitcomb	79	108	103	118
Knee (ϕ)				
Miller (Double Knee Bend)	11	63	58	88
Whitcomb	2	50	46	62
Back (γ)				
Miller (Double Knee Bend)	37	40	79	95
Whitcomb	32	30	56	97

Velocity Parameters Associated With the Clean and Jerk

Ono et al (1969) studied film records of Olympic champions and Japanese lifters and computed velocity data from the information obtained. Whitcomb (1969) also obtained average velocity data from his study and the results from these two investigations have been summarized in Table 4. In both cases, the exact nature of the cleaning technique being used is unknown. As mentioned elsewhere in this study, the evidence suggests that the subjects, in Whitcomb's study, used the back extension style of lifting. Similarly, many of the subjects in Ono's study were probably using the back extension style also. In addition, the Japanese subjects would have used the Frog Style of cleaning.

Studies conducted by Shakirzianov (1974) and Garhammer (1978) contain bar velocity information for lifters using the double knee bend style of lifting. Shakirzianov reported velocity data for first and second pulls performed by Rigert. Garhammer, as part of a longitudinal study of world class Olympic weight lifters, produced peak bar velocity data for the clean and jerk from the lifts of 12 American and Russian athletes who performed at either the United States championships or the Las Vegas International Invitational Meet. Garhammer's data for the clean contained one value (203 cm/sec) which did not appear to fit the pattern of the others. It was excluded by the writer and the resultant mean and range are tabulated in Table 4.

The average velocity value computed by Ono was over a time interval of six-sixty-fourths of a second. Therefore, the designation of his values to a specific position should be regarded as an estimate which was effected in order that a comparison to other studies could be made. Ono computed two velocity values for the bar during the jerk. The first of these has been recorded in Table 4 and it appears to be the velocity of the bar as it passes its preparatory position in the preparation for jerk position. The exact nature of the second value is unclear but it appears to be the average velocity after the bar has passed the preparation for jerk position.

TABLE 4

Velocity Parameters of the Bar
From Studies Reported in the Literature
(cm/sec.)

	Knee High Position	Full Extended (Clean)	Velocity as the Bar Passes the Prepara-Tory Position (Jerk)
Ono	162	187	137
Whitcomb	61	119	144
Failures (Ono)	-	-	81
Rigert	137	157	-
Garhammer	-	145	148
(Range)	-	(127-168)	(140-181)

Power Output During the Second Pull and Thrust Phases

Garhammer (1978) computed the power generated by world class weight lifters during the second pull and the thrust phases of the clean and jerk. Values in the vertical plane for the second pull phase varied from 2121 to 2335 watts for two athletes weighting 52 and 56 kilograms. The loads on the barbell ranged from 117 to 130 kilograms. Values for the jerk were 2563 and 2611 watts for lifts of 117 and 130 kilograms respectively.

Anatomical Considerations

Body Segment Parameters

A number of anatomical characteristics of the body have special relevance for the performance of the clean and jerk. The most obvious of these features are the body segment proportions.

McCammon (1970) and associates conducted a longitudinal study of 334 subjects from which yearly anthropometric measurements were taken. Mean absolute and relative stature and crown-rump heights did not vary

Figure 6

Axis of the Thigh and Leg Segments

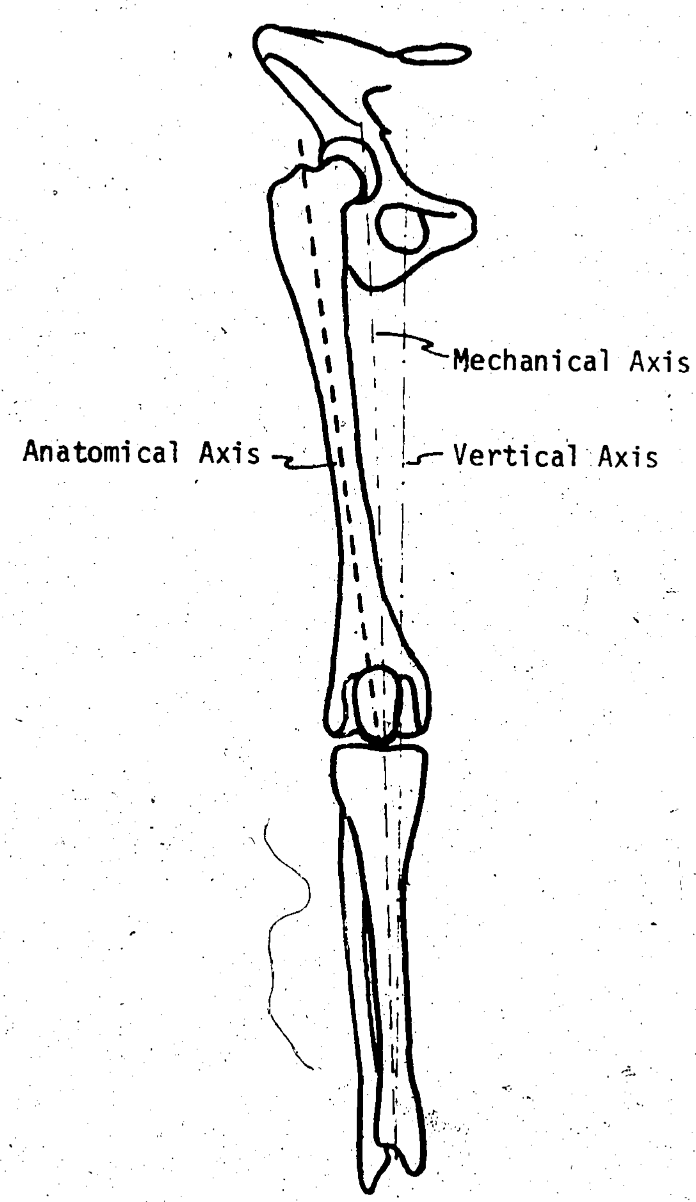


TABLE 5

Comparison of Bone Lengths as a Percentage of Height from McCammon and Maresh

	McCammon	Maresh	Average
Femar	28.7%	28.6%	28.7%
Tibia	24.1%	24.0%	24.0%
Lower Limb	52.8%	52.6%	52.7%
Humerus	19.6%	19.6%	19.6%
Ulna	14.7%	14.8%	14.7%
Upper Limb	34.3%	34.4%	34.3%

significantly after the age of 19 years. Sitting height (crown-rump height) was found to average 52.2% of stature.

Due to the peculiar structure of the femur, direct measurement of its lever length is impossible where lever length is defined as the distance along the mechanical axis of the femur between the proximal and distal centres of rotation. The mechanical axis is one of three axis associated with the lower limb (see Figure 6). Both McCammon (1970) and Maresh (1959) have published tables containing bone lengths along the mechanical axis of the femur and the other limb segments as well. Measurements were taken from X-ray photographs and they include the most proximal and distal aspects of the bones. The findings are summarized in Table 5.

TABLE 6

Summary of Body Segment Proportions Used in Mechanical Analysis (as a Percentage of Stature)

Upper Limb:	Humerus	17.4%
	Ulna	16.9%
	Total	34.3%
Lower Limb:	Femur	25.8%
	Tibia	24.8%
	Total	50.6%
Other:	Crown/Rump Height	45.8%
	Ankle to Floor	3.9%
	Metatarsal/Phalangeal to Ankle	7.8%

The data from McCammon and Maresh was adjusted in accordance with figures produced by Plagenhoef (1971) in order to compute the distance between the joint centres of the limb segments. The height of the ankle joint off the floor was measured to be approximately 3.9% of stature. The distance from the ischial tuberosities to the axis of rotation in the acetabulum was estimated to be 6% of stature. As a result of these adjustments, a set of segment lengths, expressed as a percentage of stature, was compiled for use in mechanical computations (see Table 6). Another lever length included in Table 6 is the distance between the metatarso-phalangeal and ankle joints. This dimension, also expressed as a percentage of stature, was measured to be an estimated 7.8% of stature.

The distribution of body mass and the locations of the segmental centres of gravity for the mean man were assumed to be as reported by Clauser et al in Miller et al (1973). The sum of the masses was greater than 100%. All ratios, except for the trunk, were similar to ratios reported in other studies. The excess was, therefore, deducted from the value assigned to the trunk to yield 47.7% rather than 50.7%. The data is summarized in Table 7.

TABLE 7

Segmental Mass and Centre of Mass Ratios

Segment	Mass as a Percentage of Total	Location of Centre of Gravity from Proximal Border as a Percentage of Limb Length
Head	7.3	47
Trunk	47.7	38
Upper Arm	2.6	51
Lower Arm	1.6	39
Hand	0.7	18
Thigh	10.3	37
Leg	5.8	37
Foot **	1.5	45

** Distance from plantar surface.

The Centre of Gravity of the Whole Body

The location of the centre of gravity has been measured by many researchers and all have concluded that, on the average, the centre of gravity in the vertical plane of the male is located a distance equal to 56% of stature above the plantar surface of the feet. Of particular interest to this study is the potential for the mass segments to move relative to the centre of gravity as a result of changing the configuration of the segments. Swearington, as reported by Duggar (1962), conducted a comprehensive study of this problem. Swearington found that the centre of gravity could be superiorally shifted as much as 29.2 cm. as a result of changing the configuration of the body from one which maximally lowered it to one which maximally raised it relative to its position when the body is in the anatomical position.

Movement of the Joints

The range of flexion at the hip joint is more than adequate for any segment configuration created during the lifting movement. The range of extension, on the other hand, is severely limited by the iliofemoral ligament. Kapandji (1970) and Steindler (1955) have both agreed that the range of extension passed the anatomical position is 20 degrees when the knee is in an extended position and 10 degrees when the knee is flexed. The joint can be forceably extended to 30 degrees.

The range of extension at the hip joint can only be increased by tilting the pelvis anteriorally which manifests itself in an exaggerated lordosis. It is worth noting, as Kapandji (1970) has pointed out, that trained ballerinas compensate for tight hip ligaments by tilting the pelvis anteriorally.

The range of movement during forced flexion is much greater than during active flexion and can be as large as 145 degrees. Within this range, the lumbar lordosis remains normal.

The normal range of dorsi flexion at the ankle joint is between 20 and 30 degrees while the normal range of plantar flexion is 30 to 50 degrees (Kapandji, 1970).

Role of Intra-abdominal Pressure During Weightlifting

The role played by intra-abdominal pressure during weightlifting was first explained by Bartelink (1957) who was searching for an explanation of why the vertebrae were not crushed during heavy lifting movements. If moments of force are computed in the manner of Bradford and Spurling (1945), one finds that the act of lifting a relatively light weight will result in a compressive force of 6,682 newtons at the lumbo- sacral disc. The significance of the magnitude of the load becomes clear when one reviews the fracture values for vertebrae (Table 8).

TABLE 8

Maximum Compressive Force Required to Fracture Lumbar Vertebrae

Researcher	LOAD Newtons
Eie (1962)	6,370
Rolander & Blair (1975)	3,018
Evans & Lissner (1959)	3,074
	6,014
Bartelink (1957)	6,236

Bartelink proposed that the abdominal cavity acts like a ball when the breath is held. Others have likened it to a rigid cylinder which is supportive along the long axis of the trunk. Intra-abdominal pressures have been measured by various researchers and the results are summarized in Table 9.

The magnitude of the supportive force generated by abdominal pressure was computed by the researchers by multiplying the area of the diaphragm by the pressure reading and it was assumed to act in a direction parallel to the long axis of the lumbo-sacral joint. Morris et al (1961) found that the abdominal force reduced the vertical load upon the lumbo-sacral disc by 30%.

TABLE 9

Intra-abdominal Pressure During Exertion

Researcher	Highest Recorded Pressure (mm of Hg.)	Remarks
Bartelink (1957)	140	Athlete
	60	Non-Athlete
Morris, Lucas et al (1961)	172	Derrick Style of Lifting
	200	Crouch Style of Lifting
Eie & Wehn (1962)	225	Athlete
	125	Non-Athlete

It was argued that confirmation of the role played by the abdominal cavity would exist if contraction of the abdominal muscular ceased when an external support system was introduced. Morris et al (1961) had their subjects wear a corset while lifting. The result was that electrical activity from the abdominal muscles ceased.

CHAPTER THREE

MECHANICAL CONSIDERATIONS

If the information contained in the literature is correct, a simple model can be constructed which is capable of describing the kinematics of key phases of the clean and jerk when appropriate assumptions are made. The following general assumptions hold true for all of the phases of the lift being examined except the flight phases.

a) the body segments form a rigid link system. The correctness of this assumption will vary between subjects and within trials for a particular subject depending upon the weight being lifted and the ability of the abdominal muscles to form a 'rigid cylinder' out of the abdominal cavity.

b) the instantaneous centre of segment rotation at the joints does not move but is fixed relative to the segments forming a joint. In other words, it was assumed that the joints act as hinges.

c) TR, T, L and F respectively, represent the lengths of the trunk, thigh, leg and foot segments where the foot segment is defined as the length between the ankle and the metatarso-phalangeal joints.

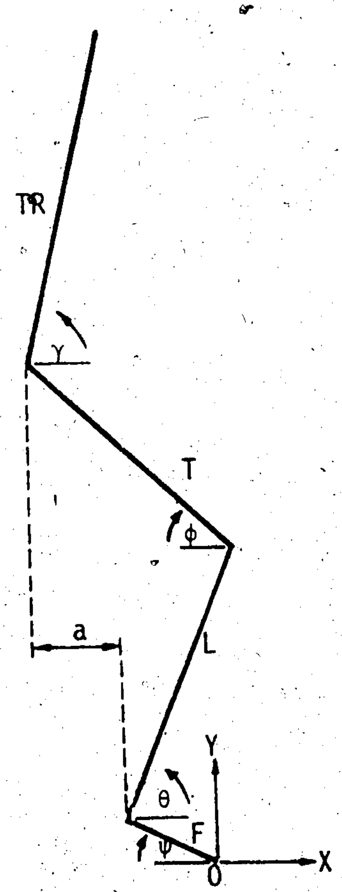
d) the metatarso-phalangeal joints are fixed.

e) movement of the body segments is planar.

The components of the model are illustrated in Figure 7. The trunk, thigh, leg and foot segment lengths are respectively represented by TR, T, L and F while the angles γ, ϕ, θ, and ψ respectively represent angles at the hip, knee, ankle and metatarso-phalangeal joints. The letter 'a' is the horizontal distance of the hip joints from the ankle joints. The metatarso-phalangeal joints are centred at the origin of the X-Y co-ordinate system.

FIGURE 7

Figurative Representation of the Components of a Model of the Clean and Jerk



The position of the shoulder joint can be specified by the following trigonometric relationships:

$$Y = TR \sin \gamma + T \sin \phi + L \sin \theta + F \sin \psi \qquad (1)$$

$$X = TR \cos \gamma - T \cos \phi + L \cos \theta - F \cos \psi \qquad (2)$$

The First Pull

The introduction of suitable constraints permits the adaptation of the above equations to important phases of the clean and jerk. The barbell moves vertically between the platform and the knees during the first pull. Smithinunt (1974), Miller (1974) and O'Shea (1969) have all recommended the application of lifting force through contraction of the knee extensor muscles as opposed to the extensors of the trunk which act about the hip joints. The hips should rise vertically throughout the first pull and the trunk should maintain a position parallel to its configuration at the commencement of the lift.

Three constraints were placed upon movement of the component parts of the model. First, the hip joint was constrained to move vertically a distance 'a' from the ankle joint. Second, the initial value of γ had to remain unchanged for the duration of the first pull. Third, the value of ψ had to maintain a constant value equal to zero for the duration of the first pull.

The two equations developed earlier to describe the position of the shoulder joint can be used to describe movement of the barbell given the constraints imposed. Since the angles γ and ψ have constant values, the bar must move vertically in the same way as the hip joint and since the hip joint can only move vertically, the position of the hip joint in the vertical plane can be specified by the equation:

$$Y = T \sin \phi + L \sin \theta \qquad (3)$$

The equation can be further simplified by writing ϕ as a function of θ:

$$\phi = \arc\cos\left[\frac{L \cos \theta + a}{T}\right] \qquad (4)$$

Values reported by Miller (1974) for θ and ϕ at the commencement of the lift were substituted into equation (3) as were values for T and L developed elsewhere in this report in order to compute the value for 'a'. The angle of θ was then allowed to take a maximum value of 88^o which, according to Miller (1974), is its value at the end of the first pull. Knee height was computed as the sum of the unadjusted shank length (24), the distance of the ankle joint above the plantar surface (3.9) and the thickness of the sole of the boots worn on the feet. It was discovered that the barbell cannot be displaced above the knee joints under these circumstances and that the maximum value which ϕ could attain was 46^o.

In view of the foregoing, it was theorized that the application of force, as the result of contraction of the knee extensors, would cease when the bar had reached the distal end of the patella. Continued vertical displacement of the bar would be effected by extension of the trunk at the hip joint until the bar was in a position superior to the patella at which time the scoop would commence.

The Scoop

It was further theorized that the scooping action would continue until the hip joint had moved horizontally to a position over the ankle joint at which time γ would have a value of 90^o. Continued vertical displacement of the barbell during the scooping movement would have to be the result of trunk extension about the hip joint. The configuration of the body segments at the end of the scoop would be similar to that which is characteristic of the dipped position of the jerk.

The Second Pull & Thrust Phase of the Jerk

It was theorized that the second pull would be essentially the same movement as the jerk except that the feet would be slightly plantar flexed. The distance 'a' would be zero and the trunk would be vertically disposed. Displacement of the barbell in the vertical plane would be the same as that for the hip joint.

In the case of the jerk, the thrust phase would be characterized by a zero value for 'a'. The trunk would be near the vertical and thus angular rotation of the trunk could be ignored insofar as its contribution towards development of vertical velocity of the bar was concerned. Vertical displacement of the bar would parallel vertical displacement of the hips. Given these conditions, the vertical position of the hip joint during the thrust phase of the jerk can be defined by:

$$Y = T\sin\phi + L\sin\theta + F\sin\psi \qquad (5)$$

where: $\phi = \arc\cos\left[\frac{L\cos\theta}{T}\right]$

Prediction of Bar Velocities By the Model

If the information contained in the literature is correct, then the model should predict the velocities attained by the bar during the different phases of the lift if expressions for γ, ϕ, θ and ψ, as functions of time, are substituted into equations 1 and 2 and its simplified versions. Expressions for the joint angles were developed for the thrust phase of the jerk. An explanation of the method used and the results obtained are contained in Chapter Six.

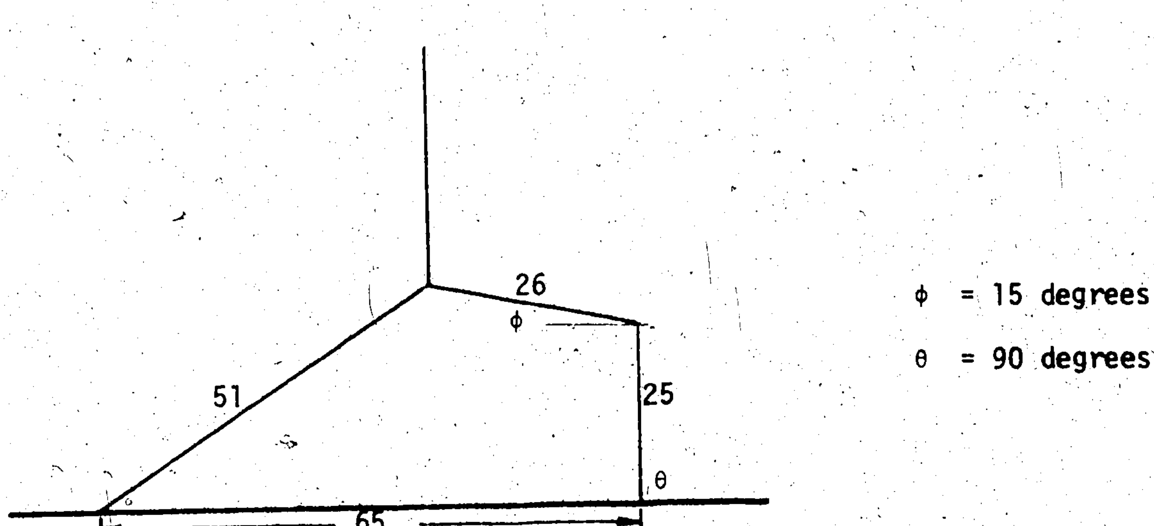
The Optimum Full Split Position

In any skill event, technique is put to optimum use when the skill is performed with the greatest possible efficiency and, therefore, least energy expended. It appears to be self evident that energy expenditure will be minimized if the bar is thrust overhead by the largest and strongest muscle group in the body (the quadriceps) and caught at arms length overhead by limbs which contain substantially smaller and weaker muscles. In order to accomplish this feat, the athlete must, in the extreme, either throw the bar to arms length or displace the body under the bar in order to catch it at arms length. Since both actions are impossible if maximum poundages are to be lifted, a compromise is effected whereby the athlete uses the quadriceps to propel the bar overhead a distance sufficient to allow time for him to drop under the barbell.

Visual observation suggests an optimum full split position which is characterized by a forward leg whose shin is nearly vertical and thigh is angled 10 - 15 degrees above the horizontal. Figure 8 illustrates the full split position where the body segment lengths are shown as a percentage of stature.

Figure 8

Optimum Full Split Position



A number of theoretical computations can be made using the stick drawing of the full split position. It was convenient to perform the calculations using body segment lengths which were expressed as a percentage of stature. The results could then be generalized to the whole population of weight lifters or could also be easily converted into specific values for a given athlete once his body height was known.

The total displacement of the feet from their starting position is 65 units of which 25 units represents the displacement of the anterior foot. As a percentage, the displacement of the front foot is 38% of the total of the two feet.

The velocity given to the bar during the thrust phase of the jerk is dissipated by the force of gravity once the bar has left the racked position at the shoulders. The time required for the bar to lose all of its upward momentum is the amount of time which the lifter has to assume the full split position if he is to catch the bar at arms length overhead before the bar commences its descent to the platform. In the full split position, the extended arms require the creation of 33 units of space (17 + 16) between the bar and the shoulders while the adoption of the full split position creates only [26(1-sinϕ)] 19 units of space. If plantar flexion accounts for an additional 3 units, then 11 units must be created by the thrust imparted to the bar.

Subjects DS and ER are respectively 157 and 160 cm in height. Assuming the conditions outlined above, these lifters must respectively throw the bar a distance of 17.3 and 17.6 cm into the air. Assuming free fall conditions, the required velocity in each case is 184 cm/sec.

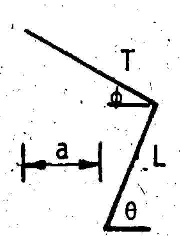


Figure 9

Computation of 'a'

$$a = T\cos\phi - L\cos\theta$$

CHAPTER FOUR

EXPERIMENTAL METHOD AND PROCEDURE

The experimental information contained in this report was gatheredfrom four substudies which comprise the total investigation into the clean and jerk.

Substudy #1

Purpose: to collect general descriptive data from a large number of trials under competitive circumstances.

to collect information about the variability of performance which could be expected from provincial calibre athletes.

Procedure: twenty-four of the best lifts performed at the 1977 Alberta Provincial Championships were filmed from a position lateral to the athlete at a distance of sixteen meters from the platform. The film transport speed was twenty-four frames per second and the exposure time was 1/280th of a second.

Substudy #2

Purpose: to collect general descriptive data from a large number of trials under competitive circumstances.

to collect information about the variability of performance which could be expected from national calibre athletes.

Procedure: twenty-two lifts performed at the 1977 Canadian Weightlifting Championships were filmed lateral to the athlete at a distance of 5.82 meters. The film transport speed was fifty frames per second and the exposure time was 1/475th of a second.

Substudy #3

Purpose: to collect kinematic data in a laboratory test session with regard to barbell and lower limb displacement.

to test the validity of the mathematical models designed to describe the application of force to the barbell.

to collect general descriptive data from a small number of trials performed by two athletes who are of international calibre.

Method: Two variable speed, variable shutter Photo-Sonics #Pl-16mm high speed motion picture cameras were used to photograph the clean and jerk from two vantage points at right angles to each other. The anterior camera, placed at a right angle to the frontal plane of the lifter, was located 15.47 meters from the subject while the lateral camera, placed at a right angle to the plane of motion, was located 12.19 meters away. Figure 10 is a schematic drawing of the layout.

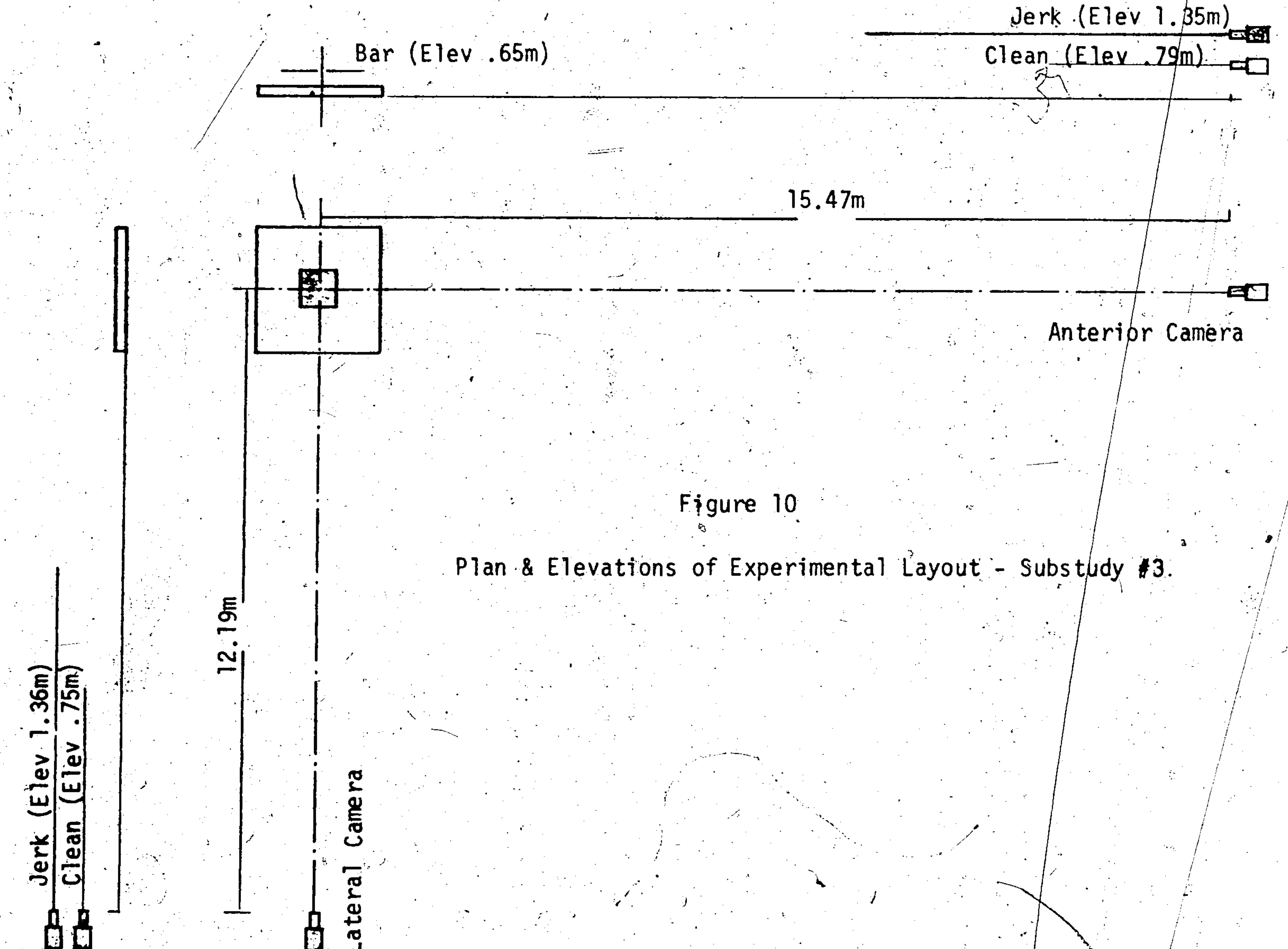


Figure 10

Plan & Elevations of Experimental Layout - Substudy #3.

In order to obtain as large an image as possible and minimize perspective error, it was convenient to separate the lift into its two parts for testing purposes in order to zoom the camera in closer than would otherwise be possible. The cameras were placed at elevations which would be most advantageous for recording the motion of the bar when it was moving at a right angle to the optical axis of the cameras. The anterior and lateral cameras were respective., at elevations of 78.74 cm and 74.93 cm for the clean phases of the lift. T corresponding elevations for the jerk phase were 134.62 cm and 135.89 cm.

The fields of view of the cameras were made small in order to produce a large image. The lateral and anterior views spanned approximately 1.22 meters in the vertical plane while filming the clean.. The corresponding fields during the jerk phase were approximately 1.83 and 1.22 meters. The depth of field for each camera did not encompass the backgrounds which, combined with a minimum f stop setting, produced black backgrounds for each view. A silver bar was used in order to create the necessary contrast required for precise displacement measurements.

The scale used in the anterior view was the bar itself as both the diameter and the distance between the knurling were known with precision. Deviations from the exact value were used to estimate the standard error of measurement and the reliability of the measurements. Each subject's lifting belt was used as a scale in the lateral view. Angular displacement measurements of the limbs were computed with the use of a specially designed ruler which located the long axis of the body segment as it rotated.

The film transport speed was set at 102 frames per second and both cameras were synchronized through the use of a strobotack. The shutter angle was set at 30 degrees with the result that the exposure time was 1/1200th of a second. Ektachrome 7240 color film with an ASA rating of 125 was used.

A timing marker, generated by a single internal electronic timer used for the film record, was attached to both cameras. The film records were synchronized by changing the frequency of the timer from 100 Hz to 10 Hz after filming had commenced.

The ICSSCU spline subroutine, found in the computing sciences library at the University of Alberta, and least square best fit polynomials were used to analyze the data for velocity and acceleration values.

Procedure: Two subjects, DS and ER, were selected for the laboratory test session because of their competance in performing the clean using the double knee bend technique. The subjects, from the 60 and 67.5 kg classes, were asked to perform four cleans and four jerks at 70, 80, 90 and 100 percent of their best lifts. If all four lifts were successfully completed, the load on the bar was increased until a failure occurred. The subjects were allowed to warm up in whatever manner they chose and in whatever amount of time needed between lifts. Spotters lifted the bar to the subject's shoulders for the jerk test phase.

<u>Substudy #4</u>

Purpose: to obtain angular kinematic data about the lower limb segments under competitive circumstances in order to validate the information obtained in Substudy #3.

Method: One of the Photo-Sonics cameras used in Substudy #3 was placed at a right angle to the plane of motion at a distance of 9.14 meters and at a height of .698 meters above the surface of the platform. The magnitude of the vertical field of view was approximately 1.22 meters. The film transport speed was 30 frames per second and the exposure time was 1/480th of a second.

Procedure: the subjects used in Substudy #3 were filmed at the 1978 Alberta Provincial Championships. Markers were placed upon the lifting boots at a point where the ankle joint would be in order to facilitate accurate data collection. Angular displacements were recorded using a ruler designed for the purpose.

CHAPTER FIVE

DESCRIPTIVE AND KINEMATIC RESULTS

Table 10 summarizes the successful lifts which were captured on film as part of Substudies #3 and #4.

TABLE 10

Summary of Lifts Filmed As Part Of Substudies #3 and #4

Substudy #3	Clean (Kg)	Jerk (Kg)	Remarks
DS 1	120*	110	*Anterior view only
DS 2	130	120	
DS 3	140*	130	*Fail
DS 4	140*	140*	*Fail
ER 1	135	125	
ER 2	145*	135	*Fail
ER 3	145	145	
ER 4	155	155*	*Fail

Substudy #4	Clean & Jerk (Kg)	Remarks
DS 1	120.0	
DS 2	130.0	
DS 3	135.0	New Canadian record
DS 4	137.5	New Canadian record
ER 1	145.0	
ER 2	155.0	

Subjects DS and ER are considered to be good lifters from a technical point of view and both have recently reached an international level of competency. The maximum lifts of both subjects are only a few kilograms away from the current Commonwealth records. The lifters are in the 60 and 67 kilogram classes respectively.

Two additional subjects were filmed as part of Substudy #4 as a source of additional descriptive information. Therefore, depending upon the data contained, a particular Table may report the results from lifts performed by two or four subjects.

The findings from each substudy have not been separately reported in the main because of the redundancy which would result. Rather, the headings found in the review of literature were used as focal points for discussing the results from all of the Substudies. Where this format was not convenient or appropriate, the information was discussed separately.

Kinematic information was not taken from the films shot in conjunction with Substudies #1 and #2. However, some information was collected which was indicative of the temporal sequencing of events. The nominal frame rate was considered sufficiently accurate as a timing mechanism and statistics were not developed because of the very large variability found. Probably the most unexpected result of the study as a whole was the variability in performance under circumstances where one would have expected consistency - individual differences notwithstanding. Large differences in performance were expected and found in the results of Substudy #1 where the calibre of performer ranged from the highly skilled to the novice. However, variability was expected to disappear at a national level of competition.

By far the best example of variability of performance was found to be associated with the jerk. If ideal form is as outlined in the chapter headed 'Mechanical Considerations', then the very strong visual impression from the film of substudies 1 and 2 was one of lack of competence. It appeared that the lifters did not know where the bar was when descending under it and/or had not been coached in proper technique. Most failures occur in competition during the jerk part of the clean and jerk and the failure rate at the international level is just as high as it was at the national level of competition. Variability in performance existed between individuals as well as within attempts of a single performer.

General Descriptive Results

The Starting Position:

The starting position exhibited a large variety of body segment configurations and the number and magnitude of the variations seen in competition seemed to increase as the calibre of athlete participating increased. Most competitors assumed a position in accordance with that which is recommended in the literature. The width of the feet never exceeded shoulder width, a hook grip was used by all and the shoulders were positioned ahead of the bar. There were a number of exceptions to the foregoing, however. A number of competitors at the Canadian Championships assumed a starting position characterized by shoulder placement over or even behind the bar. One lifter swung back and forth in an apparent attempt to put the extensor muscles of the lower limb into a prestretched configuration in order to generate more contractile power from them.

The variation found suggests that the configuration of the body segments at the starting position is not of crucial importance although coaches place great importance upon it. The film analyzed as part of this study supports this conclusion.

The First Pull:

Bar Off Floor Position:

All of the lifters pulled the bar off the floor as opposed to jerking it off. Slow motion analysis revealed a noticeable change in body segment configuration once the lift had been initiated. The shoulders moved to a position over the bar and the leg and thigh segments became more vertically disposed while the trunk became more horizontal during the first few hundredths of a second. It would thus appear that the body makes its own small adjustments to the load being lifted regardless of the position adopted in the starting position.

Once the body had begun to lift the weight and the initial configuration adjustments had been made, the bar was lifted by extension at the knee and hip joints such that the hips rose vertically while the trunk maintained its position relative to the horizontal.

A phenomenon not reported in the literature and one which could only be clearly seen in the high speed laboratory film of Substudy #3, was noted as the bar approached the knee high position. When the bar was opposite the patella, the hips momentarily ceased their vertical motion; that is, extension at the knee joint stopped. Continued vertical displacement of the barbell was effected by extension at the hip joint. This phenomenon lasted until the scooping action was initiated.

Knee High Position:

This position did not coincide with knee height but was found to be slightly above the superior border of the patella. As noted above, the only segmental motion in evidence at this position was trunk extension.

The Scoop:

When the bar reached the knee high position, the scooping motion commenced. The angular motion of the trunk continued as the hips began to rotate towards the bar and the leg began to rotate anteriorally. The position of the ankle joint remained fixed during the initial moments of the scoop but when the angle θ decreased to approximately 80^{o}, the position of the leg became fixed relative to the foot and both leg and foot rotated together until plantar flexion had reached a value of approximately 15^{o}. Rotation of all of the segments continued until the bar on thigh position was reached.

The Second Pull:

The Bar On Thigh Position:

The bar on thigh position marked the beginning of the second pull phase of the lift and it occurred with a definite collision between the thigh and the bar. The collision has been described as a "brushing" together but visual evidence from the film suggests that "collision" would be more appropriate. The trunk rotation exhibited during the scoop continued as the bar passed through the bar on thigh position although at a much lesser rate and rotation did not cease until the trunk had extended approximately 10 degrees past the vertical.

At the bar on thigh position, the knee joint commenced extension while the lifter remained on the balls of his feet. At this moment the barbell was just below the level of the crotch. The subjects used in Substudies #3 and #4 tended to extend vertically from this point through to the full extended position. However, greater rotation of the trunk during the second pull was exhibited by many lifters at the Canadian National Championships. As extension neared completion, the feet plantar flexed a further 5 - 10 degrees.

The Full Extended Position:

Full extension of the body was found to almost never occur as there was always slightly less than 10 degrees of flexion at the joints. The angle γ at the hip joint had passed through 90 degrees for all subjects.

Once the full extended position had been achieved, there tended to be a slight pause lasting approximately 5/100th's of a second during which time the arms were observed flexing. However, elevation of the shoulders was not seen. The pause has been referred to by some authors as the 'top pull' where the weaker muscle groups in the arms and shoulders apply force after the large muscles of the thigh have completed their action.

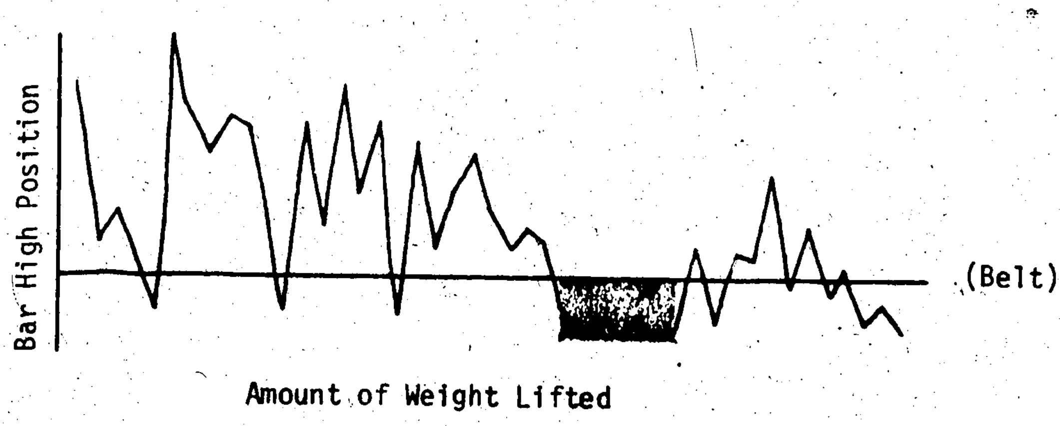
The Bar High Position:

The bar high position occurred after the second pull had ended and at almost the exact moment of replant during the squat phase of the lift. The less able and less experienced athletes pulled the bar much higher during the second pull and as a result, the maximum height attained was higher also. Data from the Alberta Provincial Championships (Substudy #1) illustrate this point. (Figure 11) The absissa may be regarded as an ability scale because it is a measure of the amount of weight being lifted. At contests such as these all weight classes lift together and the bar is progressively loaded. Thus, the more capable lifters tend to lift last. Referring back to the graph, a general trend towards a lower bar high position can be seen as the weight on the bar increased. The lowest values, which have been shaded, are the values for the two subjects used in Substudies #3 and #4.

The bar high position in Substudy #3 depended upon the magnitude of the load being lifted and it ranged from a position just below the belt to one slightly below the level of the hip joint.

Figure 11

Bar High Position 1977 Alberta Championships



The Squat Phase:

The descent into the full squat position was initiated by flexion at the knee and ankle joints followed by displacement of the feet off the platform and hip flexion several hundredths of a second later. Flexion at all three joints continued until an angle of approximately 90 degrees at the knee joint was reached at which time flexion at the three joints ceased. The lifter then fell under the influence of gravity to the platform without changing the configuration of the body segments. Once contact had been re-established, flexion continued until the thighs were approximately parallel to the floor whereupon descent ceased until the bar was racked at the shoulders. The body and bar then descended to the full squat position from which the lifter recovered to an erect standing position (the preparation for jerk position).

The bar was situated between the areoli and the clavicles upon re-establishing contact with the platform. The trunk then descended relative to the bar until the elbows were directly under the bar where-upon relative motion ceased. The bar was then above the clavicles. Both the barbell and the athlete continued to descend at the same rate until the thighs approached a position parallel to the platform. As already described, the lifter ceased his descent in order to allow the bar to settle onto the shoulders.

An attempt was made to compute the average velocity of descent into the full squat position in order to compare the resultant value with those provided by O'Shea (1969). The time taken by the subjects was approximately double the value of the times reported in the literature. Termination of descent was then redefined as the moment when the shoulders ceased their descent and the lifter waited for the bar. The heaviest lifts performed in Substudies #3 and #4 were analyzed and the resultant average velocities were still equal to or less than those characteristic of the 'good' lifter in O'Shea's study (see Table 11).

TABLE 11

Descent Velocity Determination During the Clean

	Trial	Distance	Time	Average Velocity (cm/second)
Substudy #3	DS	41	.294	139
	ER	42	.346	121
Substudy #4	DS	40	.233	172
	ER	36	.233	154

It is interesting to note that the descent velocities were much lower in the laboratory session than they were in competition.

The Dip:

Preparation for Jerk Position:

Foot placement varied somewhat but it never exceeded shoulder width. The body was always held erect as possible to the extent that a noticeable arch to the thoracic cage was evident in some. The arch had the effect of displacing the head posteriorally and thus partially eliminating it as an obstacle to the bar when jerked. A determination of the manner of support at the shoulders was not made but since the angle of the upper arm to the horizontal tended to be near 30 degrees, it was assumed that the bar was held in Hise's second position (see the review of literature - the Preparation for Jerk Position on page 14).

The actual dipping motion also varied. A number of lifters at the Canadian Championships left the bar behind when dipping with the result that a gap was clearly visible between the bar and shoulders. As a general rule, however, most dipped at a moderate speed and the displacement of the hip joint tended to be vertical. The subjects used in Substudy #3 dipped vertically as can be seen from Figure 13.

The Dipped Position:

Figure 12 tabulates depth of vertical displacements from Substudy #3. The depth reached by each subject exhibited a slight tendency to increase as the amount of weight increased. The value recorded in every trial was greater than that recommended in the literature.

Figure 12

Magnitude of Vertical Displacement During Dip

(Substudy #3)

Subject	Cm.
D1	17.29
D2	17.11
D3	17.11
D4	20.16
E1	18.37
E2	18.71
E3	18.60
E4	19.70

The Thrust:

After a momentary pause in the dipped position, most lifters commenced the thrust phase of the lift with a slight displacement anteriorally. In every case the knee was initially extended by moving the thigh only for a short period of time after which the leg commenced its angular motion. A great deal of variability was found amongst the athletes attending the Canadian Championships but, in contrast, the subjects used in this study exhibited vertical trajectories (See Figure 13). Once under way, the act of imparting thrust to the bar was accomplished by first extending simultaneously at the knee and ankle joints and then plantar flexing as the end of the range of motion neared.

The Full Extended Position:

Just as in the case of the clean, this position marked the end of the application of thrust by the large muscle groups. The full extended position was typically held for a few hundredths of a second after which flexion at the knee of the anterior limb marked the beginning of the descent into the full split position. Unlike the clean, however, only the anterior foot was in contact with the platform at this time because the rear foot had already begun its displacement posteriorally.

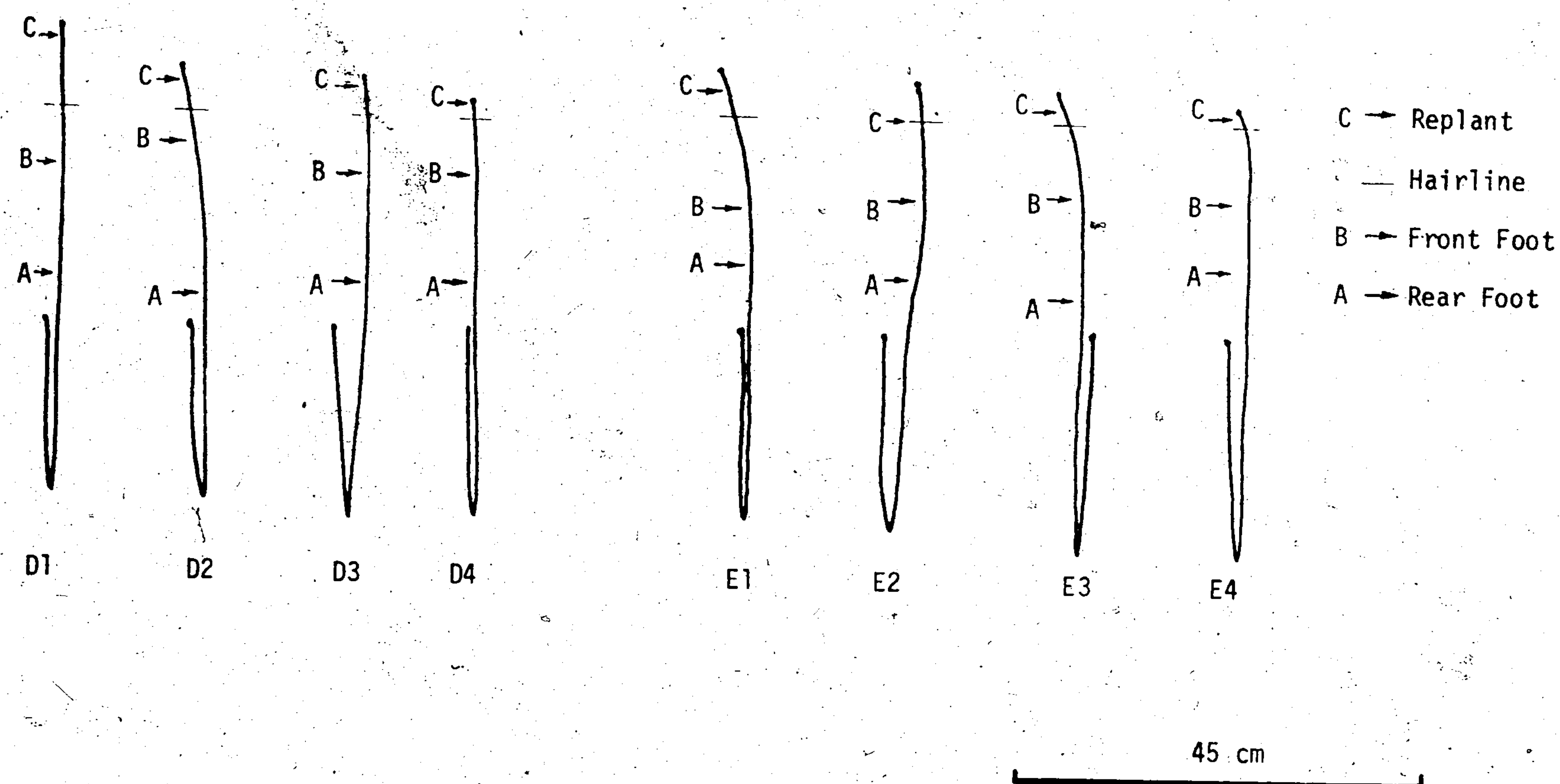
The displacement pattern for the jerk was very uniform. Points A & B respectively represent the moments in time when displacement of the rear and front feet began. A straight line marks the location of the lifter's hairline along the forehead while standing in the preparation for jerk position. The data indicates that the rear foot commences its posterior displacement when the bar is approximately chin height or just below. The front foot commences its anterior displacement when the bar is in the vicinity of the nose.

The Bar High Position:

A review of Figure 13 indicates that the final resting place or the barbell at the end of its upward trajectory is a point at the top of or slightly above the top of the head. When a relatively light weight was being handled the bar high position was 9.15 cm above the hairline. Otherwise, the bar high position tended to be

Figure 13

Path of Bar During Jerk (Substudy #3)



located near the top of the head.

The Split:

Of all the phases of the clean and jerk, the split phase exhibited the worst form if ideal form is as described elsewhere in this report. Many competitors at the Canadian Championships appeared to have no idea of where the bar was or what to do with their feet. The result is all the more astonishing when it is realized that many of these same athletes were national champions.

Flexion of the knee of the anterior leg always proceded anterior displacement of the foot. Thus, the splitting movement did not coincide with the beginning of the descent of the body into the full split position. Further, the rear foot replanted itself well ahead of the anterior foot in the majority of cases. There were a few exceptions and subject ER was one of them. In his case, both feet tended to replant themselves simultaneously. Increased hyper-extension of the back was not observed during the split phase of the lift.

The Full Split Position:

The front foot was found to point forward or medially while the rear leg remained rigid and extended. Recovery was initiated by moving the front leg back one step while the rear leg remained stationary. The rear leg was then brought forward. Vision was straight ahead and the bar, head, shoulders tended to lie in the same vertical plane when viewed laterally.

The body segment configurations were similar to that theorized in the mechanical relationship chapter of this report. However, Figure 14 presents foot displacement data taken from Substudy #1 as an illustration of the variation in foot placement which can be expected relative to their position at the start of the dip. The anterior displacement of the forward foot from its starting position as a percentage of the total displacement of both feet has also been shown.

Figure 14

Foot Placement - Full Split Position

(Substudy #1)

Trial	Percentage Displacement
1	42
2	41
DS	47
DS	42
DS	47
6	42
ER	34
8	44
ER	36
ER	36
11	43
12	33
13	30
14	34
15	37
16	23
17	49
18	38
19	27
20	39
21	38
22	45
Rounded Mean	40

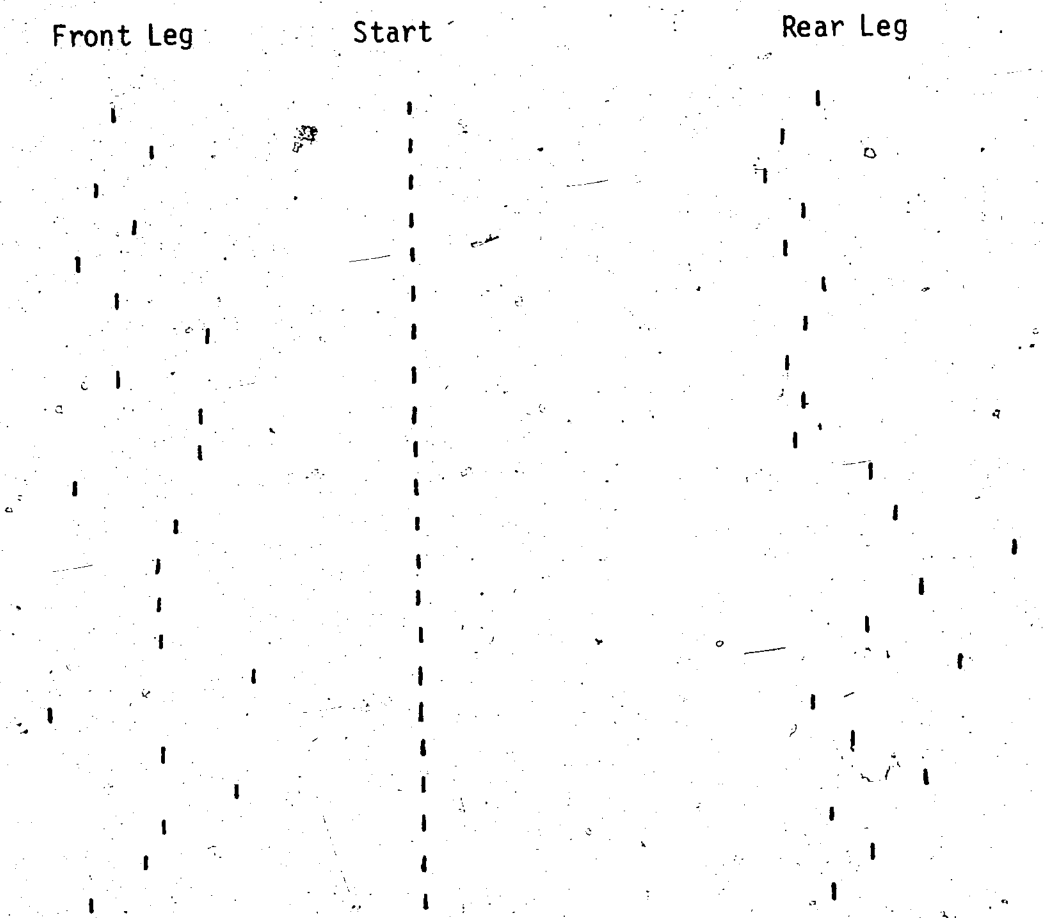


Table 12 displays displacement values for the lifts recorded in Substudies #3 and #4. The values are in the same range for all of the studies but the means differ slightly. The rounded mean for Substudy #1 was 40% while for Substudies #3 and #4, it was 44%.

A Pearson Product Moment Correlation computation was carried out for the values of the displacement and the angle of the thigh. A value of .22 was found. Since a mechanical analysis indicated that there is a direct relationship, it must be concluded that, in actual practise, variance due to other factors so overwhelms the relationship, that the correlation between the two is completely lost.

TABLE 12

Anterior Foot Placement - Full Split Position
(Substudies #3 & #4)

Trial		Displacement as a Percentage of Total
Substudy #3	DS 1	47
	DS 2	40
	DS 3	53
	DS 4	48
	ER 1	42
	ER 2	52
	ER 3	34
	ER 4	41
Substudy #4	DS 1	47
	DS 2	43
	DS 3	43
	DS 4	45
	ER 1	42
	ER 2	40
Mean		44

Paths of the Bar, Hip and Shoulder Joints and Their Relationship During the Clean

Figure 15 illustrates the paths of the barbell of the successful cleans performed as part of Substudy #3. All of the curves exhibit the same general form as those found in the literature. A striking feature of the plotted paths is the uniformity of the pattern of ER from one trial to the next. Each lift tended to have the same bar high position and the magnitude of posterior displacement during the first pull was identical in each case.

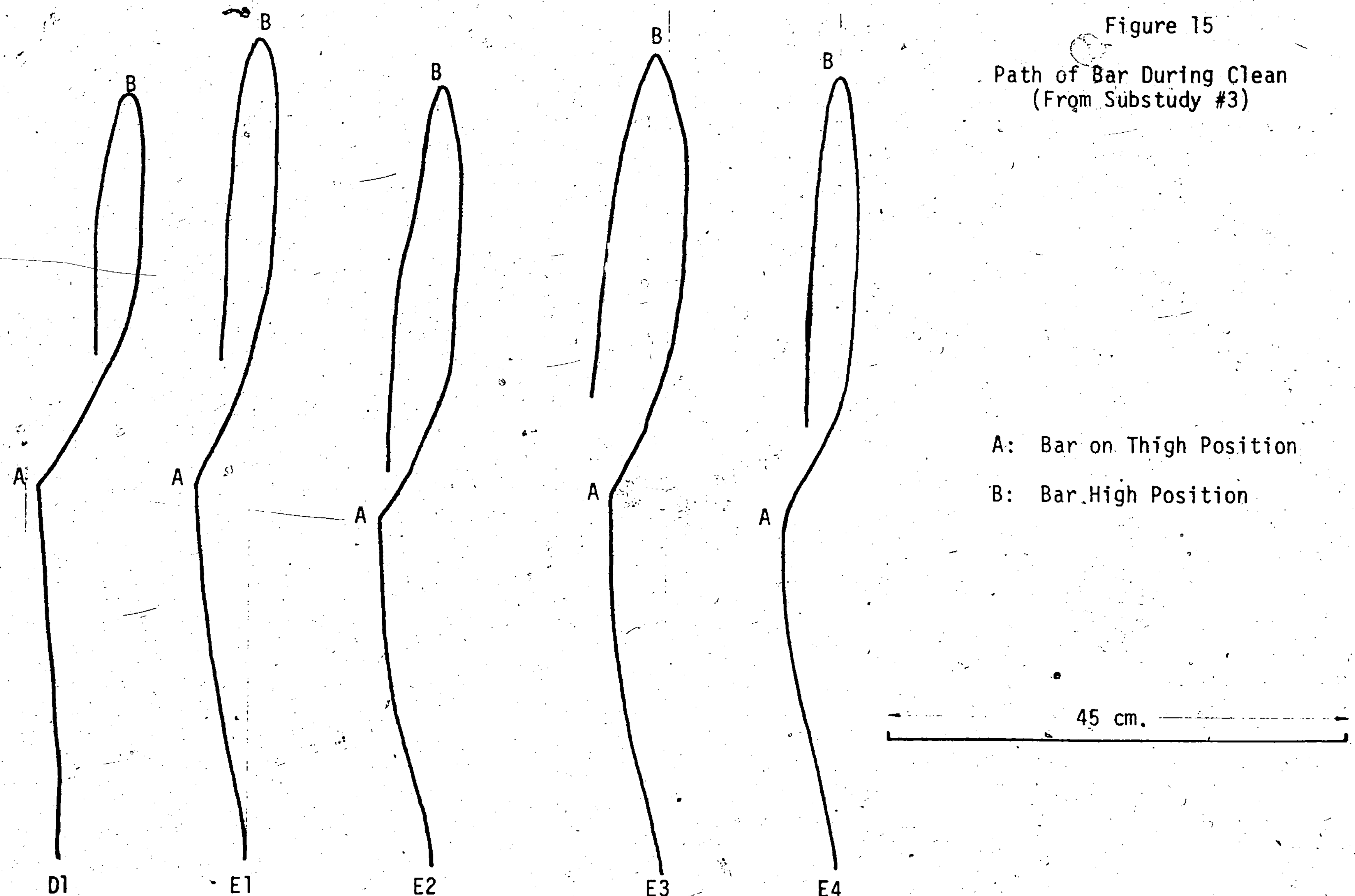
Although similar in form, the curve of DS differs in detail from that of ER. Posterior deflection is not as great but anterior deflection during the second pull is larger than the corresponding values for ER. Also, the bar high position is anterior to the starting position of the bar.

Maximum horizontal displacement exceeded that of Rigert in all cases. It is apparent that horizontal movement during the second pull is the result of the 'brushing' action at the bar on thigh position. In view of the lower displacement values for Rigert, this athlete must perform the scoop with less contact with the bar.

The vertical paths of the bar, shoulders and hips were all similar but not identical to those reported by O'Shea (Figure 5). The displacement curve of the shoulder joint did not possess the hump at 'B' and the displacement durve of the hip joint displayed the same general form as that of the champion lifter except that it decreased in value just before peaking at 'C'.

Figure 15

Path of Bar During Clean
(From Substudy #3)



Lifting in Terms of Joint Angles

The results of Substudies #3 and #4 have been tabulated below in Tables 13 and 14a and 14b.

TABLE 13

Experimental Comparison in Degrees of Joint Angles for Clean (Substudies #3 & #4)

			POSITIONS			
			Bar Off Floor	Knee High	On Thigh	Full Extension
A.	Ankle (θ)	#3	66	83	68	82
		#4	64	86	70	83
B.	Knee (ϕ)	#3	30	63	61	67
		#4	29	63	63	79
C.	Hip (γ)	#3	27	32	75	91
		#4	26	34	72	97

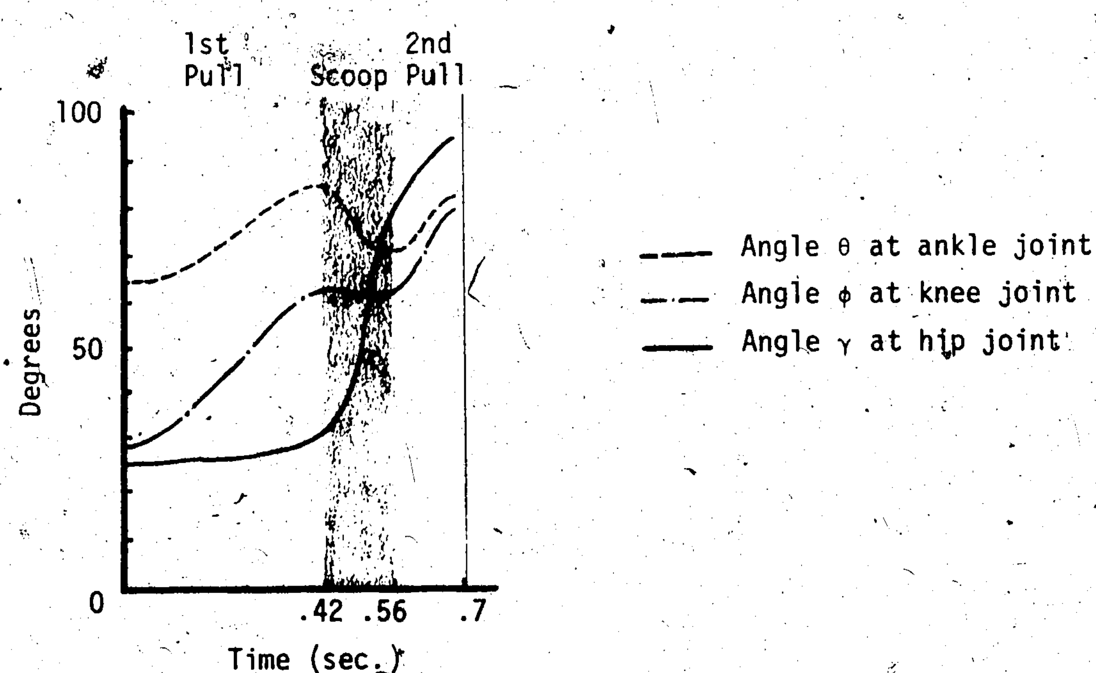
The pattern of the double knee bend can be seen in terms of the values of the angles at the ankle, knee and hip joints. The angle θ had an initial value in the mid 60 degree range which increased by 20 degrees at the knee high position and then decreased by 15 degrees by the end of the scoop. The said 15 degrees was recaptured at the full extension position. The angle ϕ at the knee had an initial average value of 30 degrees which doubled by the time the knee high position had been reached. The new value was in the low 60 degree range and was maintained through the scoop. The angle ϕ had increased by a further 20 degrees by the time the full extended position had been reached. From an initial value in the mid 20 degree range the angle γ increased to the low 30 degree range at the knee high position. Commencement of the scooping motion caused the value of γ to increase by 40 degrees to the mid 70 degree range at the bar on thigh position. The value of γ increased by another 20 degrees to produce an angle whose magnitude was in the mid 90 degree range at full extension.

TABLE 14

(a)
Experimental Comparison in Degrees of Joint Angles for Jerk
(Substudies #3 & #4)

		Dipped Position	Full Extended Position
A. Ankle (θ)	#3	51	78
	#4	53	81
B. Knee (ϕ)	#3	51	86
	#4	48	85
C. Hip (γ)	#3	81	8[illegible]
	#4	83	88

(b)
Angular Displacement at the Ankle, Knee & Hip Joints
During the Pull Phase of the Clean
Utilizing the Double Knee Bend Technique



Kinematics From Substudy #3

The edges between the knurling on the barbell are a known distance apart and can be seen in the anterior view. Repeated measurements were taken of these landmarks and the mean value was used as a scale in subsequent computations of displacement of the barbell in the vertical plane. Maximum variation from the mean never exceeded 1%.

Displacement points were taken at .021 second intervals and were smoothed with a cubic spline curve which was differentiated to produce velocity and acceleration values for each point. A Chi-Square goodness of fit test was used to compare the smoothed and raw data points. The fit was found to be a good one as the data in Table 15 demonstrates.

TABLE 15

X^2 Goodness of Fit Test for Spline Curves
(Substudy #3)

	CLEAN		JERK	
Trial	X^2	Critical Value(p=.001)	X^2	Critical Value(p=.001)
D1	3.68	86.661	2.48	56.89
D2	4.99	86.661	3.03	56.89
D3	-	-	3.91	56.89
D4	-	-	4.34	56.89
E1	3.73	86.661	2.63	54.05
E2	2.78	86.661		
E3	4.82	86.661	6.71	54.05
E4	-	-	11.75	58.30

The smoothed displacement points and the corresponding velocity and acceleration values were graphed and are displayed in Figures 16 through 22. Table 16 summarizes pertinent velocity information and compares it to values found in the literature.

TABLE 16

Velocity Parameters for the Clean and Jerk - Substudy #3 (cm/sec)

Trial	CLEAN Knee High Position	Peak	JERK Peak
D1	116	138	146
D2	110	122	136
D3	97	99 (Failed)	129
D4	106	105 (Failed)	122 (Failed)
E1	107	133	137
E2	102	127	126
E3	101	110	127
E4	92	113 (Failed)	122 (Failed)
Literature	**Average**	**Average**	**Average**
Ono	162	187	137
Whitcomb	61	119	144
Rigert	137	157	-
Garhammer	-	145	148

The experimental results for the jerk agree with values found in the literature. With regard to the clean, values produced by Ono (1969) are greater than the experimental results while the values obtained from the study of Whitcomb (1969) are less in the case of the knee high position and in agreement in the case of peak values attained. It should be noted that five of the eight values for the knee high position fall within two standard deviations of Ono's mean. Only two peak values, however, are within two standard deviations of Ono's mean for that parameter.

Caution must be exercised when making direct comparisons with results in the literature. The change in style of lifting which has taken place over the past few years has caused direct comparison to become a venture full of risk. It is a virtual certainty that both Ono and Whitcomb examined a variety of styles which resembled the double knee bend technique in varying degrees. Second, the degree of smoothing performed by these researchers is unknown and further, the fact that both used averaging techniques guarantees different results even if the lifting style had been the same.

Of more interest is the pattern of velocity values yielded by the eight clean trials. Subject DS failed when the velocity at the knee high position went below 105 cm/sec whereas subject ER was sucessful until it went below 101 cm/sec. This is an interesting result because subjective judgement would rate DS as being the significantly superior lifter from a technical point of view while, on the other hand, ER is clearly the stronger of the two. The peak velocity values are remarkably similar for the first two trials. Subject DS failed when the velocity was less than 105 cm/sec. Subject ER, on the other hand, was successful at 110 cm/sec. but failed on his last lift even though the peak velocity was 113 cm/sec.

The evidence suggests that, with in reason, the velocity of the bar during the first pull is not of crucial importance. Rather, the function of the first pull is to place the bar in a good position to scoop from. The opposite is true for the second pull which is a powerful position to pull from if the correct bar on thigh position has been attained. It is not uncommon for a good lifter (from a technical point of view) to be able to rack more weight from a hang position (bar on thigh position) than he can accomplish from the floor.

The evidence also suggests that correct execution of the scoop is crucial for successful performance of the clean. An examination of the data from Substudy #3 revealed falling velocity patterns as the scoop progressed when a subject failed to clean a weight. In one instance (E3), the falling pattern was reversed and the lift saved. The tide was also reversed in the case of trial E4 but this was due to changing the attempt to a dead lift from a clean. As a result, the subject was unable to effect the second pull and thus the clean attempt failed.

Power Generated During the Second Pull and Thrust Phase

The maximum bar velocity values for the second pull and thrust phases (Table 16) were used to calculate the power generated in the vertical plane by subjects ER and DS where power is defined as the product of force and velocity. Total power in the vertical plane was computed as the sum of the works performed on the barbell and the centre of gravity of the athlete divided by time. The values computed have been displayed in Table 17 as have comparable values for world class weightlifters of a similar size.

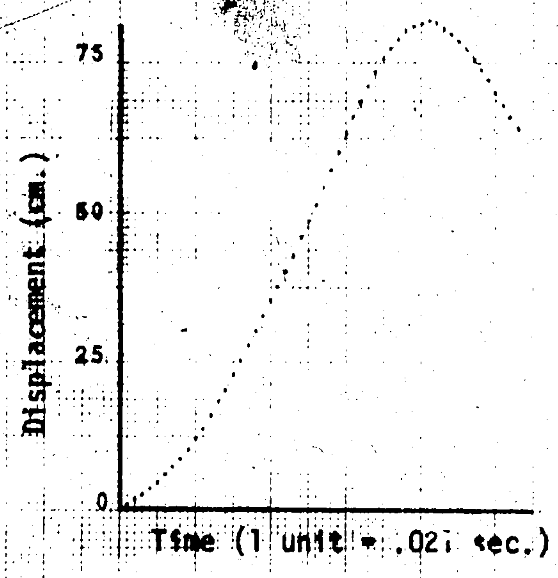
Table 17

Maximum Power in Watts Developed
During the Second Pull and Thrust Phases
of the Clean and Jerk
(Substudy #3)

Trial	Second Pull		Thrust Phase		Literature
	Load (kg)	Power	Load (kg)	Power	(Mean)
DS1	120	2434	110	2432	
DS2	130	2272	120	2399	(2336)
DS3	-	--	130	2402	
DS4	-	--	-	--	
ER1	135	2633	125	2578	
ER2	-	--	135	2494	(2336)
ER3	145	2638	145	2638	
ER4	155	2393	-	--	

Figure 16

Displacement of Bar During Pull Phase
(DS)



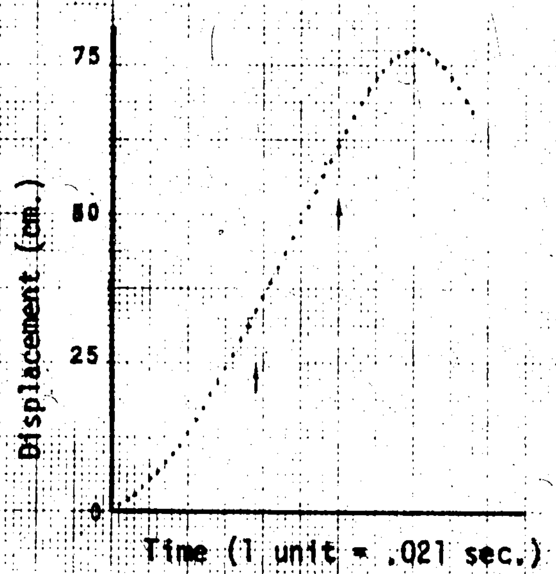


Figure 17

Velocity and Acceleration During Pull Phase of Clean
(DS)

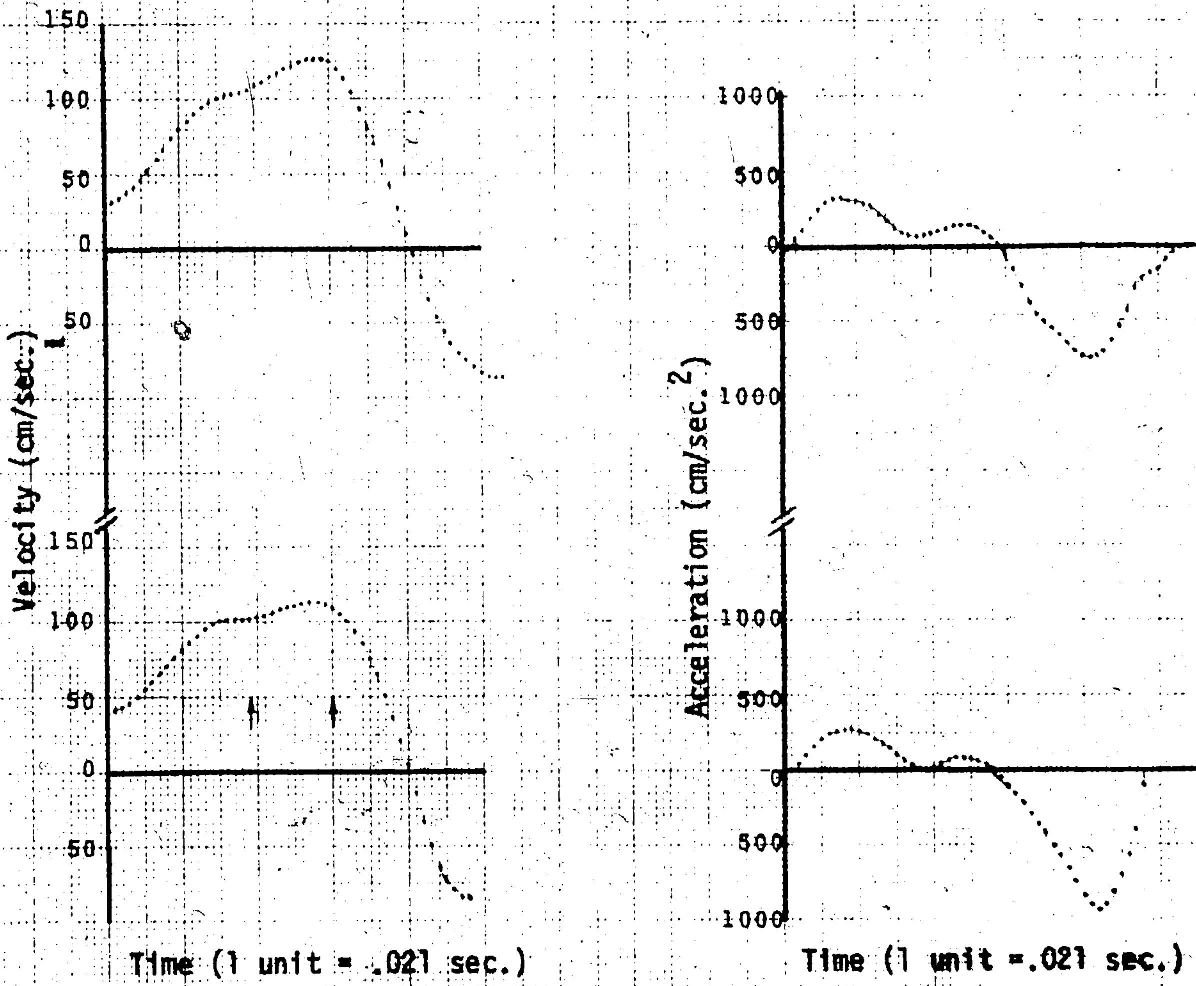
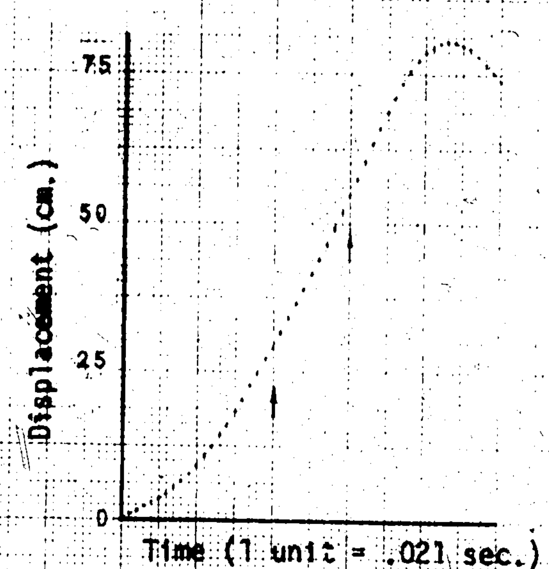
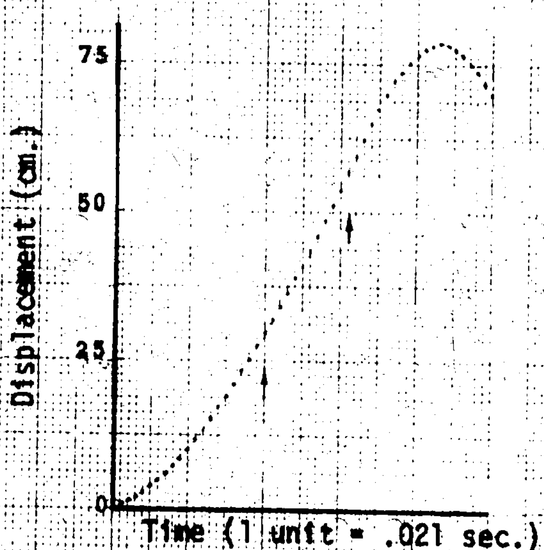


Figure 18

Displacement of Bar During Pull Phase
(ER)





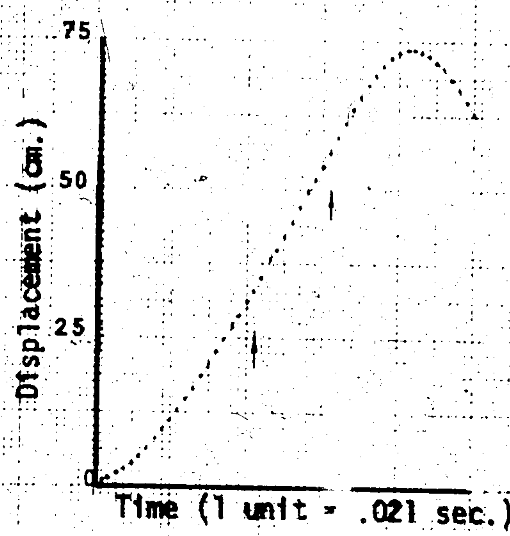


Figure 19

Velocity and Acceleration During Pull Phase of Clean (ER)

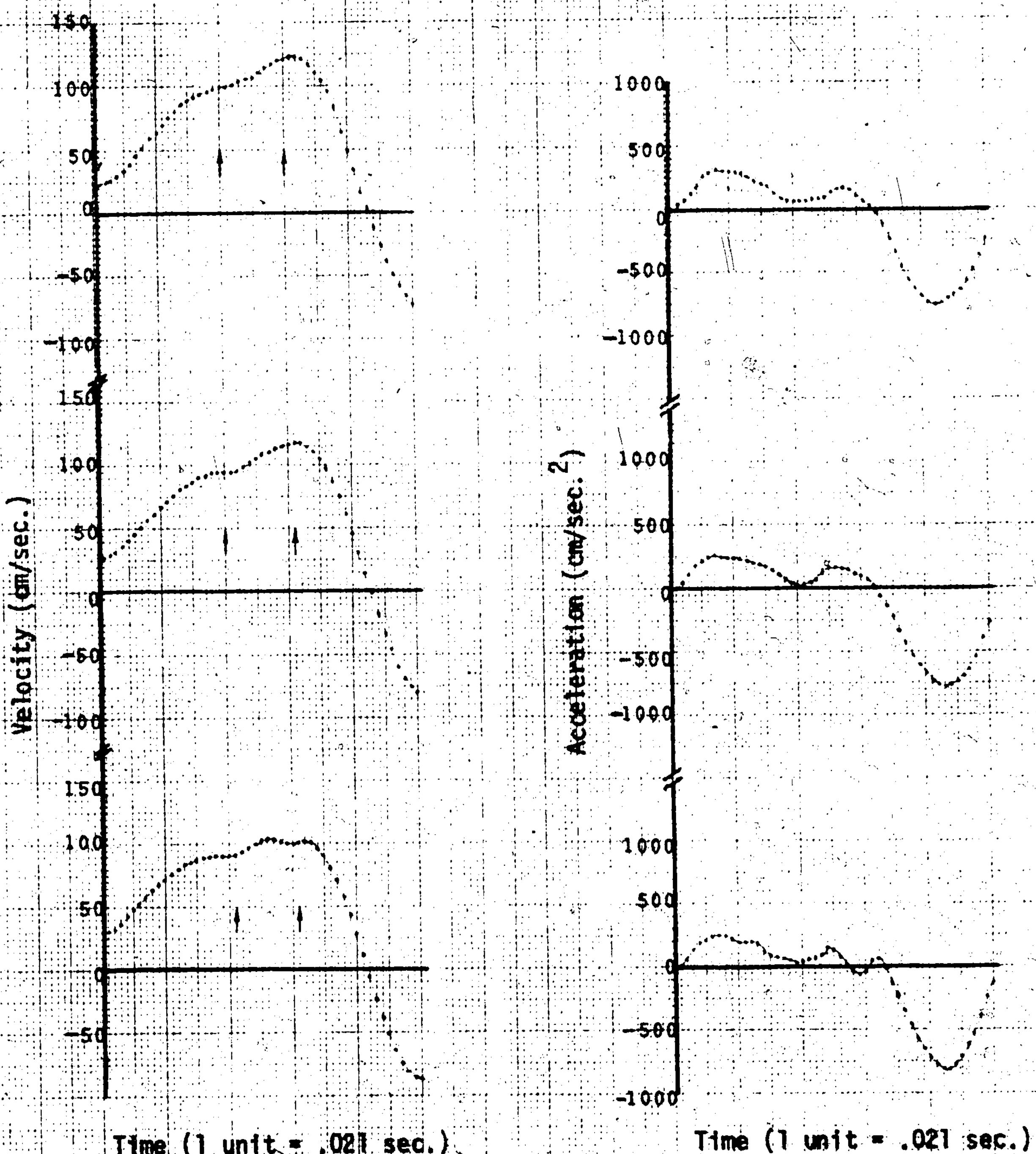


Figure 20

Displacement of Bar During Thrust Phase of Jerk

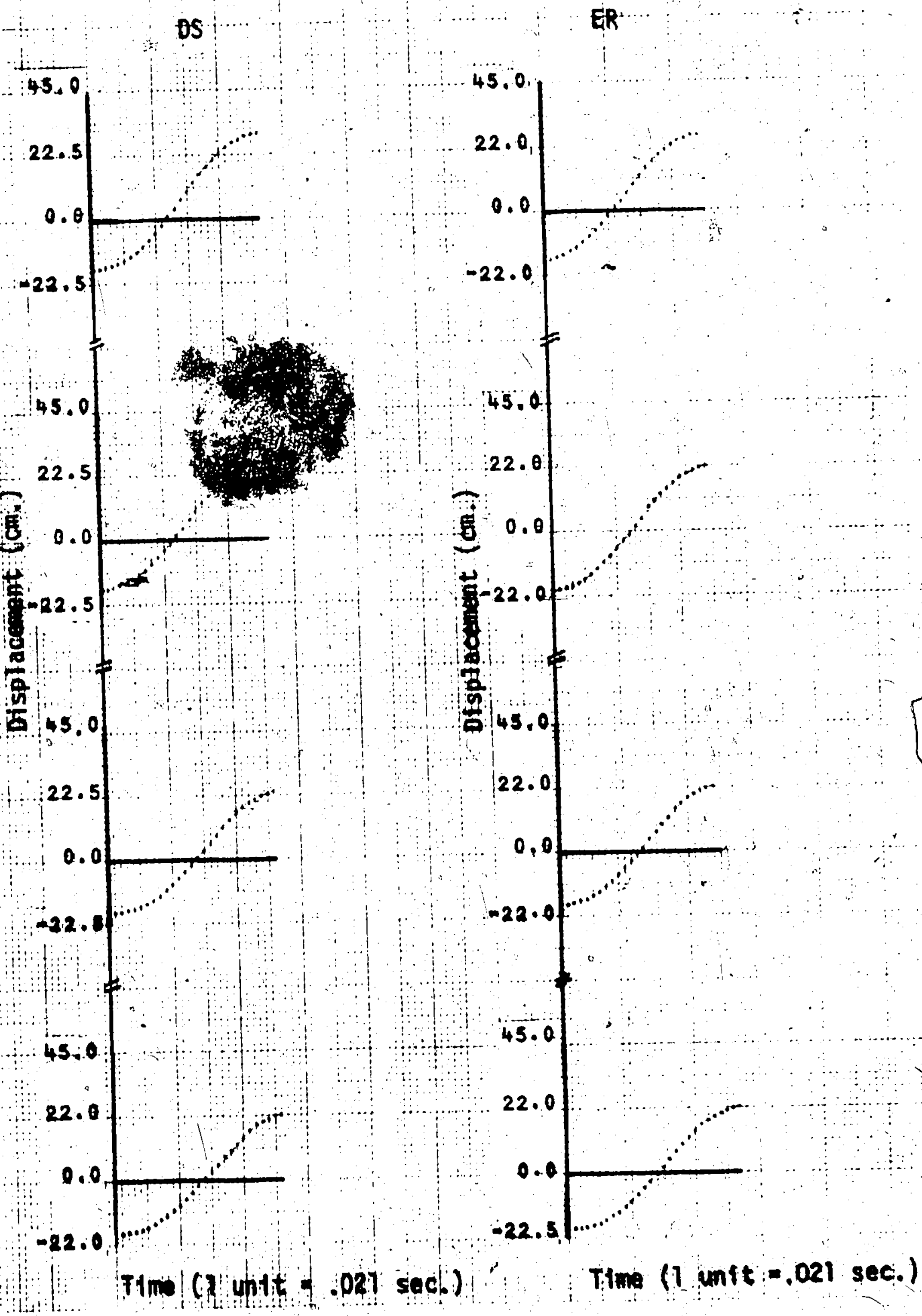


Figure 21

Velocity and Acceleration of Bar During Thrust Phase of Jerk (DS)

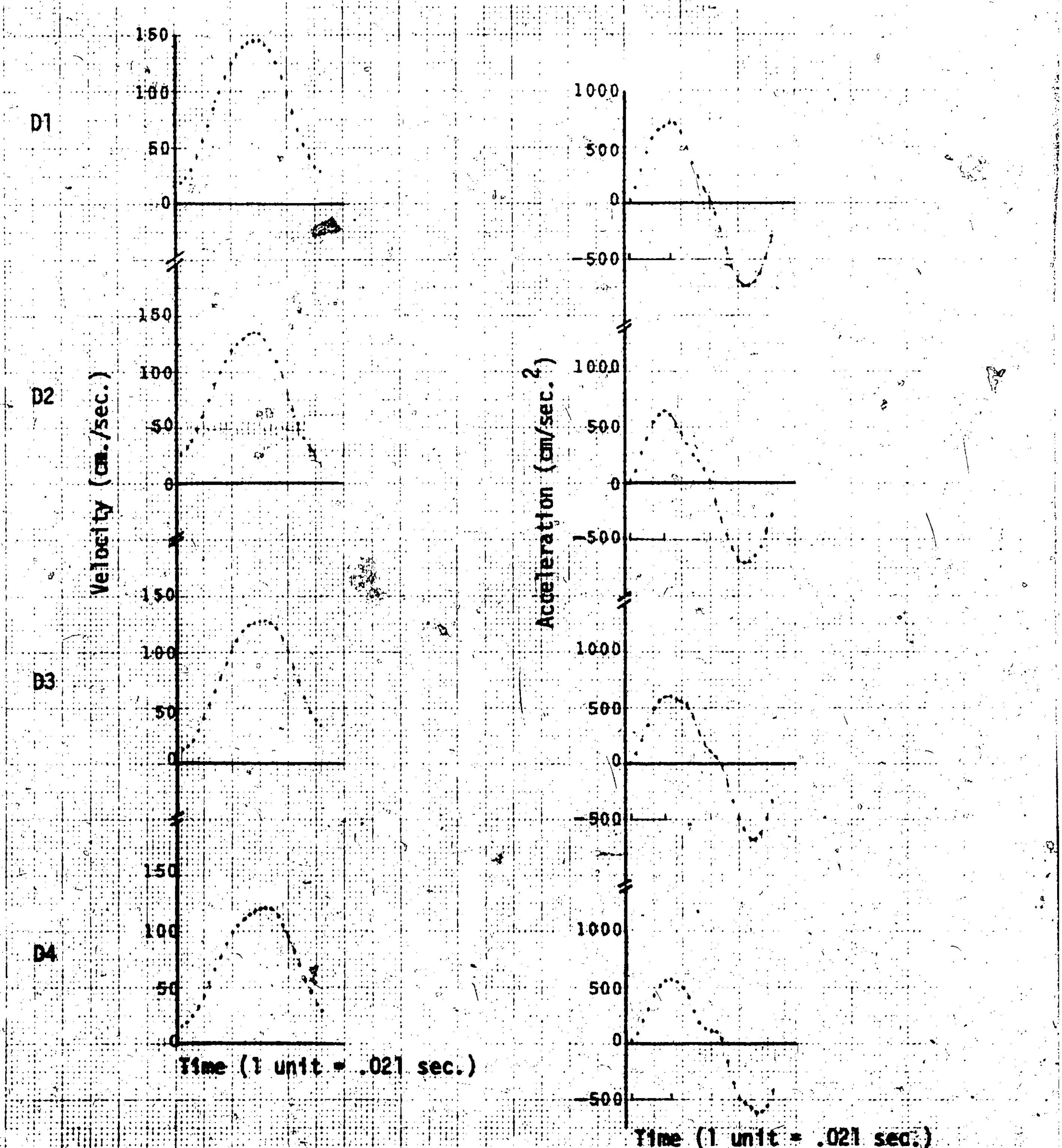
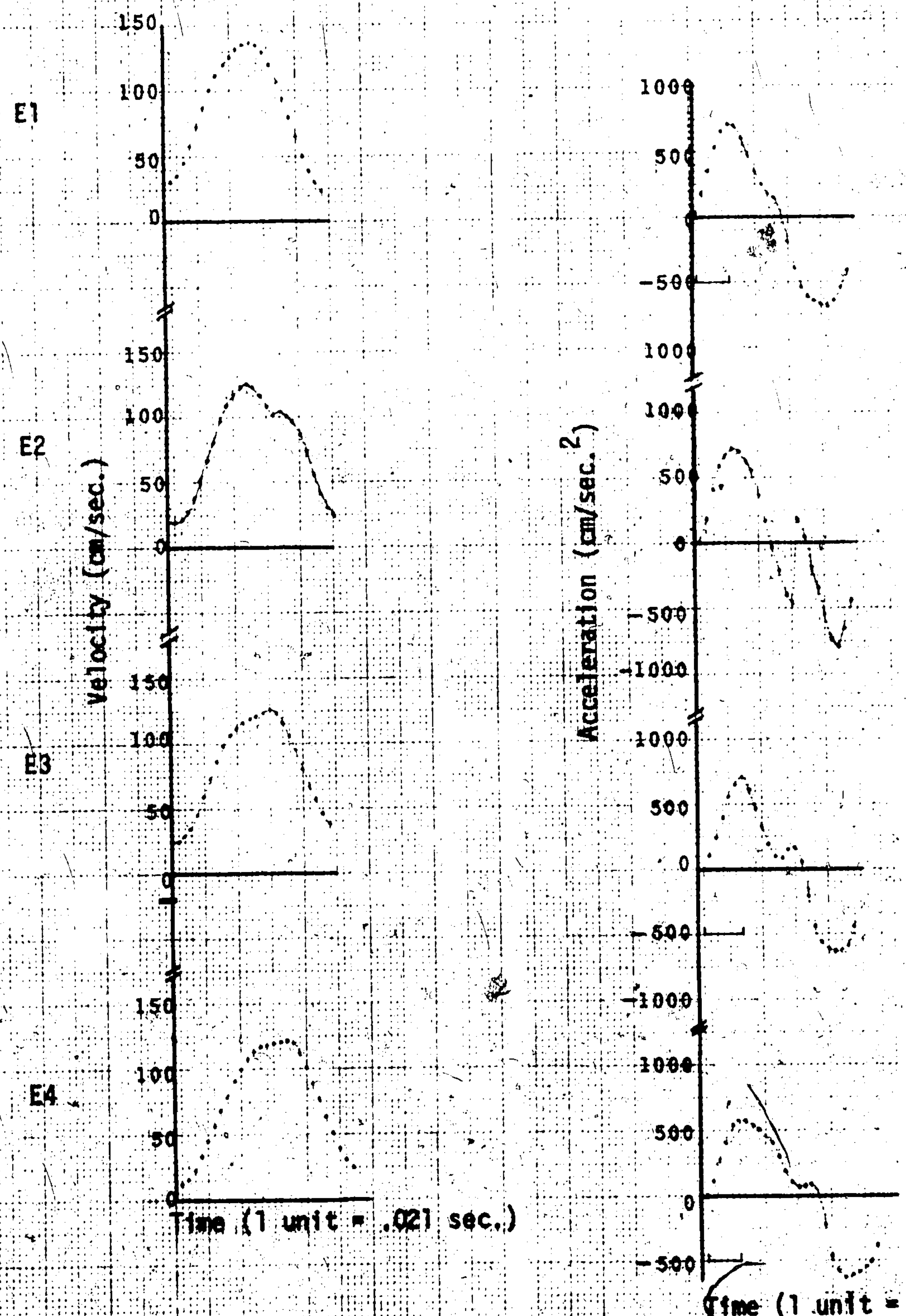


Figure 22

Velocity and Acceleration of Bar During Thrust Phase of Jerk
(■R)



The velocity of the centre of gravity was assumed to be the same as that of the barbell. This assumption was necessary because it was not possible to develop a time-displacement curve describing its motion. The assumption probably does not introduce gross error. Since the phases examined involve displacement when the body is relatively extended, the movement of the centre of gravity would be expected to be similar to that of the barbell. The results appear to bear this conclusion out. Values are similar for the two phases examined and to values found in the literature.

CHAPTER SIX

MECHANICAL ANALYSIS

Angular Displacement Functions for Limb Segments

The plates on the ends of the bar blocked direct view of either the hip or knee joint throughout the pull phase. Repeated measurements indicated that joint angles at the various defined positions of the pull could be measured with acceptable consistency for descriptive purposes but that the level of accuracy was not acceptable when the purpose was to develop time functions which described angular displacement. Functions for those joints, therefore, were not developed.

In the case of the jerk, angular displacement functions could not be formulated for plantar flexion from the data gathered from Substudy #3 due to a small image size and poor lighting around the feet. Angular functions, therefore, could not be substituted into the models for validation purposes. Since the subjects used in Substudy #3 were also part of Substudy #4 and the magnitude of the weights they handled were similar, functions developed from Substudy #4 were substituted into the models.

Angular displacement data from the film record of the jerk from Substudy #4 was differentiated for velocity and acceleration values. Each lift was analyzed three times and the average was used in the formulation. An example of the data recorded is contained in Table 17. Variation from the mean averaged approximately one-half degree.

Least square quartic and cubic functions were developed from the data. An analysis of variance sub program accompanied the least square program. The value of 'p' associated with the functions for θ and ϕ never exceeded 0.0001 while the 'p' associated with ψ attained a maximum value of 0.0072. A function for γ was not formulated since, according to the model, the contribution of γ is negligible.

TABLE 18

Sample of Raw Angular Data Points - E1
(Substudy #4)

Frame	θ_1	θ_2	θ_3	ϕ_1	ϕ_2	ϕ_3	ψ_1	ψ_2	ψ_3	AVERAGE θ	AVERAGE ϕ	AVERAGE ψ
1	0.00	0.00	0.00	0.00	0.00	0.00				0.00	0.00	
2	0.00	0.00	0.00	1.75	1.75	1.00				0.00	1.50	
3	0.75	0.75	1.00	3.00	3.00	3.00				0.83	3.00	
4	2.00	2.25	2.50	4.25	5.00	5.25				2.25	4.83	
5	3.75	4.25	4.00	8.50	8.00	8.25				4.00	8.25	
6	7.00	7.25	7.00	12.00	12.00	12.00				7.08	12.00	
7	12.50	12.25	12.50	18.75	18.00	18.25				12.42	18.33	
8	19.00	21.50	20.75	27.00	27.00	26.75	0.00	0.00	0.00	20.42	26.92	0.00
9	29.00	29.00	28.25	35.50	36.75	36.75	7.50	8.50	8.25	28.75	36.33	8.08

Graphs of the smoothed angular displacement points and their derivatives are illustrated in Figures 25 through 27. The least square curves did not generate zero derivatives at the commencement of the lift and the result, therefore, is distorted values until the lift is well underway. The displacement pattern changed slightly as the load being lifted increased. In all cases, extension at the knee joint commenced before extension at the ankle joint.

Time functions for ϕ, θ and ψ were substituted into equations (1) and (2) of the model (page 34) and into equation (5) which is a simplified version of the model (page 36) applicable to the thrust phase of the jerk. [illegible] lengths for the lower limb were scaled to be similar to the lengths of the subjects. A stature of 163 cm. was assumed. Subjects DS and ER have statures 158 and 166 cm. respectively.

TABLE 19

Peak Bar Velocity During the Thrust Phase of the Jerk
Yielded by the Model - Substudy #4
(cm/sec.)

Trial	Model	Simplified Model	Successful Values From Substudy #3
D1	114	141	146
D2	120		136
D3	126	142	129
D4	118 - 105	134	-
E1	110 - 133	168	137
E2	112	110	126
E3	-	-	127

In all but the heaviest of lifts performed by DS, the velocity of the bar peaked either before or coincident with plantar flexion. It would appear, in view of this finding, that plantar flexion does not contribute to the thrust applied to the bar in circumstances where the

Figure 23

Kinematic Values For θ, φ, ψ
(Substudy #4)

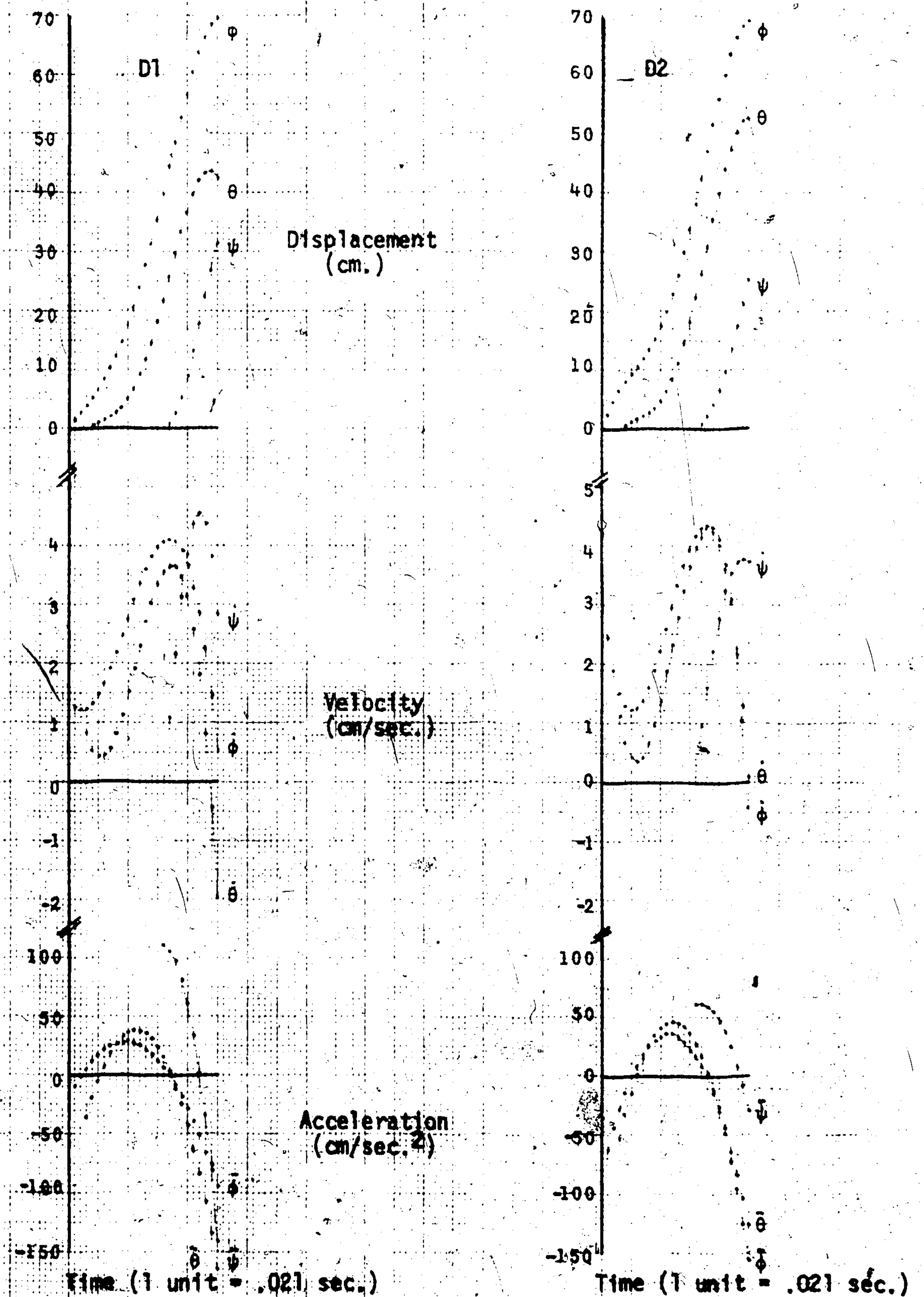


Figure 24

Kinematic Values for θ, φ, ψ
(Substudy #4)

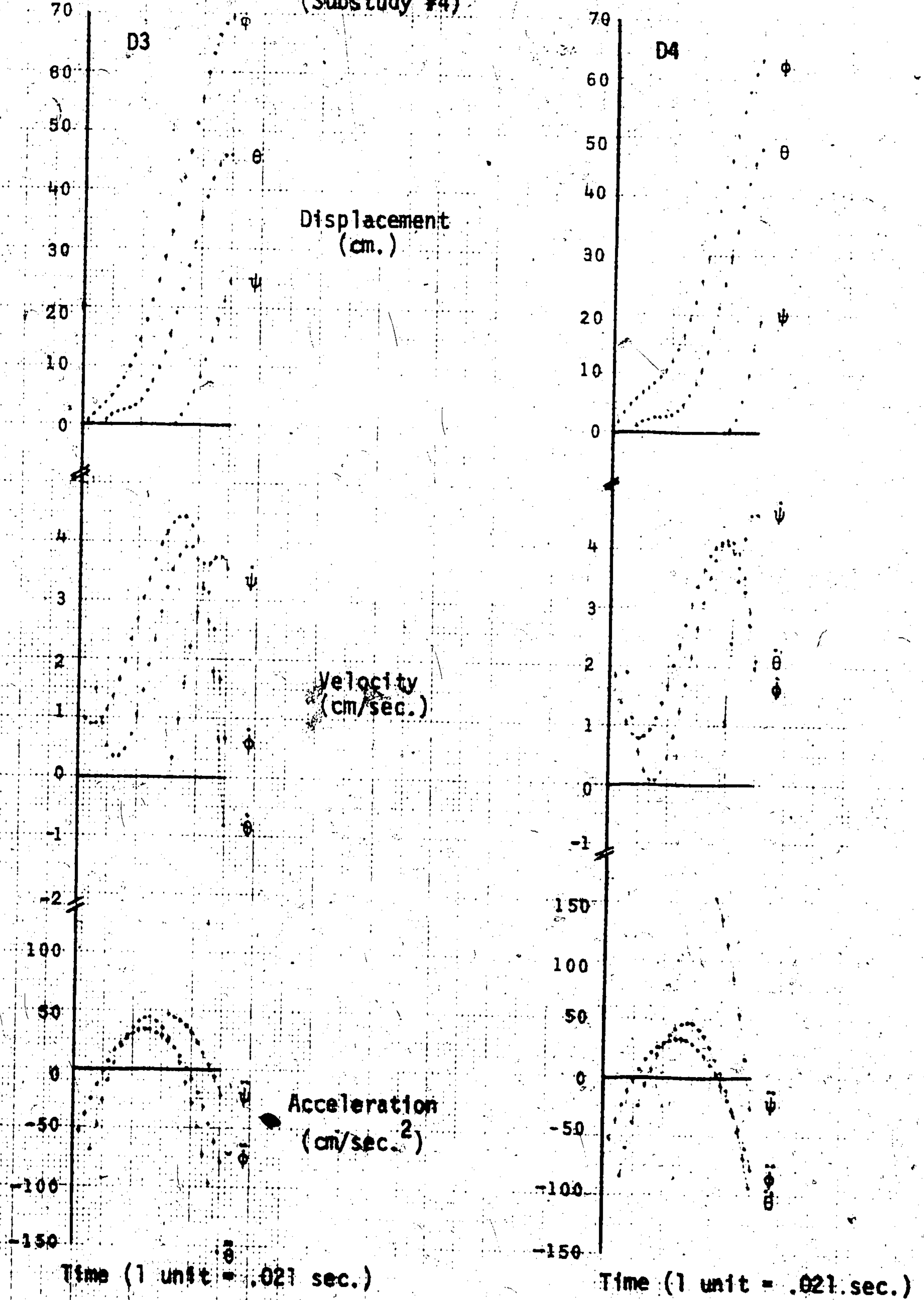
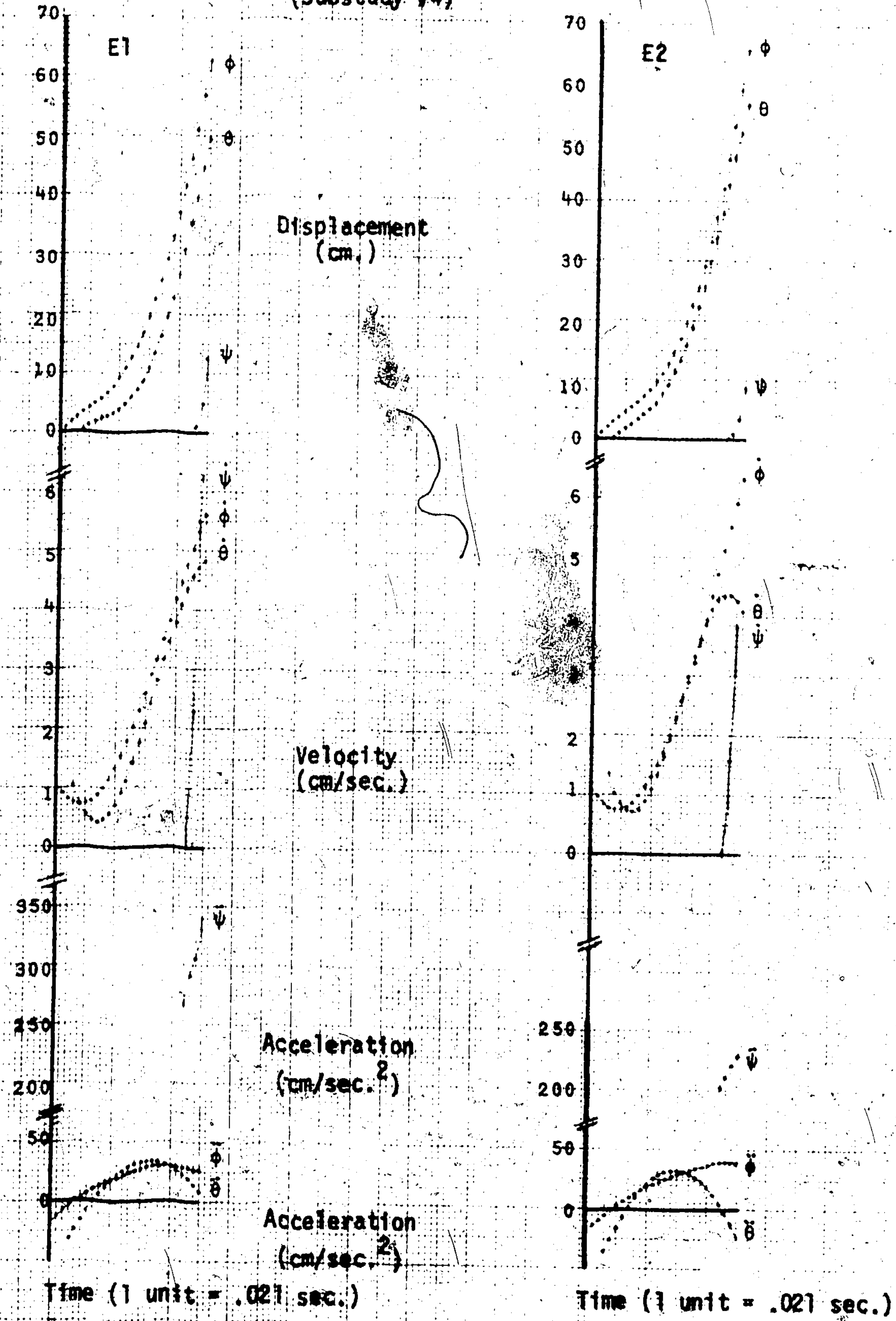


Figure 25

Kinematic Values for θ, φ, ψ
(Substudy #4)



bar is light. In the case of trial D4, a second peak occurred after plantar flexion had been initiated. Since the model describes the path of the bar only while in contact with the shoulders, it is not clear whether or not the bar had lost contact with the lifter. The same twin peak was produced as part of trial E1.

The angular functions for the thigh and leg were such that the model produced horizontal movement in every case and additional horizontal velocity was added when the feet plantar flexed. In view of the vertical displacement curves traced by the bar as seen from the side, it appears that trunk rotation is of sufficient magnitude so as to offset unwanted horizontal movement. Horizontal movement of the hips appears to be a normal movement and if not compensated for, a horizontal velocity component can be easily transmitted to the bar. A re-examination of the film produced as part of Substudy #3 indicated that failures, resulting from forward displacement of the bar, were characterized by the absence of significant trunk rotation.

With the exception of trial E1 and E2, the simplified model produced results which were very comparable to the actual velocities computed for the lifts completed in the laboratory test session and represent additional evidence that the velocities computed for Substudy #3 are correct. As explained previously, the comparability of the values was expected. Subject DS demonstrated a high degree of consistency in other aspects of the lift (as did ER) and Garhammer (1978), Shakirzianov (1974) have provided evidence of high levels of consistency by highly trained weight lifters.

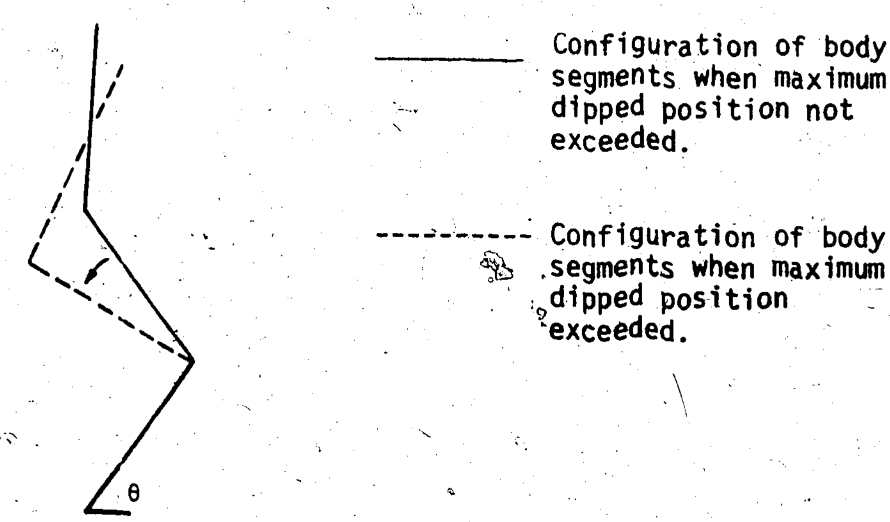
The lesser degree of agreement between the predicted and the actual velocities for ER can be partially explained. Plantar flexion was of such short duration that it could only be seen in four frames. Thus, there were insufficient data points for the formulation of anything except a second or third degree polynomial. A quartic expression appears to be more representative of the movement.

Maximum Dipped Position

Given a maximum range of movement for dorsi flexion of 30 degrees and the constraint that the hip joint must move only in a frontal plane which passes through the ankle joint, the minimum value which θ can take is 60 degrees. The minimum will be lowered to 55 degrees if lifting boots with a half inch heel are worn. The value of ϕ which, in terms of the model, corresponds to a value of 55 degrees for θ, is 56 degrees. Once this limit has been reached, further descent can only be accomplished by knee and hip flexion which will put the trunk into an intolerable position from which to jerk the weight (Figure 28). The angle of the back will have significantly moved away from the vertical and the moments of force required to bring it back to the normal will be large. From a physiological point of view, the optimum value f ϕ is 59 degrees which is the angle at which the quadriceps exert maximum effective force (Williams and Stutzman, 1959).

Figure 26

Maximum Dipped Position



Descent Under the Bar

It is widely believed that force applied to the bar accounts for the extra-ordinary speed with which the athlete can descend into the full squat and split positions. The flight phases of both the clean and the jerk were tested for an acceleration of the bar equal to 'g' using least square parabolic functions and cubic spline analysis. Both procedures failed and both indicated values which were less than 'g' which is indicative of barbell/lifter interaction.

Visual observation suggests that there is a mechanism apart from the direct application of force which will explain, in part, the high average velocity of descent. The squatting and splitting movements of the legs cause a redistribution of the body's mass about the centre of gravity. The net result is a downward displacement of the trunk relative to the centre of gravity in addition to that which results from gravity alone. In order to examine this phenomenon more closely, a model of a hypothetical weight lifter was developed and manipulated.

Using the segmental data for the mean man found in the chapter on anatomical considerations, the location of the centre of gravity of the whole body was calculated for the full extended and full squat positions of the clean and the preparation for jerk and full split positions of the jerk. The shoulders were found to descend relative to the centre of gravity an amount equal to 7.0% of stature in the case of the clean and 4% of stature in the case of the jerk. The magnitude of this relative displacement was not enough to account for the high velocities of descent characteristic of world class lifters (see page 13).

It seems unlikely that an applied impulse at the full extended position is the answer either. As mentioned elsewhere, there is a distinct pause in the full extended position which is followed by knee flexion. It is only after flexion is under way that the lifter loses contact with the platform.

Theory dictates that displacement of the hips and shoulders should be vertical and at the same rate during the first pull, but analysis of the movement from film records clearly demonstrates the natural tendency of the hips and shoulders to move forward. An examination of Figure 27a is instructive of the consequences arising out of movement performed according to theory. The centre of mass of both the thigh and leg are displaced posteriorially causing a relatively small posterior displacement of the centre of gravity of the system as a whole in the absence of any compensating anterior displacement of the barbell and arms.

Anterior displacement of the hips, on the other hand, causes a relatively large forward displacement of the centre of gravity of the body unless the trunk is accelerated to a more vertical position as is done during a 'dead lift' (Figure 27b). However, this body configuration does not permit the development of a strong second pull and a cleaning movement, therefore, is not possible. The alternative is a trunk angle which remains parallel to its original position or decreases relative to the starting configuration. In either of these events, the only means by which balance can be maintained is to displace the bar posteriorially.

If it is given that the ideal starting position is one where the bar is initially at rest over the metatarso-phalangeal joints, then, by virtue of the attachment of the body to the bar by the arms, the configuration of the remaining body segments is determined by the position of the shoulders along the arc of a circle whose radius is the athletes arm. Anterior displacement of the shoulders rapidly raises the hips and produces a powerful position from which the lower limbs can exert force. The back muscles, however, are in an impossible position from which to work (Figure 27c). The reverse problem presents itself when the shoulders are positioned posterior to the bar. The lower limbs are in a poor position to exert force and the arms must work to hold the bar forward over the base of support.

Figure 27

Ideal Displacement of Body Segments During First Pull

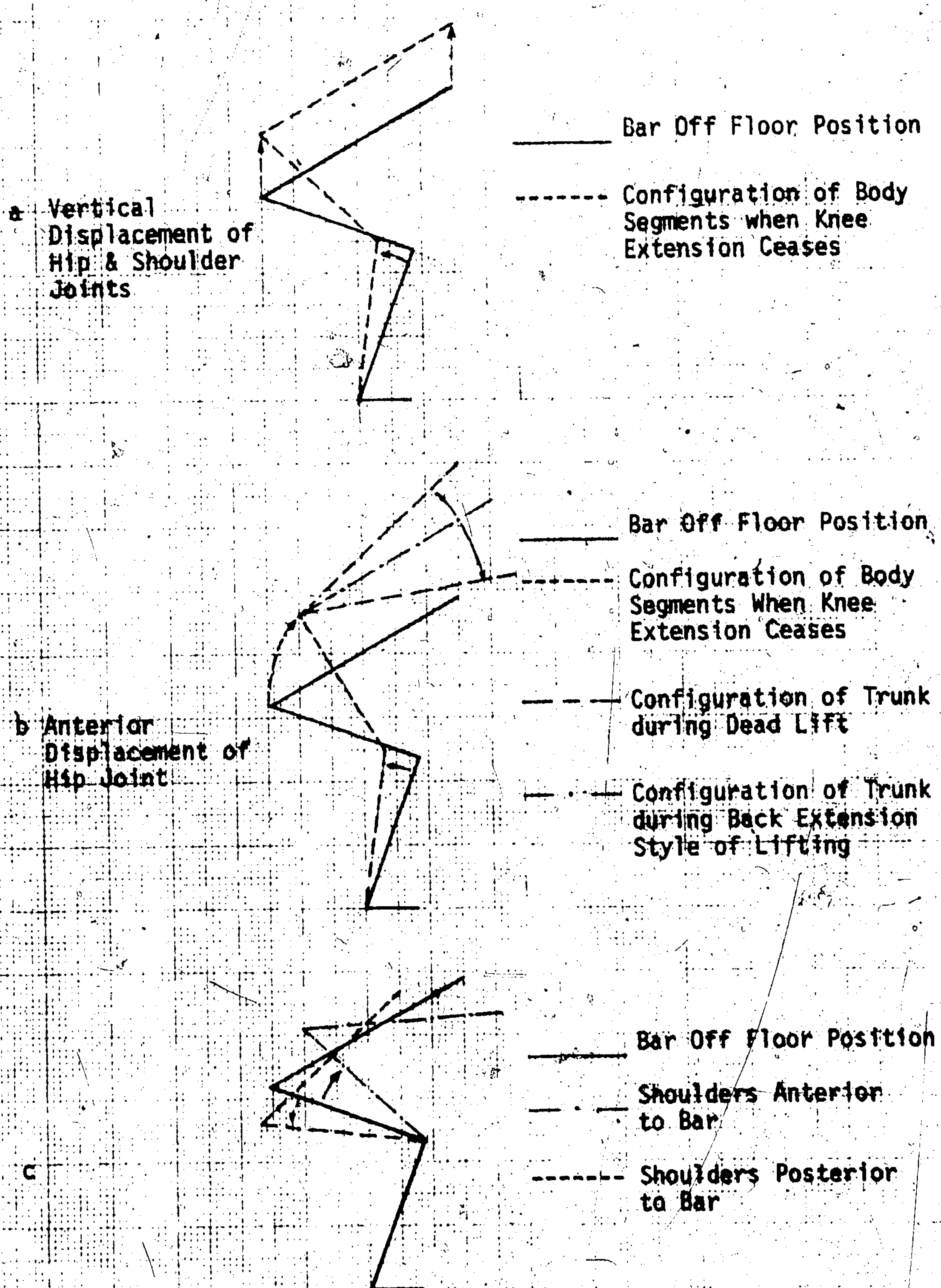
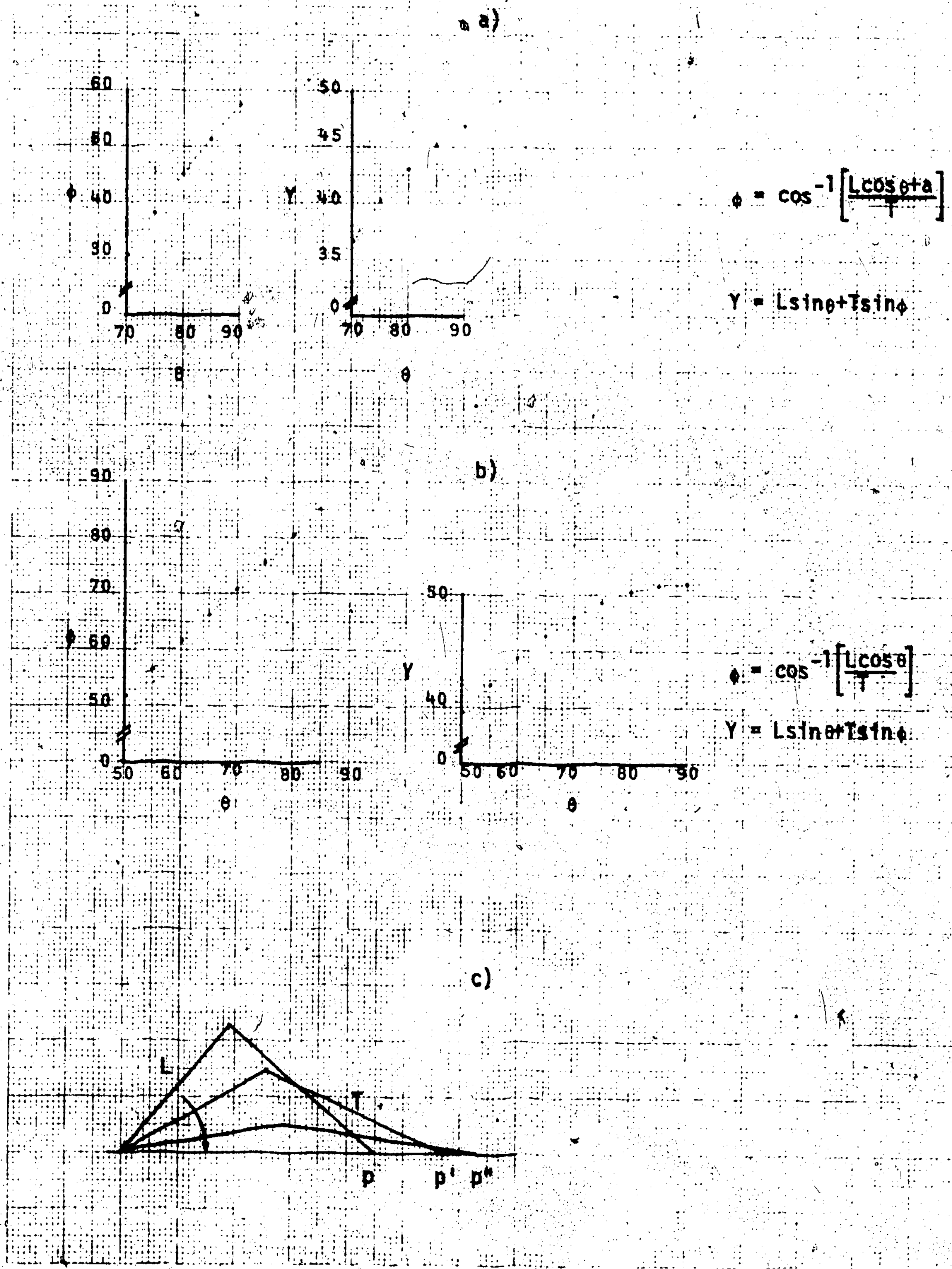


Figure 28

Kinematic Relationships of the Lower Limb Segments



The lever system formed by the lower limb segments exhibits different potentials for developing high velocities depending upon the phase of clean and jerk examined (Figure 30a and b). The angle ϕ does not increase as quickly as θ, in the case of the clean, as θ increases in value from 70 to 90^0 during the first pull (Figure 30a). When the displacement of the hip joint (Y) is graphed as a function of θ and ϕ (equations 3 and 4), the slope of the curve becomes increasingly negative. However, the changes in slope are not large and slightly accelerated values for θ will produce constant or accelerated vertical movement at the hip joint.

Although the relationship between ϕ and θ is nearly linear for the thrust phase of the jerk, the function, which graphs the displacement of the hip joint (Y) as a function of θ and ϕ (equation 5 of the model), exhibits a slope which rapidly goes to zero once a value of 70^0 for θ has been reached (Figure 30b). The loss in velocity generating potential can be best explained in terms of Figure 30c. The figure shows a rigid link system consisting of two segments labelled L and T. As L cuts equal arc lengths while rotating clockwise, the end point P of segment T is displaced increasingly lesser distances along the horizontal.

<u>The Grip</u>

An ordinary grip will normally be strong enough to hold the heaviest of barbells if one hand is the reverse of the other as is done when dead lifting. However, both hands must take an over-the-bar type of grip if the bar is to be racked. Assumption of a cleaning grip immediately entails an estimated 25-50% less in gripping strength in all but the strongest of lifters. The reason lies in the ability of the bar to rotate thus enabling the bar to roll out of the individual's hands. Adoption of a hook grip will restore gripping strength by providing resistance to the tendency of the bar to roll out of the hands. The grip involves wrapping the first and second fingers over the thumb of each hand.

CHAPTER SEVEN

DISCUSSION OF THE RESULTS

GENERAL

There is a maxim in physical education which states that the gifted athlete will be successful in spite of faulty technique. There is a good measure of truth to that statement and given the variability which accompanies human performance, it is the wise coach or researcher who will avoid defining proper technique in too rigid a manner. In the absence of knowledge of the principles of performance involved in an event, idiocyncracies will be confused with technical error. The literature, as it relates to olympic weight lifting, is a case in point. Although it contains much that is correct, it also dwells upon factors which appear to have little to do with correct performance. The ensuing discussion will have, as its focus, the development of principles of performance for each phase of the clean and jerk. Application of these principles will enable the coach or athlete to focus upon significant performance indicators rather than individual idiocyncracies.

The starting position is not a position of crucial importance in the sense that the alignment of the body segments must be precisely defined. Once the lift has been initiated, the body will make adjustments in keeping with the need for balance. Preliminary movements, such as rocking back and forth or diving for the bar, are quite permissible provided care is taken to ensure that the bar off floor position is correct. If, for psychological reasons, a lifter must dive for the bar, he should be sure that this preliminary movement allows him to take a proper grip and that unwanted horizontal force is not applied to the bar as a result of the dive.

Foot and hand widths should respectively be narrower and wider than the shoulder joints. A hook grip is mandatory for those with sufficient finger length because of the extra security it affords. The bar should be placed near metatarso-phalangeal joints but exact placement will depend upon the stature of the athlete.

There appears to be an optimum speed of performance which is desirable during the first pull. A rapid jerking motion, when maximum loads are used, invariably causes failure to complete the first pull. Reversion to a very slow movement, such as is typical of a dead lift, changes the lift to a relatively easy one to accomplish. If, for simplicity sake, the kinetic energy of the bar is representative of the energy expended by the muscles of the thigh, then the energy required to successfully execute a given lift will vary as the velocity squared. A 25% increase to 125 cm/sec. from 100 cm/sec. will require a 64% increase in the energy required to lift the weight. Since the energy source during performance is the alactic system, small increases in velocity will cause relatively large demands upon this energy source and if near maximum loads are being lifted, failure is likely to be the result.

Some authors recommend that the bar should be pulled as fast as possible but, in view of the foregoing, emphasis upon developing speed during the first pull will significantly increase the energy requirements of the musculature and thereby, place heavy demands upon the alactic system. Further, the lever system formed by the lower limb segments is in a poor configuration for developing high velocities and the restriction that the hip must be a distance 'a' from the ankle joint, is a detriment to maintenance of velocity at the end of the range of motion. The evidence appears to support those who advocate a submaximal effort during the first pull.

Hoffman (1959), Massey et al (1959), Miller (1974a), Gardner (1974) and Smithinunt (1974) have all agreed that the first pull is performed slowly. In an effort to define 'slowly', Miller (1974a) recommended that the athlete "pull as fast as the levers will allow". However, this statement is not entirely satisfactory either because a very slow pull, as performed in the dead lift, will permit the attainment of a much greater lift than a fast pull as performed in the snatch event. It would appear, therefore, that the operating principle should be to pull with the force necessary to attain the velocity required to effect a smooth transition to the scoop. Velocity values for the first and second pulls obtained from film analysis and the literature indicate a velocity for the first pull which is 15-20% of the peak attained during the second.

The recommendation, that the athlete maintain a shoulder position anterior to the bar during the first pull, is not a sound practice in the writer's opinion. As indicated elsewhere in this study, the position of the shoulders is determined by the position of the hips and the need to maintain balance. If movement is to be performed in accordance with the limiting parameters set forth in the model, then the position of the shoulders is predetermined and instructions to position the shoulders elsewhere will be a conflict.

The importance of the foregoing becomes clear if one speculates about the possibility of eliminating the transition phase between the point where knee extension ceases and the scoop begins. The reader will recall that continued vertical displacement of the bar was carried out through trunk rotation during this transition phase. The value of θ at the ankle was found in this study to be less than the corresponding value reported by Miller (page 22) while the respective values for ϕ and γ at the knee and hip joints were significantly smaller and greater. As a result, the position of the bar was lower when knee extension ceases in the case of subjects DS and ER than it is when values reported by Miller are used. Thus it would appear that a lower initial position of the hips, resulting in a more vertical position of the trunk than characteristic of the lifts performed by DS and ER, is conducive towards eliminating the transition phase. This configuration places the shoulders over the bar rather than anterior to it. Execution of the first pull in this new configuration will eliminate most of the posterior deflection of the bar which occurs during the first pull and the result will be a curve similar to that of Rigert.

All of the available evidence suggests that the critical phase of the pulling action is the scoop. A weight lifter should normally be able to handle any load during the first pull. When a failure occurred during the experimental test session, the scoop phase was characterized by a dropping velocity pattern.

The scooping action causes the quadriceps to contract eccentrically but it is not correct to conclude that the restretched quadriceps muscle is able to contract more powerfully as a result. It is not clear that the loading is of sufficient magnitude to stimulate the muscle spindles or is of sufficiently short duration to prevent adaptation of the spindles to the load. The most important significance of the scoop is it's function of realigning the body segments.

Personal experience and the results of informal testing while coaching have demonstrated, to the writer, the need to provide exercises specifically designed to strengthen the scoop part of the clean. Weight lifters in Alberta are weak in this phase of the pull in the absence of special training. The scoop is very trainable and load values well in excess of a lifter's best clean are easily attained. The natural strength of the movement has its origin in the eccentric contractions performed by the quadriceps.

The performance goal in effect during the second pull is the attainment of full vertical extension of the body having regard for certain limitations and qualifications. Full extension, in a literal sense, is both undesirable and not attained in actual practise. Full extension at the knee joint, for example, would cause the knee "screw home". Subsequent flexion will require the knee to unlock before the flexor muscles can operate upon the joint. When flexion is able to take place, the flexor muscles will be acting upon the joint at a very poor angle.

There are, however, more important reasons for not over emphasizing full extension. The most important of these is the inefficiency of the lower limb lever system at the end of the range of motion. The angular velocity of the body segments must increase enormously in order to prevent deceleration at the end point of the system. Compounding this problem is the weakness of the arm and shoulder muscles which cannot fully compensate. In sum, full extension represents wasted effort. The amount of extra height achieved by pulling with the arms will probably be more than offset by the loss of time created for the descent.

Concentration upon the action of the wrists at the top of the pull will cause the athlete to lengthen his pause at the top of the pull and all of the above negative consequences will accrue. Further, the anatomical consequence of wrist flexion, as reported in the literature, is largely incorrect. (The position of the elbows does not alter the action of the trapezius.) It is very unlikely that wrist flexion prevents bar swing because, given the magnitude of the weights being lifted relative to the strength of the flexor muscles, wrist flexion can only take place when the thrust being applied to the bar is reduced. Invariably, the body moves towards the bar in these circumstances.

In view of the foregoing, the principle of performance requires that the coach stress attainment of a full extended position for the purpose of ensuring a properly extended second pull. If an athlete does not extend over the maximum range possible, the coach should take the above factors into consideration before insisting upon more complete extension. All reference to a 'top pull' with the arms should be eliminated from coaching theory and in its place, a shoulder shrug timed to coincide with extension at the knees and ankles should be recommended. Not only are the trapezius muscles capable of delivering an effective force but the large well developed trapezius and relatively underdeveloped biceps brachii muscles of world class lifters suggest that the foregoing analysis is correct. The above argument, coupled with the decreasing ability of the lower limb to produce high accelerations once a value of approximately 70^0 for θ has been achieved, suggest that the second pull should be of very short duration. Once the impulse has been delivered, the body immediately descends to the full squat position.

The magnitude of the velocity of descent into the full squat position reported in the literature is difficult to understand because it is hard to imagine the movement executed with more rapidity than that performed by subject DS. A possible explanation lies in the method of computation. The studies in the literature were all characterized by the use of relatively slow film transport speeds. Shakirzianov (1974) used 20 frames per second and the others were in the range of 60 frames per second. As a result, the initial knee flexion and/or the absolute bottoming in the full squat may not have been seen. The definition of when the movement commenced and finished may have differed. In conclusion, it may be said that the mechanism, whereby weight lifters create large velocities during descent under the bar, is not at all clear.

The most important principle of performance to be observed during the jerk is the attainment of vertical displacement during the dip and thrust phases of the lift. As was the case with the other principles, a slight amount of variation can be tolerated.

A problem associated with a vertical jerk is getting the bar passed the head. In a normal standing position, the bar is inferior to the angle of the mandible and when the bar has left its racked position, the head must be withdrawn if flight is to continue. The tendency of all lifters to impart a forward velocity to the bar during the thrust phase may have, in part, its origin in the need to avoid a collision with the head. A 'tall' position can be assumed in which the intercostal muscles are contracted in order to lift the rib cage. The resultant reduction in kyphosis causes the head to be displaced posteriorally and the centre of pressure in the feet to likewise move back towards the heels of the feet. Vertical displacement of the bar is greatly facilitated when the body is in this configuration. Subject DS was observed to jerk in this manner.

The primary source of bar velocity is extension of the knee joints and the peak is attained before full extension of the joints occurs. It appears safe to conclude that extension passed 80^0 contributes little to the production of velocity and efforts to achieve greater extension should be considered as a waste of time.

An ideal anterior foot displacement ratio of .38 was developed in conjunction with the full split position. Deviation from this ratio can be used as an indicator of unwanted horizontal movement of the body as a whole. It is unlikely that forward movement will ever be entirely eliminated and the question, which then presents itself, is how much displacement can be tolerated. It would appear that a normal range would be .4 to .45.

Certain joint angles appear to be more important than others. The values for ϕ and γ for the bar off floor position are a case in point. Since these angles determine the position of the shoulders, only the latter needs to be monitored by the coach. The value of the joint angles at the commencement of the scoop are also important and these may vary somewhat with body structure. The values applicable to a particular lifter can be easily computed using the equations and diagrams found in the report.

The bar velocities characteristic of DS and ER were at the low end of the ranges reported by other researchers. Subject MK, in Garhammer's study (1978), lifted with peak velocities of 124 and 127 cm/sec. during the clean which are comparable to the average values produced by DS and ER, namely, 130 cm/sec. for DS and 123 cm/sec. for ER. Subject AV, in Garhammer's study, lifted in the 52 kg. class and attained a peak velocity of 140 cm/sec. during the jerk. The average values for DS and ER were 137 cm/sec. and 130 cm/sec. respectively.

The evidence suggests that highly skilled weightlifters do not throw the bar into the air and catch it as hypothesized by the model outlined in this study. It appears that they throw the bar high enough to enable the arms to easily 'press' the bar to its final resting position.

The double knee bend technique appears to offer the potential for being a very efficient method of lifting. A vertical displacement path for the barbell is, in theory, mechanically possible and large velocities do not appear to be required for success. In order to develop the technique to its full potential, weight lifters should be trained to use the first pull and scoop as a means to position the bar for the second pull. The second pull should then be performed with a rapid extension of the body and a concomitant shoulder shrug after which the body immediately descends into the full squat position. The large trapezius muscles are quite capable of delivering a short impulsive force while extension is being carried out. All thought of pulling with the arms should be forgotten for two reasons. First, the arms are not strong enough to prevent deceleration and second, pulling the bar to a low bar high position before descending is not compatible with delivering thrust with the arms. The fact that champion weight lifters are characterized by a low bar high position strongly suggests that they do not waste time pulling with the arms.

The double knee bend technique can also be viewed as a means whereby the compressive forces upon the lumbo-sacral disc are minimized. The increasing velocity of the bar as the pull progresses parallels the decreasing torque required of the erector spinae to maintain an arched spinal configuration. At the level of the disc, this translates into decreasing compressive force. Upon completion of the scoop, the trunk is in a nearly vertical position and the torques required of the erector spinae are significantly reduced. The body is now in a good mechanical position to deliver a large impulsive force to the bar and the lumbar spine is in a superior position to withstand the concomitant compressive forces.

The principle involved can be more easily understood if it is assumed that the limiting factor in weightlifting, from an anatomical point of view, is the magnitude of the compressive forces which the lumbosacral junction can withstand. Chaffin (1969) has provided evidence that this assumption is not unrealistic and that the body will limit the amount of compressive force to approximately 5880 newtons. Given a maximum value of this amount, this magnitude of load can be supported only when it is applied vertically to a stationary disc which is horizontally disposed. The amount of weight, which can be supported, will decrease from the maximum when an angle of inclination is introduced to the disc or if an upward vertical acceleration is introduced. Both of these factors exist during the pull phase of the clean. The double knee bend technique can be regarded as a means whereby disc inclination and acceleration are varied to produce optimum conditions for lifting maximum weights.

Reformulation of the Phases and Positions of the Clean and Jerk

The experimental results indicate the need for modification to the breakdown of phases and positions used in this study. The following paragraphs contain a summary of a new breakdown.

The thrust segment or pull part of the clean was originally subdivided into first and second pull phases separated by the scoop or rebend phase. The data suggests that recognition of a transition phase may be needed inorder to complete the description. This phase was seen in the lifts of ER and DS but it is not known whether or not this is a characteristic of the technique or a phenomenon displayed by the two subjects. The mechanical analysis performed suggests that it is the former. In either event, the transition phase will be either something to avoid or a constant feature of the rebend style of lifting.

It has been decided to include the transition phase as a subphase of the first pull. The knee low position has been created to mark its beginning and its end is marked by the knee high position.

The scoop or rebend phase remains unaltered as does the second

second pull phase comprised of the bar on thigh position, the full extended position and the bar high position. This latter position occurs when the squat phase is under way and so temporally, it belongs to that phase. However, it is logically a part of the second pull and hense its inclusion as part of that phase.

The squat phase remains unaltered as well. However, this was done with reservations. It is clear that the squat can be broken up into descent and ascent phases. The descent phase can be further subdivided into numerous other divisions. The temptation to effect further subdivisions was resisted because it is unclear which of these are significant and which are not. At the root of the problem is the question of how world class athletes descend to the full squat position so quickly.

The breakdown of the jerk remained the same except for the addition of a bar high position as part of the thrust phase. Recognition of this position will focus attention to its importance which lies in its inverse relationship with the magnitude of the splitting action during the split phase.

CHAPTER VII

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

SUMMARY

Based upon the data gathered in this study, the clean and jerk event may be broken down int the following phases and key positions.

Clean

a) First Pull Phase

i) Starting Position

ii) Bar Off Floor Position

iii) Knee Low Position

Transition Phase

iv) Knee High Position

b) Scoop or Rebend Phase

c) Second Pull Phase

i) Bar On Thigh Position

ii) Full Extended Position

iii) Bar High Position

d) Squat Phase

i) Full Squat Position

Jerk

a) Dip Phase

i) Preparation For Jerk Position

ii) Dipped Position

b) Thrust Phase

i) Full Extended Position

ii) Bar High Position

c) Split Phase

i) Full Split Position

The phases and positions appear to represent significant parameters of the clean and jerk event. The deliniation of phases permits the break up of the whole lift into meaningful parts which are readily amenable to further analysis. The defined positions represent important visual touch stones for the recognition of proper execution of technique.

Associated with the positions are angles at the hip, knee and ankle joints. Their pattern of movement during the pull segment of the clean appears to be characteristic of the double knee bend technique. The experimental values gathered in the study basically agree with values reported in the literature.

When the lift is executed properly, a characteristic path of the barbell is generated as are velocities and power outputs. The literature supports the findings of this study, namely, that the power output in the vertical plane is similar during the second pull and thrust phases. One might have guessed this to be the case from a knowledge of the positions associated with these two phases. The body configurations and movements are highly similar.

Having identified phases, an attempt was made to formulate principles of performance which suggested themselves from the data collected. These have been summarized below.

1. The starting position is not of crucial importance.
2. There appears to be an optimum velocity characteristic of the first pull. Although a numerical value was not assigned, it appears that it must be of sufficient magnitude to ensure a smooth transition to the scoop phase.
3. The position of the shoulders relative to the bar will be determined by the technique of pulling used. Once a technique has been determined as desireable for an athlete, the position of the shoulders will be determined by the need to maintain balance.

4. The scoop phase appears to be of critical importance for the execution of a successful clean.
5. Full extension during the second pull and the 'top pull' are probably detrimental to optimum performance.
6. Vertical displacement of the bar during the dip and thrust phases of the jerk is of crucial importance to a successful lift.
7. The magnitude of the upward displacement of the bar during the jerk is inversely related to the magnitude of the split necessary for successful completion of the lift.

CONCLUSIONS

The double knee bend technique used by subjects DS and ER was found to be essentially the same as described in the literature. Velocity values of the bar at critical phases of the lift were at the low end of the value ranges typical of world class athletes. It was concluded, therefore, that although the size of the sample of subjects was small, it was representative of performance of the double knee bend technique as performed by highly skilled athletes.

The double knee bend technique is a means by which an Olympic weightlifter can use the structural characteristics of the body's lever systems to lift more than he could otherwise. High bar velocities are not required throughout the pulling phase of the clean and the energy expenditure required to lift a given load can be minimized. In addition, there is evidence to suggest that the compressive forces upon the lumbo-sacral disc are minimized. The importance of this lies in the belief of some researchers that the ultimate determinant of lifting ability is the capacity of the body to absorb the loads put upon the lumbo-sacral disc.

The double knee bend technique of pulling involves three distinct movements; the first pull, scoop and second pull. Analysis indicated that the literature does not sufficiently recognize the uniqueness of these three movements. In view of the principle of specificity of training, knowledge of the three movements is required for optimum results.

The model developed from information contained in the literature appears to be capable of describing bar velocity and acceleration patterns during the jerk when ϕ is written as a function of θ. The model was also capable of predicting a transition phase during the first pull when extension at the hip joint sustained the application of force to the bar.

Full extension of the joints does not appear to be compatible with optimum performance and evidence was found which suggested that plantar flexion contributes minimally to the application of thrust to the bar during the pull phase of the clean and the thrust phase of the jerk.

The descent phase of the jerk is the weakest segment of the clean and jerk in terms of performance. Not only is it a naturally difficult movement but the visual evidence suggests that it is a poorly understood and coached phase of the lift.

Cinematography, as a means of investigating Olympic weightlifting was found to be an indispensible tool for descriptive purposes. Coordinated anterior and lateral cameras at 100 frames per second provided detail of movement, temporal sequences and bar/body relationships which would have been very difficult to obtain using other tools. However, cinematography was found to be an inadequate investigative tool when a more detailed examination was required. The need to record planar motion resulted in an experimental design which did not permit visual access to all aspects of the lifts.

Recommendations

1. Further research is needed into the exact nature of the mechanism which operates during the descent phases of the clean and jerk to produce the large velocities attained.

2. A smaller lateral field of view than used in Substudy #3 is required if accurate angular displacement data for the

lower limb is to be obtained. The original intent was to have a field of view large enough to capture movement of the trunk during the jerk but it is now clear that this was not necessary.

3. Further research is required to determine the nature of angular limb displacement when large resistances are imposed in general and of displacement during the clean in particular.

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