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THE EFFECTS OF LOAD ON LIFTING CHARACTERISTICS
OF THE PARALLEL SQUAT

by

Iveta Doktor

A Thesis
Submitted to the Faculty of Graduate Studies and Research
through the Department of Kinesiology
in Partial Fulfilment of the Requirements for the
Degree of Master of Human Kinetics at the
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1993
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THE EFFECTS OF LOAD ON LIFTING CHARACTERISTICS

OF THE PARALLEL SQUAT

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ABSTRACT

The purpose of this study was to investigate the influence of increasing load on the lifting characteristics of the parallel squat. Special attention was directed to the sticking point phenomenon. Specifically, the goal of this study was to determine the percentage of maximal load at which the sticking point first appears.

Eight male powerlifters, of provincial and national calibre were recorded, via high-speed cinematography, while performing a single repetition of parallel squat at six levels of performance, in the following order: 50%, 60%, 70%, 80%, 90% and 100% of maximal load.

The coordinates of five points: the fifth toe, the ankle, the knee, the hip, and the geometric center of the weights on the bar were collected on every frame throughout the movement. These data were subsequently used to determine the movement times, and to calculate desired angular displacements and velocities of body segments, and vertical velocity of the bar during each trial.

The results of this study show that the movement during the descending phase of the parallel squat was controlled. The descending phase movement time remained unchanged regardless of the increase in load. The peak vertical
bar velocity and the peak angular velocity of the trunk and the thigh decreased in the downward direction as the load increased. The peak angular velocity of the shank did not change with the increase in load. The time at which the peak vertical bar velocity and the peak segmental velocities occurred paralleled the descending phase movement time.

In the ascending phase, the lifting characteristics of the parallel squat had been affected by the increasing load. The ascending phase became longer as the load increased. The peak vertical bar velocity and the peak angular velocity of the trunk and the thigh decreased as the load increased. The peak angular velocity of the shank remained unchanged as the load increased. The timing of the peak vertical bar velocity and the peak segmental velocities coincided with the ascending phase movement time findings.

Mid-way through the ascending phase of 60%-of-maximal-load trial to 100%-of-maximal-load trial, the sticking point occurred. The sticking point was caused by increased trunk lean during the initial part of the ascending phase. As the load increased the trunk lean increased, which in turn led to a more pronounced sticking point. As the sticking point became more pronounced the segmental angular velocities decreased and subsequently, so did the vertical bar velocity.
DEDICATION

Dedicated to my parents Petr and Jana Doktor:

Thank you for your support and a chance for a better life.
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CHAPTER I
INTRODUCTION

Powerlifting is a popular North American sport where maximal performance is sought. It is made up of three distinct skills: the bench press, the deadlift, and the parallel squat. The parallel squat is a skill which combines lower body strength and technique to obtain maximal performance. The principle behind the parallel squat seems quite simple: develop the proper technique and strength, and the performance will increase. Yet, it is not that simple. There is one phenomenon that limits performance, which all powerlifters encounter. It is the sticking point. Very little is known about the sticking point. In fact, what causes it, at what percentage of maximal load it first appears, and how to eliminate it are unknown.

As a result, the purpose of this study is to learn more about the sticking point by determining the level of performance at which the onset of the sticking point occurs in the parallel squat movement.
Statement of the Problem

The intent of this study was to use cinematography to obtain various kinematic measures at different levels of performance of the parallel squat in order to study the effects of increasing load on the lifting characteristics. Special attention was directed to the sticking point phenomenon. Specifically, the goal of this study was to determine the percentage of maximal load at which the sticking point first appears.

Definitions

The following terms are defined in the order of occurrence in this study:

The parallel squat is a deep knee bend. The powerlifter initially steps up to the bar which is resting on the support racks at shoulder level. He/she positions himself/herself with the bar across the shoulders. Then he/she removes the bar from the support racks and places the feet more than shoulder width apart. At this point, the powerlifter is ready to begin the parallel squat movement. According to the official rules of the International Powerlifting Federation, for the parallel squat to be acceptable "... the lifter shall bend the knees and lower the body until the tops of the thighs are below parallel with the platform ..." (International Powerlifting Federation Rules, 1974). The powerlifter then ascends to an upright position, which marks the end of the movement, and returns the bar to the support racks.
The **sticking point** is a point in time, during mid-ascent, when the bar's vertical velocity reaches a minimum value.

The **bar** is a metal barbell weighing 20.5 kg (45 lbs). It is 223 cm long and has a diameter of 5 cm. To increase the mass of the bar, metal weights, shaped like discs, are added to both ends of the bar. The weights range in mass from 1.1 kg (2.5 lbs) to 20.5 kg (45 lbs).

The **turn-around point** is the lowest thigh angle position in the parallel squat. It marks the end of the descent and the beginning of the ascent.

The **weightbelt** used by powerlifters consists of three layers of leather. It is 1.1 cm thick and 10 cm wide for its entire length.

The **lifting suit** worn by powerlifters during competitions is an elastic sleeveless suit, covering the torso and the upper third of the thigh.

The **knee wraps** are elastic, bandage-like wraps, 7.5 cm to 10 cm wide.

The **shutter factor** is an index which refers to how long the camera shutter is open and the film is exposed to light. As the shutter factor increases the exposure time decreases.
The **f-stop** is a ratio of the focal length of the camera lens to the diameter of the opening of the diaphragm. The lower the f-stop number is the wider the opening of the lens and the more light is allowed to enter into the camera.

**Limitations**

There were several limitations to this study. First, seven out of the eight subjects used in this study were not elite athletes. They had never competed at the international level. They were provincial and national calibre powerlifters. Thus, their performances were not necessarily model performances.

Secondly, the head, the shoulders, and the wrists of the powerlifter are obscured when squatting, by the large weights added onto the bar. As a result, these points were not digitized. The geometric center of the weights on the bar was digitized. Since the bar with the added weights rested across the powerlifter’s upper back, the center of the weights with respect to the hips was used as an indicator of the trunk motion.

Although, the subjects maintained a grip on each side of the bar in order to prevent any undesirable movement of the bar, some movement in the anterior-posterior direction did occur due to the twisting of the trunk at the hips. Such undesirable movement had an effect on the measurement of the trunk angle.
Joint markers were originally placed on subjects' hips, however, they did not adhere well to the lifting suit material and some fell off during the testing. As a result, in some trials, the location of the hip joint had to be estimated during digitizing.

The stance which the subjects adapted when squatting was such that their feet were slightly more than shoulder width apart, and their legs were somewhat externally rotated at the hips. Thus, their feet and knees were pointed away from the midline of the body when squatting. As a result, the thigh and the shank segments were not perpendicular to the camera, which slightly affected the shank and thigh angle.

**Delimitations**

This study was delimited to the number of the subjects, the gender of the subjects, the experience of the subjects, and the level of performance of the subjects. In this study, eight male subjects representative of the Canadian population of competitive powerlifters, were used. All subjects were provincial and national calibre powerlifters, which means they all had at least 1 year of experience as competitors. Therefore, their performance reflected their experience and ability. In this study, the subjects performed one repetition of parallel squat at each of the six levels: 50%, 60%, 70%, 80%, 90%, and 100% of maximal load.
CHAPTER II
REVIEW OF LITERATURE

Introduction

Not only is the parallel squat one of three competitive skills performed in powerlifting, it is also a popular strength training exercise for many competitive and recreational athletes whose goal is to gain strength, power, and muscle mass in the thigh. Yet, relatively few studies on the parallel squat have been published. The most comprehensive study was done by McLaughlin, Dillman, and Lardner (1977, 1978) on the kinematics and kinetics of the parallel squat performed by national level powerlifters. Other directly applicable information includes a study by Plagenhoef (1971) on the moments of force in various static positions in the parallel squat. Ariel (1974) examined bone-on-bone, shearing, and compression forces acting on the knee joint during submaximal-load parallel squat. More recent research concentrates on lifting aids, such as the weightlifting belts (Lander, Simonton, and Giacobbe, 1990), lifting suits and knee wraps (Escamilla and Sawhill, 1990), and their effectiveness during the parallel squat movement.
Kinematics

To date, McLaughlin and co-workers’ (1977) study of kinematic factors that describe the movements in the parallel squat is the only kinematic study of the skill. In this study, McLaughlin et al. (1977) recorded, via high-speed cinematography, 24 subjects of various bodyweight classes performing one maximal-load lift during the 1974 U.S. Senior National Powerlifting Championships. After the competition, the performances of the 24 subjects were compared to the 1974 list of top ten world performances in the parallel squat for each bodyweight class. Seventeen of the subjects’ performances ranked within the top ten in the world in their respected bodyweight class. As a result, they were classified as skilled. The other seven powerlifters were not ranked within the top ten world performances, and therefore were categorized as less-skilled.

A detailed analysis of the movement patterns of the skilled and less-skilled powerlifters revealed one common movement characteristic and several differences in technique between the two groups. First, the profile of the vertical bar velocity-time curve was similar among all subjects regardless of bodyweights and bar loads. It was considered to be representative of each powerlifter’s technique, as it reflected the action of muscular forces exerted by the powerlifter. Therefore, any slight differences in the vertical bar velocity among the two groups of subjects would represent differences in technique. Indeed, four general technique differences between the two skill groups were
isolated. The less-skilled subjects: 1) descended with a greater downward bar velocity, 2) approached the turn-around point (the lowest position) at a greater downward bar velocity, with more of a "bounce" effect, 3) demonstrated a greater forward torso lean, and backward knee and hip movement in the early ascent, and 4) maintained a greater forward torso lean, and a lower vertical bar velocity through the sticking point region. It was interesting to note that the sticking point occurred at 30 degree thigh angle with respect to the horizontal in all subjects (McLaughlin et al., 1977). The sticking point had also been identified in the bench press, which is the second of three competitive powerlifting movements (Elliott, Wilson, & Kerr, 1989; Lander, Bates, Sawhill, & Hamill, 1985). Thus, it seems that competitive powerlifters encounter the sticking point in two of the three competitive skills. Yet, very little is known about this performance limiting phenomenon. It is still unclear what causes the sticking point and at what percentage of maximal load it first appears.

**Kinetics**

Unlike the kinematics, more extensive work has been done involving kinetic analyses of the parallel squat. Again, the most comprehensive study in this area has been conducted by McLaughlin, Lardner, and Dillman (1978). In this study, McLaughlin et al. used the same data from their kinematic study of the parallel squat to calculate torques at the hip, the knee, and the ankle. They found that the hip torques during the parallel squat movement were similar in
pattern for all subjects and were extensor dominant. Thus, the gluteus maximus, the erector spinae, and the hamstrings muscles were the net contracting muscles. The skilled powerlifters demonstrated lower maximal hip torques than less-skilled powerlifters due to lesser forward trunk lean, and the resulting shorter lever-arm of the bar relative to the hip.

The skilled powerlifters also demonstrated greater extensor-dominant knee torques than the less-skilled, in fact, some less-skilled subjects exhibited flexor-dominant knee torques. According to Garhammer (1989), this is perhaps due to a greater reliance on the knee extensor muscles rather than on hip extensor muscles by the skilled subjects. McLaughlin et al. (1978) took this explanation one step further and suggested that the magnitude and dominance of the knee torques are influenced by the magnitude of the hip torques, which are in turn affected by the magnitude of the forward torso lean. A greater forward torso lean, as exhibited by the less-skilled subjects, requires a greater hip extensor torque to maintain the powerlifter in equilibrium. Thus, the hamstring muscle group must contract in order to contribute to creating this torque. However, the action of the hamstrings has a dual effect: it creates a hip extensor torque as desired, but also a knee flexor torque which negates somewhat the effect of the quadriceps activity (McLaughlin et al., 1978; Garhammer, 1989). This observation is in agreement with Plagenhoef (1971) who used a static three-segment rigid link model of a lifter performing the parallel squat, to show that excessive forward torso lean resulted in a net knee
flexor torque. Carlsoo and Molbech (1966) also support the contention that forward trunk lean reduces the muscle activity of the quadriceps.

The hamstring dual effect was particularly well demonstrated at the sticking point, where the less-skilled subjects had a greater tendency to increase their forward trunk lean. As a result, the knee torques were found to be relatively low and the hip torques were generally near maximum at the sticking point (McLaughlin et al., 1978).

The knee torques were generally maximal at the turn-around point (McLaughlin et al., 1978). Ariel (1974) found that a skilled powerlifter squatting 650 lbs. exhibited smaller extensor knee torque, and smaller knee shearing force at the turn-around point than a less-skilled powerlifter squatting a lighter weight. The less-skilled subject bounced at the turn-around point, which resulted in a sharp increase in the knee torque and the knee shearing force. Ariel (1974) pointed out that it is important to reduce the large shearing forces by improving lifting technique, in order to decrease the potential for injuries.

**Lifting Aids**

In the last few years, the research focus has shifted from performance in powerlifting to the effectiveness of lifting aids. As more and more people are becoming involved in weightlifting, the market is flooded with various types of lifting aids such as weightbelts, knee wraps, body suits, and so on. The
question is: do the lifting aids help to increase performance and decrease the risk of injury, or do they just provide the weightlifter with a false sense of security?

Lander, Simonton, and Giacobbe (1990) conducted a study on the effectiveness of weightbelts during the parallel squat. In this study six skilled subjects performed the parallel squat at 90% of maximal load, with and without a weightbelt. Lander et al. found that the greatest stresses on the spine occurred at the point of the greatest forward trunk lean: at the turn-around point and during the first part of the ascent, through the sticking point. The stress on the lumbar spine could be reduced by increasing the intra-abdominal pressure. By placing a weightbelt tight around the waist, the abdominal cavity becomes pressurized, and it supports some of the load normally supported by the lumbar spine.

In the weightbelt condition, the intra-abdominal pressure was maximal at the turn-around point, during the first part of the ascent, and at the sticking point. The subjects exhibited greater moments around the fifth lumbar and the first sacral vertebrae and smaller moments around the knee during ascent. This occurs when the knee extends at a faster rate than the hip. Thus, the subjects relied on the knee extensors more than on the hip extensors when wearing a weightbelt. The subjects also felt more secure when squatting with a weightbelt (Lander et al., 1990).
Therefore, a weightbelt is an effective lifting aid. It increases the intra-abdominal pressure, which in turn has a positive effect on the musculature. The weightbelt also acts as a stabilizer of the lumbar spine by compressing the tissues around the spine. For these reasons, all powerlifters wear weightbelts. They do not train or compete without them.

A lifting suit and knee wraps are other lifting aids used by powerlifters regularly. In a study done by Escamilla and Sawhill (1990), six powerlifters performed the parallel squat with and without the lifting aids. All six subjects increased the amount of weight lifted by 6% to 18% when lifting aids were used. All subjects had greater mean torques around the knee and the hip joints with lifting aids. However, the increase in the torques was due to the increase in the weight lifted, and not due to a change in technique. When using lifting aids, the subjects required on the average 0.5 sec. less time to complete one repetition. Thus, it appears that the lifting suit and the knee wraps are effective lifting aids. Their use leads to an increase in performance without compromising proper technique.

Conclusion

Although relatively few studies on the parallel squat have been published in the last two decades, the research available provides many insights into the kinematics and kinetics of the parallel squat. The subtle differences in technique that separate the skilled from the less-skilled have been isolated. The
effectiveness of various lifting aids has been evaluated. There is still one mystery that remains: the sticking point phenomenon. McLaughlin et al. (1977) observed that the sticking point occurred in all powerlifters, during their maximal effort, at 30 degree thigh angle with respect to the horizontal. A film analysis of failed trials revealed that the lifters’ upward movement stopped at the sticking point.

It seems that every powerlifter encounters the sticking point. Yet, the cause of it is unknown. It is also unknown at what level of performance the sticking point first occurs.

Therefore, the purpose of this study was to determine the level of performance at which the onset of the sticking point occurs in the parallel squat.
CHAPTER III
METHODS

Introduction

The purpose of this study was to investigate the effects of increasing load on the lifting characteristics of the parallel squat movement and to determine the percentage of maximal load at which the onset of the sticking point occurs.

Independent Variable

The independent variable that was manipulated in this study was the level of maximal load lifted. There were six levels of the independent variable: 50%, 60%, 70%, 80%, 90%, and 100% of maximal load.

Dependent Variables

The variables that were measured in this study were: the total movement time (s) of the parallel squat, the movement time (s) of the descending phase, and the movement time (s) of the ascending phase. The peak positive and peak negative vertical bar velocity (m/s) was measured as
well as the time to peak vertical bar velocity (s) and the percentage of
movement time to peak vertical bar velocity (%).

Other kinematic measurements included the peak negative angular
displacement (degrees) of the trunk, the thigh, and the shank; the time to peak
angular displacement (s) of the trunk, the thigh, and the shank; and the
percentage of movement time (%) to peak negative angular displacement of the
trunk, the thigh, and the shank. The peak positive and peak negative angular
velocity (degrees/s) of the trunk, the thigh, and the shank was also measured
as well as the time to peak angular velocity (s) of the trunk, the thigh, and the
shank; and the percentage of movement time (%) to peak angular velocity of
the trunk, the thigh, and the shank.

In addition, the following kinematic measures were taken at the sticking
point: vertical bar velocity (m/s), time to sticking point (s), and percentage of
movement time to sticking point (%); trunk, thigh, and shank angle (degrees);
and trunk, thigh, and shank angular velocity (degrees/s).

Subjects

Eight male powerlifters of national and provincial calibre were used in this
study. Five powerlifters were members of various weightlifting clubs in the
Niagara region, and three lifters belonged to the Golden Triangle Powerlifting
Club in Kitchener. The subjects were between 20.7 - 33.3 years of age (\(\bar{x} = 
27.21 \pm 4.4\) yrs), and their experience as competitive powerlifters varied from
1 to 9 years ($\bar{x} = 4.4 \pm 3$ yrs). Individual subject's personal data are listed in Table 1.

Table 1.

<table>
<thead>
<tr>
<th>SUBJECT</th>
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<th>HEIGHT</th>
<th>EXPERIENCE</th>
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<td>± 0.13</td>
<td>± 3</td>
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16
Procedures

The data for this study were collected in three testing sessions. The first two testing sessions took place at the YMCA in St. Catharines, Ontario and the third session occurred at the Popeye’s Gym in Kitchener, Ontario. During the first session two subjects were tested; and three subjects were tested during each of the second and the third testing session.

Prior to the start of testing, all participants were informed of the experimental procedures and were required to sign a consent form verifying their understanding of the purpose and protocol of the experiment (Appendix B).

Subjects were asked to perform a single repetition of the parallel squat movement at each of the following levels of maximal load: 50%, 60%, 70%, 80%, 90%, and 100%. Since the testing was designed to mimic a real-life event, the levels of maximal load lifted were not randomized. Instead, the testing was conducted in ascending order, starting with 50% of maximal load, and finishing with maximal performance. The amount of weight lifted at each level was determined from individual lifter’s prediction of his maximal performance on the day of the testing. Individual subject’s performance data are listed in Table 2.

To make the handling of the weights easier, the order in which subjects performed was assigned according to their expected performance. The subject with the lowest expected maximal load lift was the first one to perform at each
Table 2.
Individual Subject Performance Data

<table>
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<tr>
<th>SUBJECT</th>
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<td>1992.8</td>
</tr>
<tr>
<td>SD</td>
<td>± 220</td>
<td>± 263</td>
<td>± 308</td>
<td>± 357</td>
<td>± 394</td>
<td>± 439</td>
</tr>
</tbody>
</table>

level, and the subject with the highest expected maximal load lift was the last one tested at each level.

Each testing session was conducted in such a manner as to mimic a competition. The subjects were allowed as much time to warm-up as desired prior to testing. The testing started with all subjects performing, in the
established order, a single repetition of the parallel squat movement at 50% of maximal load, then lifting at 60%, and so on up to maximal performance. Between attempts, each subject had 10-15 minutes of recovery time.

All subjects were instructed to wear weight-belts, knee wraps and lifting suits during testing. Two spotters were used, for safety reasons, one at each end of the bar, ready to secure the bar and help the subject, if necessary.

Filming Procedures

A motor-driven, 16 mm, Locam camera, loaded with video news film, was used to record the performances during testing sessions. For the first two testing sessions the camera, secured to a tripod 80 cm above the floor, was set up approximately 6 meters from the squatting area, perpendicular to subjects’ left sides. The subjects’ performances were filmed at a rate of 50 Hz, using a 10 mm lens. The shutter factor was set at 2.5, and the f-stop at 2.4. One studio light was set up beside the camera, and was used to provide proper lighting conditions.

In the third testing session, the camera, again locked onto a tripod 80 cm above the floor, was placed 5 meters away from the squatting area, perpendicular to subjects’ right sides. One studio light was positioned beside the camera to produce the required lighting conditions. Using the same 10 mm lens, the camera was set at a film speed of 50 frames per second, shutter factor of 2.5, and f-stop of 3.0.
The required f-stop was determined from the shutter factor, the film speed, and light meter readings which were taken prior to filming.

At the beginning of every testing session, a meter stick was filmed in the squatting area to provide a scale factor, or reference for determining real distances. Also, joint markers were placed on every subject to indicate the location of the fifth toe, the ankle, the knee, and the hip.

During testing, each subject positioned himself under the weighted bar, which was resting on support racks. The subject then straightened up and took a step backward with the bar placed across his upper back. After adjusting his feet for the desirable spacing, the subject was ready to begin the squat. At this point the filming was started and continued until the subject completed the movement and began moving forward to replace the bar onto the supporting racks.

At the beginning of every attempt numbered cards were placed in the field of view of the camera, for the purpose of subject and trial identification.

Six rolls of film (total of 183 m) were shot during the testing. The film was developed and analyzed.

**Data Collection**

The developed film was projected by a Vanguard projection system onto a digitizing tablet, connected to an Altec AC 30 on-line digitizer, and an IBM compatible personal computer. In house software was used to determine and
record the x and y coordinates of selected points. There were 5 points digitized on every frame throughout the entire parallel squat movement, which would indicate the motion of the various body segments during the execution of the skill: 1) the fifth toe, 2) the ankle joint, 3) the knee joint, 4) the hip joint, and 5) the geometric center of the weights on the bar.

The head, the shoulder, and the wrist were hidden from the view of the camera by the large weights that were added onto the bar. As a result, these points were not digitized. The center of the weights on the bar was the point chosen to indicate the trunk movement, since the bar rested across each subject’s back, and extended through the center of the weights. The rationale for choosing the center of the weights on the bar as an indicator of trunk motion as opposed to the end of the bar was such that the bar had a tendency to bend due to the moment of heavy weights added to it at each side. Since the weights were added onto the bar, but were situated closer to the body, the bending of the bar at that point was less. As a result, the center of the weights on the bar was a better indicator of trunk motion than the end of the bar.

The hand on each side of the body maintained a grip on the bar as it rested across the upper back. As a result, any movement of the hand, forearm, and arm was due to the movement of the bar. Thus, there was no need to digitize these points.
The x and y coordinates of every point digitized, along with time increments, were saved in columns, in ASCII format, which allowed for the analysis of data.

First, the beginning of the parallel squat movement had to be found. The film was viewed frame by frame. The frame where noticeable downward motion of the bar first occurred was considered the first frame of the parallel squat movement. The film was then rewound 10 additional frames. From this point on, the above mentioned 5 points were digitized on every frame until the end of the movement, where the subject’s legs were in full extension and there was no noticeable upward motion of the bar. Ten additional frames from the end of the movement were digitized. Then, the next trial was located and digitized. Data from each trial were saved as an individual file.

The toe, the ankle, and the knee joints were identified by joint markers which made the digitizing of these points consistent. As a result, each of these points was digitized once on every frame. The hip joint was also digitized once on every frame throughout the movement. Hip markers were not used because they did not adhere to the lifting suit material, and were continuously falling off. However, an effort was made to be consistent in locating and digitizing the hip joint. No markers were used to identify the center of the weights on the bar. Since the weights have a hole in the center, where the bar fits through, locating this point was easy and consistent. Thus, the centre of the weights on the bar was digitized once on every frame throughout the movement.
Each end of the meter stick, that was filmed prior to testing, was also digitized to provide a scaling factor when image distances measured in digitizing units were converted to real-life distances.

Data Analysis

Before any calculations of the dependent variables were carried out, three assumptions had to be made: 1) the movement of the left side of the body was representative of the movement of the right side of the body, and vice versa, 2) the bar was fixed across the upper back, and the center of the weights on the bar, with respect of the hip joint, was a good indicator of the trunk movement (although, some movement of the bar, and subsequently of the weights, in the anterior-posterior direction did occur, as well as slight bending of the bar due to the added weights), and 3) each subject’s performance during testing was representative of his usual technique.

In order to calculate movement time, instantaneous bar velocity, instantaneous angular displacements and velocities of the trunk, the thigh, and the shank, several necessary steps had to be carried out. Initially, all raw data points were multiplied by the scaling factor to convert them to real measurements. The scaled raw data were then filtered at 4 Hz using the Butterworth Second Order Digital Filter. The filtering frequency was determined by residual analysis between the filtered and unfiltered data (Winter and Wells, 1978).
The total movement time and the beginning and the end of the movement were determined from the vertical bar velocity profile, which was obtained by differentiating the vertical bar displacement. The beginning of the movement was indicated by 0 m/s vertical bar velocity before the velocity started to increase in the negative direction. The end of the movement was indicated by the decrease in the vertical bar velocity to 0 m/s. The parallel squat movement was divided into two phases: the descending phase and the ascending phase, according to the vertical bar velocity profile (see Figure 1). The point where the descending phase ended and the ascending phase began was marked by 0 m/s vertical bar velocity in the middle of the movement. The descending phase movement time and the ascending phase movement time was obtained.

The instantaneous vertical bar velocity was normalized to 101 points to examine the occurrence of dependent measures without regard for movement time differences. The highest and the lowest vertical bar velocity values, the time at which they occurred, and the percentage of movement time at which they occurred were picked out and analyzed. The sticking point was also located and analyzed, as well as the time of its occurrence and the percentage of movement time of its occurrence. The sticking point was identified as the point where the instantaneous vertical bar velocity decreased to a minimum value in the middle portion of the ascent.
Figure 1. Mean Vertical Bar Velocity Profile at 80% of Maximal Performance. (The vertical line indicates the end of the descending phase and the beginning of the ascending phase.)
The instantaneous angular displacements were obtained by adding a reference point on the horizontal axis and calculating the angle of the given body segment with respect to the horizontal at each frame throughout the movement (see Figure 2). Instantaneous angular displacements were then differentiated to acquire instantaneous angular velocities. The instantaneous angular displacements and velocities were normalized to 101 points. Again, the peak positive and negative values, the time at which they occurred, and the percentage of movement time at which they occurred were picked out and analyzed, as well as the instantaneous angular displacements and velocities at the sticking point.

When calculating instantaneous bar velocity, only the vertical bar velocity was calculated. The parallel squat is the type of skill in which very little movement occurs in the horizontal direction. According to McLaughlin, Dillman, & Lardner (1977) it is the vertical bar velocity which is the most meaningful parameter of performance. It reflects the action of muscular forces exerted by a lifter, and therefore it is representative of a lifter's technique. As a result, the instantaneous bar velocity in the vertical direction only, was the measure of choice.
Figure 2. Schematic of Link System

Hypotheses

The following null hypotheses associated with the manipulation of the independent variable were tested in this study.

$H_0_1$: There are no statistically significant differences in the total movement time of the parallel squat, the movement time of the descending phase, and the movement time of the ascending phase of the parallel squat between the different levels of performance.
Ho₂: There are no statistically significant differences in the peak positive and peak negative vertical bar velocity, the time to peak positive and peak negative vertical bar velocity, and the percentage of movement time to peak positive and peak negative vertical bar velocity between the different levels of performance.

Ho₃: There are no statistically significant differences in the peak negative angular displacement of the trunk, the thigh, and the shank; the time to peak negative angular displacement of the trunk, the thigh, and the shank; and the percentage of movement time to peak negative angular displacement of the trunk, the thigh, and the shank between the different levels of performance.

Ho₄: There are no statistically significant differences in the peak positive and peak negative angular velocity of the trunk, the thigh, and the shank; the time to peak positive and peak negative angular velocity of the trunk, the thigh, and the shank; and the percentage of movement time to peak positive and peak negative angular velocity of the trunk, the thigh, and the shank between the different levels of performance.
Ho₅: There are no statistically significant differences in the vertical bar velocity at the sticking point; the time to sticking point; the percentage of movement time to sticking point; the trunk, the thigh, and the shank angle at the sticking point; and the trunk, the thigh, and the shank angular velocity at the sticking point between the different levels of performance.

**Statistical Analysis**

All dependent variables were calculated on a trial by trial basis and then a mean was calculated across trials. Each mean was subjected to a one-way repeated measures analysis of variance. If statistically significant treatment effects were obtained, Tukey’s HSD (honestly significant difference) post hoc test was used to determine where significant differences between experimental conditions existed. Statistical significance was accepted at an alpha level of p < .05.
CHAPTER IV
RESULTS

Summary statistics for the levels of performance are provided in Table 3.

Table 3.
Level of Performance Summary Statistics

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<th>WEIGHT LIFTED AT EACH LEVEL (IN)</th>
<th>50%</th>
<th>60%</th>
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<th>80%</th>
<th>90%</th>
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<td>MEAN</td>
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<td>1393.9</td>
<td>1600.9</td>
<td>1796.8</td>
<td>1992.8</td>
</tr>
<tr>
<td>SD</td>
<td>± 220</td>
<td>± 263</td>
<td>± 308</td>
<td>± 357</td>
<td>± 394</td>
<td>± 439</td>
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Movement Time

There was a significant main effect of load on total movement time (F(5,35) = 26.01, p < .05). Tukey’s HSD post hoc test revealed that mean total movement time at 50% of maximal load was significantly less than the
mean total movement time at 80% and 90% of maximal load. Mean movement time at 60% of maximal load was significantly less than the mean movement time at 90% of maximal load. There was also a statistically significant difference between mean total movement time at 100% of maximal load and the mean movement time at the other five levels of performance. Figure 3 illustrates these results and Table 4 (Appendix A) contains the movement times at the various levels of performance.

The parallel squat movement was divided into two phases: the descending phase and the ascending phase (see Figure 1 in Methods). Repeated measures analysis of variance was performed on movement times of both phases at the different levels of performance. There was no statistically significant difference between the mean descending movement times at the various levels of performance (F(5,35) = 2.51, p > .05). The results are illustrated in Figure 4.

However, a main effect was noted for the mean ascending movement time at the different levels of performance (F(5,35) = 39.61, p < .05). The ascending movement time at 50% of maximal load was significantly less than the ascending movement time at 80% and 90% of maximal load. Statistically significant differences were found between the ascending times of 60% and 90% of maximal load trials. Statistically significant differences were also revealed between ascending movement time at 100% of maximal load and
ascending movement time at the other five levels of performance. The ascending movement times are plotted in Figure 5.

![Graph showing mean total movement time at each level of performance.](image)

Figure 3. Mean Total Movement Time at each Level of Performance.
Figure 4. Mean Descending Movement Time at each Level of Performance.
Figure 5.  Mean Ascending Movement Time at each Level of Performance.
Therefore, the temporal findings for the ascending phase parallel those of total movement time. Since the total movement time is comprised of both the descending movement time and the ascending movement time, it would seem that the differences in overall movement time were produced by the changes in the ascending phase. The lack of difference in the descending phase are not surprising given the effects of gravity.

The descending and ascending movement times show that the movement in each of these phases was affected differently by the increasing load. Consequently, the results for each of these phases will be discussed separately.

**Descending Phase**

During the descending phase, the body and the load were moving in the downward direction. Thus, the peak velocity values reached by the various segments and by the bar were negative. The peak segmental angular displacements are also reported as peak negative displacements. They refer to the minimum angle reached by each segment.

**Segmental Displacements**

Statistical analysis on the mean peak negative angular displacements of the thigh at the various levels of performance revealed statistically significant
differences \( F(5,35) = 4.29, p < .05 \). The peak negative thigh angular displacement at 50\% of maximal performance was significantly less than those at 90\% and 100\% of maximal load. The peak negative angular displacements of the thigh are summarized in Table 5 (Appendix A).

Statistically significant differences were revealed between the mean peak negative angular displacements of the shank at the various levels of performance \( F(5,35) = 2.96, p < .05 \). The peak negative shank displacement reached at 50\% of maximal load was significantly less that the displacement at 100\% of maximal load. The peak negative angular displacements of the shank are shown in Table 6 (Appendix A).

**Segmental Velocities**

Statistically significant differences were revealed between the mean peak negative angular velocities of the trunk at the various levels of performance \( F(5,35) = 3.83, p < .05 \). Specifically, the peak trunk angular velocities at 50\% and 70\% of maximal load were significantly greater in the downward direction than the peak trunk angular velocity at 90\% of maximal load. The results for the peak negative trunk velocities are shown in Table 7 (Appendix A).

Repeated measures analysis of variance indicated that there were statistically significant differences between the mean peak negative thigh angular velocities reached at the various levels of performance \( F(5,35) = \)
3.03, p < .05). The peak negative thigh velocity reached at 50% of maximal load was significantly greater in the downward direction than the peak velocity at 90% of maximal load. The peak negative thigh velocities are summarized in Table 8 (Appendix A).

There were no statistically significant differences between the mean peak negative angular velocities of the shank at the various levels of performance (F(5,35) = 0.40, p > .05). The peak negative shank velocities are presented in Table 9 (Appendix A).

**Bar Velocity**

A main effect was found for the peak negative vertical bar velocity for the different levels of performance (F(5,35) = 5.11, p < .05). The peak negative vertical bar velocity at 50% was significantly greater in the downward direction than the peak negative vertical bar velocity at 80%, 90%, and 100% of maximal load. The bar kinematics are presented in Table 10 (Appendix A). The vertical bar velocity profiles at the different levels of performance are plotted in Figure 6.

**Movement Time to Peak Segmental Displacements**

There were no statistically significant differences between the mean times to peak negative thigh angular displacements at the six levels of performance (F(5,35) = 2.70, p > .05). This finding parallels the descending
Figure 6. Mean Vertical Bar Velocity Profile at each Level of Performance.
movement time. The movement times to peak negative thigh displacements are presented in Table 5 (Appendix A).

There were no statistically significant differences found between the mean times at which the peak negative angular displacements of the shank occurred at the various levels of performance ($F(5,35) = 1.36, p > .05$). Again, this finding parallels the descending movement time. The movement times to peak negative shank displacements are listed in Table 6 (Appendix A).

Movement Time to Peak Segmental Velocities

The results show that the mean peak negative angular velocities of the trunk occurred at the same time regardless of the load, as there were no statistically significant differences between them at the various levels of performance ($F(5,35) = 1.31, p > .05$). This finding parallels the descending movement time. The temporal measures relevant to the peak angular trunk velocities are presented in Table 7 (Appendix A).

There were no statistically significant differences found between the mean times at which the peak negative thigh velocities occurred at the different levels of performance ($F(5,35) = 1.83, p > .05$). This finding supports the results of the descending movement time analysis. The movement times to peak negative thigh velocities are shown in Table 8 (Appendix A).

No statistically significant differences were found between the mean times at which the peak negative angular velocities of the shank occurred at the
six different levels of performance ($F(5,35) = 0.86, p > .05$). Again, this finding parallels the descending movement time. Table 9 (Appendix A) contains the movement times to peak negative shank velocities.

Movement Time to Peak Bar Velocity

There were no statistically significant differences between the mean times to peak negative vertical bar velocity at any level of performance ($F(5,35) = 0.68, p > .05$). This finding supports the results of the descending movement time analysis. The movement times to peak bar velocities are presented in Table 10 (Appendix A).

Percentage of Total Movement Time to Peak Segmental Displacements

There was a significant main effect for the mean percentage of total movement time to peak negative angular displacement of the thigh at the different levels of performance ($F(5,35) = 4.29, p > .05$). The percentage of movement time at 100% of maximal load was significantly less than the percentage of movement time at the other levels of performance. The percentages of total movement time at which the peak negative angular displacements of the thigh occurred are listed in Table 5 (Appendix A).

The mean percentages of total movement time at which the peak negative angular displacements of the shank occurred were statistically significant at the different levels of performance ($F(5,35) = 10.89, p < .05$).
The percentage of movement time to peak negative shank displacement at 50% of maximal load was significantly greater than the percentage of movement time at 90% of maximal load. Also, the mean percentages of movement time at 50%, 60%, 70% and 80% of maximal load were significantly greater than the mean percentage of movement time at maximal load. Table 6 (Appendix A) contains the percentages of total movement time to peak negative angular displacements of the shank.

**Percentage of Total Movement Time to Peak Segmental Velocities**

There was a significant main effect of load on the mean percentage of total movement time at which the peak negative angular velocity of the trunk occurred ($F(5,35) = 5.25, p < .05$). The mean percentage of movement time at 50% of maximal load was significantly greater than those at 90% and 100% of maximal load. The percentages of movement time to peak trunk velocities are summarized in Table 7 (Appendix A).

There were statistically significant differences between the percentages of total movement time at which the peak negative thigh angular velocities were reached at the various levels of performance ($F(5,35) = 6.00, p < .05$). The percentage of movement time to peak negative thigh velocity at 50% was significantly greater than the mean percentage of movement time at 70% and 100% of maximal load, and the mean percentage of movement time at 60% was significantly greater than the mean percentage of movement time at 70%,
80%, 90% and 100% of maximal load. The percentages of total movement time at which the peak negative thigh velocities occurred are presented in Table 8 (Appendix A).

There were no statistically significant differences between the mean percentages of total movement time at which the peak negative shank angular velocities occurred at the various levels of performance (F(5,35) = 2.39, p > .05). Table 9 (Appendix A) contains the percentages of total movement time to peak negative shank velocities.

Percentage of Total Movement Time to Peak Bar Velocity

The mean percentages of movement time to peak negative vertical velocity were statistically significant at the various levels of performance (F(5,35) = 5.76, p < .05). The percentage of movement time at maximal load was significantly less than the percentage of movement time at 50%, 60% and 70% of maximal load. The bar kinematics are shown in Table 10 (Appendix A).

Ascending Phase

During the ascending phase, the movement of the body and the bar was in the upward direction. Thus, the peak velocity values reached by the various body segments and by the bar were positive. The peak negative angular displacements of the trunk, and temporal measures pertaining to the peak negative angular trunk displacements are reported in this section since the trunk
segment reached a minimum angle during the initial portion of the ascending phase.

**Segmental Displacements**

Statistically significant differences were found for the mean peak negative angular displacements of the trunk for the various levels of performance ($F(5,35) = 6.48, p < .05$). The peak negative angular displacement of the trunk at 50% of maximal load was significantly greater than the peak negative angular displacement at 80%, 90% and 100% of maximal load. The peak negative trunk displacement at 60% of maximal load was also significantly greater than the displacement at 100% of maximal load. The peak negative angular displacements of the trunk are presented in Table 11 (Appendix A).

**Segmental Velocities**

The statistical analysis revealed a significant main effect of load on the mean peak positive angular velocity of the trunk ($F(5,35) = 5.15, p < .05$). The peak positive trunk velocity at 50% of maximal load was significantly greater than those at 90% and at 100%. The peak positive trunk velocity at 60% was also significantly greater than the peak velocities at 90% and 100% of maximal load. The peak trunk velocities are presented in Table 12 (Appendix A).

A significant main effect was revealed for the mean peak positive angular...
velocity of the thigh at the various levels of performance ($F(5,35) = 6.10, p < .05$). The peak positive velocity reached at 50%, 60%, 70% and 80% of maximal load was significantly greater than the peak positive velocity at maximal load. Table 13 (Appendix A) contains the peak thigh velocities.

Statistical analysis revealed no significant differences between the mean peak positive angular velocities of the shank at the various levels of performance ($F(5,35) = 2.32, p > .05$). The peak shank velocities are summarized in Table 14 (Appendix A).

**Bar Velocity**

The results of the statistical analysis show that there was a significant main effect for the mean peak positive vertical bar velocity at the different levels of performance ($F(5,35) = 20.14, p < .05$). Tukey’s HSD post hoc procedure revealed that the peak positive vertical bar velocity at 50% of maximal load was significantly greater than the peak positive vertical bar velocity at 70%, 80%, 90% and 100% of maximal load. The peak positive vertical bar velocity at 60% was significantly greater than those at 90% and 100% of maximal load. Also, the peak positive vertical bar velocity at 70% and 80% of maximal load were significantly greater than the peak positive vertical bar velocity at maximal load. The means are presented in Table 15 (Appendix A) and plotted in Figure 7.
Figure 7. Mean Peak Positive Vertical Bar Velocity at each Level of Performance.
Movement Time to Peak Segmental Displacements

There was a significant main effect of load on the mean time to peak negative angular displacement of the trunk \( F(5, 35) = 4.13, p < .05 \). The times to peak negative trunk displacement at 50% and 60% of maximal load were significantly less than the time to peak negative displacement at maximal load. The times at which the peak negative trunk displacements occurred are summarized in Table 11 (Appendix A).

Movement Time to Peak Segmental Velocities

The mean times to peak positive angular velocities of the trunk were significantly different at the various levels of performance \( F(5, 35) = 26.54, p < .05 \). The time to peak trunk velocity at 50% of maximal load was significantly less than the time to peak velocity at 80% of maximal load. The times to peak trunk velocity at 50% and 60% were also significantly less than the time to peak velocity at 90%. The time to peak trunk velocity at 100% was significantly greater than those times at the other five levels of performance. These findings parallel the total movement time and the ascending movement time. The times to peak trunk velocities are summarized in Table 12 (Appendix A).

The mean times to peak positive thigh angular velocities were also significantly different at the different levels of performance \( F(5, 35) = 27.42, p < .05 \). The time to peak thigh velocity at 50% was significantly less than the
time at 70%, 80% and 90% of maximal load. The time to peak thigh velocity at 60% was also significantly less than the time at 90% of maximal load. The time to peak thigh velocity at maximal load was significantly greater than the times at the other five levels of performance. These findings coincide with the total movement time findings and with the ascending movement time findings. Table 13 (Appendix A) contains the times to peak thigh velocities.

There were statistically significant differences in the mean times to peak positive angular velocities of the shank at the six levels of performance ($F(5,35) = 29.94, p < .05$). The time to peak shank velocity at 50% of maximal load was significantly less than the time at 70%, 80%, and 90% of maximal load. The time to peak shank velocity at 60% was also significantly less than the time at 90% of maximal load. The time to peak shank velocity at 100% was significantly greater than the times at the other five levels of performance. Again, these temporal findings coincide with the total movement time and the ascending movement time. The times to peak shank velocities are presented in Table 14 (Appendix A).

Movement Time to Peak Bar Velocity

There were statistically significant differences between the mean times to peak positive vertical bar velocity at different levels of performance ($F(5,35) = 24.22, p < .05$). Specifically, the time to peak velocity at 50% was significantly less than the time at 80% and 90% of maximal load. The time to
peak bar velocity at 60% of maximal load was significantly less than the time at 90%, and the time to peak vertical bar velocity at 100% was significantly greater than the times at the other five levels of performance. These findings parallel the total movement time and the ascending movement time. The temporal measures relevant to the peak vertical bar velocity are shown in Table 15 (Appendix A).

**Percentage of Total Movement Time to Peak Segmental Displacements**

There were statistically significant differences between the mean percentages of total movement time to peak negative angular displacement of the trunk at different levels of performance ($F(5,35) = 2.79, p < .05$). Specifically, the percentage of movement time to peak negative trunk displacement at 60% was significantly greater than the percentage of movement time at maximal load. The temporal measures relevant to the angular trunk displacements are shown in Table 11 (Appendix A).

**Percentage of Total Movement Time to Peak Segmental Velocities**

A significant main effect was discovered for the mean percentage of total movement time to peak positive angular velocity of the trunk at the various levels of performance ($F(5,35) = 12.02, p < .05$). The percentages of movement time to peak trunk velocities at 50% and 60% of maximal load were significantly less than the percentage of movement time at maximal load. The
percentages of movement time to peak trunk velocities are shown in Table 12 (Appendix A).

There were statistically significant differences between the mean percentages of movement time at which the peak positive angular velocities of the thigh were reached at the various levels of performance ($F(5,35) = 6.34, p < .05$). The percentage of movement time at 50% of maximal load was significantly less than the percentage of movement time at 70%, 80%, 90% and 100% of maximal load. The velocity results are summarized in Table 13 (Appendix A).

A significant main effect was revealed for the mean percentage of total movement time to peak positive angular velocities of the shank for the different levels of performance ($F(5,35) = 5.69, p < .05$). The percentage of movement time at 50% was significantly less than the movement times at the other five levels of performance. The percentages of movement time to peak shank velocities are shown in Table 14 (Appendix A).

*Percentage of Movement Time to Peak Bar Velocity*

There were no statistically significant differences between the mean percentages of total movement time to peak positive vertical bar velocity at the six levels of performance ($F(5,35) = 1.93, p > .05$). Table 15 (Appendix A) contains the percentages of total movement time to peak vertical bar velocity.
**Sticking Point Profile**

The sticking point first appeared at 60% of maximal load in four of the eight subjects. In order to determine the effects of increasing load on various kinematic measures at the sticking point, repeated measures analysis of variance was carried out.

**Movement Time to Sticking Point**

There were statistically significant differences found between the mean times at which the sticking point occurred at the various levels of performance ($F(4,28) = 9.30$, $p < .05$). The time to sticking point at 60% of maximal load was significantly less than the time at 90% of maximal load. Also, the mean times to sticking point at 60%, 70% and 80% of maximal load were significantly less than the time at 100% of maximal load. These temporal findings parallel the total movement time and the ascending movement time.

**Percentage of Total Movement Time to Sticking Point**

No statistically significant differences were revealed between the mean percentages of movement times at which the sticking point occurred at the various levels of performance ($F(4,28) = 2.44$, $p > .05$). The temporal findings at the sticking point are presented in Table 16 (Appendix A).
Segmental Displacements at the Sticking Point

There were no statistically significant differences found in the mean trunk angles at the sticking point at the various levels of performance \( (F(4,28) = 0.30, \ p > .05) \).

No statistically significant differences were found between the mean thigh angles at the sticking point at the five levels of performance \( (F(4,28) = 2.75, \ p > .05) \).

There was no main effect found for the mean shank angles at the sticking point at the various levels of performance \( (F(4,28) = 1.30, \ p > .05) \). The segmental displacements at the sticking point are summarized in Table 17 (Appendix A).

Segmental Velocities at the Sticking Point

The results show that there were statistically significant differences between the mean trunk angular velocities at the sticking point at the various levels of performance \( (F(4,28) = 3.19, \ p < .05) \). The trunk velocity at the sticking point at 60% was significantly greater than that at 100% of maximal load.

Statistically significant differences were found between the mean thigh angular velocities at the sticking point at the various levels of performance \( (F(4,28) = 46.63, \ p < .05) \). The thigh velocities at the sticking point significantly decreased with increasing load, except there were no statistically
significant differences between the velocities at 60% and 70%, and at 80% and 90% of maximal load.

There were statistically significant differences found between the mean shank angular velocities at the sticking point at the various levels of performance (F(4,28) = 2.50, p < .05). Specifically, the shank velocity at 60% of maximal load was significantly greater than the velocity at maximal load. The segmental velocities at the sticking point are shown in Table 18 (Appendix A).

*Bar Velocity at the Sticking Point*

There was a significant main effect of load on the mean vertical bar velocity at the sticking point (F(4,28) = 51.26, p < .05). The bar velocity at 70% of maximal load was significantly greater than the bar velocity at 90% of maximal load. The vertical bar velocity at the sticking point at 60% was significantly greater than those at the sticking point at 80% and 90% of maximal load. Also, the bar velocity at the sticking point at 100% was significantly less than the velocities at the other four levels of performance. The bar velocities at the sticking point are presented in Table 18 (Appendix A) and plotted in Figure 8.
Figure 8. Mean Vertical Bar Velocity at the Sticking Point at each Level of Performance.
Parallel Squat Movement

The parallel squat is a relatively slow, controlled, gross motor movement which is comprised of two distinct phases, a descending and ascending phase. The same two phases and movement patterns could be observed in other skills such as the vertical jump (Hay, 1975; Jaric, Ristanovic, & Corcos, 1989).

In the descending phase of the parallel squat the powerlifter has to lower the body through flexion of the hips, the knees, and the dorsi flexion of the ankles until the thighs are below parallel with the lifting surface. At this point, the movement of the body has to be arrested as the lifter prepares for the ascending phase. In the ascending phase the lifter has to exert enough force to overcome the gravitational force provided by the weight across the lifter’s back. The powerlifter has to extend the hips, the knees, and plantar flex the ankles until the body is straightened and the bar is no longer moving upward.

The question was whether an increasing load has any effects on the parallel squat movement. The answer could be found in the movement time.
As the results show, there was a trend toward increasing the total movement time with the increasing load. Although, the total movement time didn’t increase significantly until 80% of maximal load. The total movement time increased sharply between 90% and 100% of maximal load.

The best way to study the effects of the increasing load on the lifting characteristics of the parallel squat was to examine the changes occurring at each of the two phases separately.

*Descending Phase*

The most important thing during the descending phase of the parallel squat is to control the movement of the load and the body. As the load increases, the downward force due to gravity acting on the powerlifter also increases. While descending, the powerlifter has to exert enough force, in the upward direction, to control the descent in order to be able to arrest the movement of the load and the body at the end of the descending phase. This control becomes especially important when squatting near-maximum and maximum loads.

When examining the dependent measures taken during the descending phase of the parallel squat it was evident that the subjects did make an effort to control the movement of the load and the body as the load increased. The time it took to complete the descent remained unchanged regardless of the load increase. The peak vertical bar velocity actually decreased in the downward
direction during the heaviest three attempts when compared to the peak bar velocity at 50% of maximal load. The mean peak vertical bar velocity at 100% of maximal load was -0.603 m/s. This finding is in agreement with mean peak vertical bar velocity found by McLaughlin, Dillman, & Lardner (1977) in their study ($\bar{x} = -0.5$ m/s in skilled powerlifters, $\bar{x} = -0.7$ m/s in less-skilled powerlifters). The time at which the peak vertical bar velocity occurred did not change with the increase in load, which supports the descending movement time findings. The peak vertical bar velocity at 100% of maximal load did occur at a lower percentage of movement time than at the first three attempts. However, that was due to the significant increase in total movement time at 100% of maximal load.

The subjects’ attempt to control the movement of the body during the descending phase was also reflected in the segmental kinematics. The peak angular velocity of the trunk decreased in the downward direction at 90% of maximal load compared to the peak velocity at 50% and 70% of maximal load. The peak thigh angular velocity didn’t change with increasing load, except between 50% and 90% of maximal load where the peak velocity decreased in the downward direction. The peak shank angular velocity remained unchanged regardless of the load.

The peak trunk velocities, the peak thigh velocities, and the peak shank velocities occurred at the same time regardless of the increase in the load.
These temporal findings coincide with the descending movement time findings, and suggest that the subjects used the same motor program regardless of the load.

The peak trunk angular velocity at 90% and at 100% of maximal load occurred at lower percentages of movement time than at 50%. This difference was due to the longer total movement time of the two heavy attempts. Similarly, the peak thigh velocity at 70% and 100% occurred at a lower percentage of movement time than at 50% of maximal load, and the peak thigh velocity at 70%, 80%, 90% and 100% also occurred at a lower percentage of movement time when compared to 60%. Again, these differences in timing are due to the increasing total movement times. The percentage of movement time at which the peak shank velocity occurred did not change with the increase in load. The differences in segmental velocity profiles between 50% of maximal load and 100% of maximal load are illustrated in Figure 9 and 10.

The end of the descending phase was marked by 0 m/s vertical bar velocity. At this point the powerlifter's body was in the lowest position. This finding was reinforced by the absolute thigh angle and the absolute shank angle which reached the lowest value at the end of the descending phase. As the load was increased the thigh angle and the shank angle increased. However, significant differences didn't emerge until the load increased to 90% and 100% for the thigh angle, and 100% for the shank angle. The increase in the lowest thigh angle and shank angle indicates that as the load increased the depth of
Figure 9. Mean Angular Velocity Profiles and Mean Vertical Bar Velocity Profile at 50% of Maximal Load.
Figure 10. Mean Angular Velocity Profiles and Mean Vertical Bar Velocity Profile at 100% of Maximal Load.
the parallel squat decreased. Since the total movement time increased with the increase in load, the percentage of total movement time at which the minimum thigh and shank angles occurred decreased. The timing differences became evident in the maximal load trial.

According to the trunk angular displacement profiles at each level of performance the trunk movement was arrested just before the end of the descending phase. Then, at the turn-around point, the trunk angle started to decrease again as each subject leaned forward. The lowest absolute trunk angle was reached during the initial portion of the ascending phase when the thigh and the shank segments were already being extended. As the load increased the lowest trunk angle decreased. The decrease in the trunk angle became significant in the last three, heavy attempts. Also, the lowest absolute trunk angle at maximal load occurred later when compared to 50% and 60% of maximal load. In addition, the minimum trunk angle occurred at a higher percentages of total movement time at 60% of maximal load than at 100% of maximal load. This finding was due to the increase in total movement time with the increasing load. The changes in segmental displacement profiles between 50% of maximal load and 100% of maximal load are illustrated in Figure 11 and 12.

McLaughlin and co-workers (1977) also found, in their study, that the subjects leaned forward during the early ascent phase of a maximum-load parallel squat. Furthermore, the less-skilled lifters leaned forward more than
Figure 11. Mean Angular Displacement Profiles and Mean Vertical Bar Velocity Profile at 50% of Maximal Load.
Figure 12. Mean Angular Displacement Profiles and Mean Vertical Bar Velocity Profile at 100% of Maximal Load.
skilled lifters.

The question is why would one want to increase the trunk lean at the beginning of the ascending phase of the parallel squat. After all, a greater trunk lean would not be desirable, since it creates a longer force arm, and results in a larger moment of force at the hip joint. One possible explanation is that by increasing the trunk lean, the mass across the powerlifter’s upper back is shifted forward, and subsequently the centre of gravity is shifted forward. As a result, the initiation of knee extension and ankle plantar flexion becomes easier.

Ascending Phase

Unlike in the descending phase, the movement in the ascending phase of the parallel squat was greatly affected by the increasing load. The ascending movement times show that the ascending phase of the parallel squat was getting longer as the load was increasing. A significant increase in the ascending movement time occurred at 80% of maximal load. Also, the ascending movement time increased sharply between 90% and 100% of maximal load.

When examining the mean vertical bar velocity profiles, it became obvious that the increase in the ascending movement times was due to the occurrence of the sticking point. The sticking point appeared between 60% and 100% of maximal load. Although, at 60% of maximal load it appeared in
the form of velocity plateau during the mid-ascent. As the load increased from 60% to 70% the vertical bar velocity plateau became more pronounced. With a further increase in load the vertical bar velocity at mid-ascent actually decreased for a brief period of time before increasing again. During the last two, heavy trials the sticking point became more pronounced, as it took longer to reach the point of the lowest vertical bar velocity and it took longer to reach the peak vertical bar velocity which occurred after the sticking point. The sticking point will be discussed later in greater detail.

The peak vertical bar velocity occurred after the sticking point at each level of performance. This finding is in agreement with the McLaughlin, et al. study (1977). As the load increased the peak vertical bar velocity decreased. The mean peak vertical bar velocity at 100% of maximal load was 0.483 m/s, which is very close to the mean peak vertical bar velocity of 0.5 m/s found by McLaughlin, et al. (1977) during a maximum effort parallel squat. The time at which the peak velocity occurred also increased due to the enlargement of the sticking point, with the increasing load. This finding parallels the total movement time and the ascending movement time results. However, the peak vertical bar velocity occurred at the same percentage of movement time regardless of the load.

The effects of the increasing load were also evident in the segmental kinematic variables. The peak trunk angular velocity decreased with the increasing load. Although, differences in the peak trunk velocities were not
significant until the last two, heavy loads. The peak thigh angular velocity did not decrease significantly until the last, maximum load trial. The peak shank angular velocity did not change with the increasing load.

The time at which the peak trunk angular velocities occurred increased with the increasing load and the presence of the sticking point. The time at which the peak angular velocity of the thigh occurred also increased with the increasing load. Similarly, the time to peak shank angular velocity increased as the load increased. The movement times to peak segmental velocities parallel the total movement time and the ascending movement time findings.

The percentages of total movement time at which the respective peak segmental velocities occurred increased with the increase in load. However, there was no specific pattern the temporal measures followed.

Unlike the vertical bar velocity, both the time to and the percentage of total movement time to peak segmental velocities were significant in the ascending phase. Thus, while the bar velocity kinematics in this phase were invariant, the segmental kinematics were not. This finding may mean that the bar movement was the highest level being controlled through the collective action of the three segments.

*Sticking Point*

Examining the individual subjects’ instantaneous vertical velocity profiles of the bar, the sticking point first appeared at 60% of maximal load in four
subjects, at 70% of maximal load in three subjects, and at 80% of maximal load in one subject. To determine the effects of the increasing load on the lifting characteristics at the sticking point several dependent measures were analyzed.

The results show that the time at which the sticking point occurred increased significantly during the last two, heavy trials due to the increase in the time from the turn-around point to the sticking point. This finding coincides with the total movement time and the ascending movement time results. However, the sticking point did occur at the same percentage of movement time regardless of the increasing load. The results also indicated a decreasing trend of the vertical bar velocity at the sticking point with the increasing load. Though, the decrease in bar velocity wasn’t statistically significant until 80% of maximal load. The mean vertical bar velocity at the sticking point at 100% of maximal load was 0.120 m/s which is comparable to the mean vertical bar velocity found by McLaughlin, et al. (1977) in their study ($\bar{x} = 0.2$ m/s in skilled powerlifters, $\bar{x} = 0.1$ m/s in less-skilled powerlifters).

The mean angular velocities of the trunk and the shank at the sticking point did not change with the increasing load until the maximum load lift, where the mean velocities decreased significantly. The mean angular thigh velocity decreased with the increasing load except between 60% and 70% of maximal load, and between 80% and 90% of maximal load. There were large between-subject differences in the angular velocities of the three segments.
The mean absolute angle of the trunk, the thigh, and the shank at the sticking point did not change with the increasing load. The mean trunk angle at the sticking point was about 52 degrees, the mean thigh angle was approximately 32 degrees, and the mean shank angle was approximately 66 degrees with respect to the horizontal. According to the McLaughlin, et al. (1977) study the mean absolute angles at the sticking point during a maximal effort parallel squat were found to be approximately 40 degrees for the trunk, 30 degrees for the thigh, and 74 degrees for the shank. Both, the McLaughlin, et al. (1977) and this study found large between-subject differences in the angular displacements of the three segments.

One question still remains to be answered and that is: What causes the sticking point? There seems to be a connection between the trunk lean in the first portion of the ascent and the occurrence of the sticking point. As mentioned previously, at the beginning of the ascending phase the subjects leaned forward more to begin the extension of the knees and the upward movement of the bar. Thus, in the first portion of the ascent the knees are being extended, and the ankles plantar flexed, while the trunk is being flexed. If such movement of the three segments was to continue, the powerlifter’s centre of gravity would shift too far forward and he/she would end up falling forward. To prevent the fall forward, the hamstrings have to contract to begin the extension of the trunk. However, the hamstring muscle group spans two
joints: the hip and the knee. As a result, the hamstrings have a dual function. They are hip extensors and at the same time knee flexors. As the hamstrings contract to extend the hip, they also flex the knee, while it is being extended by the quadriceps. The result is a co-contraction of the hamstrings and the quadriceps (Plagenhoef, 1971; McLaughlin et al., 1978). Similar types of co-contractions have been observed in other bifuncional muscles (Perot & Goubel, 1982).

If the initial forward trunk lean is small as it was during the first three, lighter-load trials, the magnitude of the knee flexion produced by the hamstrings is also relatively small. Thus, the net muscle action at the knee is an extension. The co-contraction appears in the velocity profiles of the thigh and the bar as a period of time during which velocity increased at a lower rate or as a velocity plateau as in the case of 60% and 70% of maximal load trials. However, if the forward trunk lean is greater, the magnitude of the muscle contraction produced by the hamstrings to maintain equilibrium is larger. The action of the hamstrings somewhat negates the action of the quadriceps and the angular velocity of the thigh, and subsequently, the vertical velocity of the bar starts to decrease, resulting in the sticking point. Figures 13 - 16 contain segmental displacement profiles and vertical bar velocity profiles at various performance levels.

At the sticking point, the trunk angle reaches the desired value, the hamstrings relax somewhat and the thigh angular velocity begins to increase
Figure 13. Mean Angular Trunk Displacement Profiles at Various Levels of Performance.
Figure 14. Mean Angular Thigh Displacement Profiles at Various Levels of Performance.
Figure 15. Mean Angular Shank Displacement Profiles at Various Levels of Performance.
Figure 16. Mean Vertical Bar Velocity Profiles at Various Levels of Performance.
as the muscle action begins to shift to knee extension. From this point on, the angular velocities of all three segments increase rapidly, which results in the rapid increase in the vertical bar velocity after the sticking point.

Thus, the sticking point is a point where the muscle action changes from hip extension to knee extension. After, the knee extension is initiated at the beginning of the ascent, the body’s number one priority becomes the maintenance of equilibrium. Once the equilibrium is restored, the action shifts back to the extension of the body.

The sticking point is viewed as undesirable by powerlifters, because it limits performance. McLaughlin, et al. (1977) analyzed failed attempts and concluded that the upward movement of the body stopped in close proximity of the sticking point region. It seems that in order to maximize performance, the sticking point has to be reduced or eliminated. The solution to this problem seems simple: eliminate the forward trunk lean at the beginning of the ascent and the sticking point will not occur. If the forward trunk lean is eliminated, the ascent must be initiated solely by the action of the quadriceps. However, the quadriceps may not be strong enough to produce a large enough force to overcome the weight of the barbell and to initiate the ascent. The performance becomes limited again, this time by the strength of the quadriceps muscle group. Thus, the current squatting technique is a compromise. The forward trunk lean at the beginning of the ascent makes it possible to initiate the
ascent, which would not occur through the action of the quadriceps alone, while the body has to make a few necessary adjustments that lead to the sticking point.
CHAPTER VI
SUMMARY AND CONCLUSIONS

The purpose of this study was to determine the effects of increasing load on lifting characteristics of the parallel squat. Special attention was given to the sticking point phenomenon. Specifically, the goal of this study was to find the percentage of maximal load at which the sticking point first occurs.

Eight male powerlifters of provincial and national calibre were filmed, from a side view, performing one repetition of the parallel squat at six levels of performance, in the following order: 50%, 60%, 70%, 80%, 90% and 100% of maximal load.

Data collection consisted of digitizing the following points once on every frame, from the start of downward vertical bar motion until the conclusion of upward vertical bar motion: 1) the fifth toe, 2) the ankle joint, 3) the knee joint, 4) the hip joint, and 5) the geometric center of the weights on the bar. Data from each trial were saved and analyzed as an individual file.

During data analysis several dependent variables were calculated using the coordinates of the digitized points. The calculated variables included: the total movement time during the parallel squat, the movement times of the
descending and the ascending phase of the parallel squat; the positive and negative peak vertical velocity of the bar; the peak negative angular displacement of the trunk, the thigh, and the shank; the peak positive and negative angular velocity of the trunk, the thigh, and the shank. The time at which the peak displacements and velocities occurred was also calculated as well as the percentage of movement time to peak displacements and velocities. Also, the sticking point was identified and the following measures were taken at the sticking point: the time at which the sticking point occurred; the percentage of movement time to the sticking point; the vertical bar velocity; and the angular velocity of the trunk, the thigh, and the shank.

The parallel squat was divided into two phases: the descending phase and the ascending phase. The following results were obtained in the descending phase:

1. The length of the descending phase of the parallel squat did not change with the increasing load.

2. The peak vertical bar velocity did not increase in the downward direction as the load increased. The time at which the peak bar velocity occurred remained the same regardless of load.

3. The peak angular velocity of the trunk, the thigh, and the shank didn’t increase with the increasing load. The peak angular velocity of each segment occurred at the same time regardless of the increase in load.

4. At the end of the descending phase, the thigh, and the shank reached
the lowest absolute angles, the trunk did not. The trunk angle continued to decrease until the initial portion of the ascending phase, where the lowest trunk angle was reached. As the load increased the lowest trunk angle decreased.

The findings in the ascending phase of the parallel squat were as follows:

1. The ascending phase of the parallel squat increased in length as the load increased due to the occurrence of the sticking point.

2. The peak vertical bar velocity decreased as the load increased. The time at which the peak bar velocity occurred increased with the increased load, as the sticking region was becoming more pronounced. However, the percentage of movement time at which the peak bar velocity occurred remained the same regardless of load.

3. The peak angular velocity of the trunk and the thigh decreased with the increasing load, and the peak shank angular velocity remained unchanged. The time at which the peak segmental angular velocities occurred increased with the increasing load, as the sticking region was becoming more pronounced. The percentage of movement time at which the peak segmental angular velocities occurred also increased as the load increased.
The results at the sticking point were as follows:

1. The sticking point first occurred at 60% of maximal load in four subjects, at 70% in three subjects, and at 80% of maximal load in one subject. The time at which the sticking point occurred increased as the load increased. However, the sticking point occurred at the same percentage of movement time regardless of the load increase.

2. The vertical bar velocity at the sticking point decreased with the increasing load.

3. The absolute angle of the trunk, the thigh, and the shank at the sticking point did not change with the increasing load.

4. The angular velocities of the trunk, the thigh, and the shank at the sticking point decreased as the load increased.

Conclusions

Within the limitations of this study several conclusions are warranted. The movement during the descending phase of the parallel squat was controlled, so that the downward motion of the body and the bar could be arrested at the end of the descending phase. This control is crucial especially when performing near-maximal and maximal load squats and it was demonstrated by all subjects.

At the beginning of the ascending phase the subjects leaned forward and shifted the centre of gravity forward, which allowed them to initiate the
extension of the knees and the plantar flexion of the ankles. The displacement of the center of gravity during the beginning of the ascending phase caused the body to make some necessary adjustments in order to maintain equilibrium and to prevent the powerlifter from falling forward. The result of the postural adjustments was a co-contraction of the quadriceps muscle group, which was acting to extend the knees, and the hamstring muscle group, which was extending the trunk and flexing the knees at the same time. The co-contraction led to the slowing down of the knee extension and the subsequent slowing down of the upward movement of the bar until the desired trunk angle was reached. At this point, the sticking point, the muscle action changed from the trunk extension to the knee extension, and the parallel squat movement was allowed to be completed.

As the load increased, the trunk lean during the initial portion of the ascending phase increased, which led to greater postural adjustments and, subsequently to a more pronounced sticking point. Therefore, the sticking point is a "switch" where the dominant muscle action changes from one muscle group to another.

**Suggestions for Future Study**

To confirm the cause of the sticking point a similar study should be undertaken using EMG. This would provide information about muscle action during the parallel squat.
The increase in trunk lean, which was demonstrated by all subjects during the initial portion of the ascending phase of the parallel squat, undoubtedly creates a greater stress on the lower back region. Future studies are recommended to evaluate the stress placed on the lower back, and to evaluate the potential for lower back injuries.

It would be interesting to find out at what performance level the trunk lean first occurs, and what would happen to the characteristics of the parallel squat if subjects were not allowed to lean forward during the initial portion of the ascending phase.

So far, little research has been done on the three powerlifting skills: the parallel squat, the bench press and the deadlift, which have gained in popularity. Therefore, further kinematic and kinetic studies that would analyze the three competitive movements are needed.
REFERENCES


APPENDIX A

Raw Data
Table 4
Movement Time at Various Levels of Performance.
(N = 8)

<table>
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<th>PERFORMANCE LEVEL</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
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</thead>
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<td>TOTAL MOVEMENT TIME (s)</td>
<td>2.620 ± 0.42</td>
<td>2.783 ± 0.54</td>
<td>3.080 ± 0.50</td>
<td>3.275 ± 0.50</td>
<td>3.525 ± 0.45</td>
<td>4.463 ± 0.65</td>
</tr>
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<td>DESCENDING MOVEMENT TIME (s)</td>
<td>1.531 ± 0.36</td>
<td>1.605 ± 0.42</td>
<td>1.720 ± 0.39</td>
<td>1.748 ± 0.39</td>
<td>1.895 ± 0.51</td>
<td>1.933 ± 0.73</td>
</tr>
<tr>
<td>ASCENDING MOVEMENT TIME (s)</td>
<td>1.089 ± 0.11</td>
<td>1.178 ± 0.22</td>
<td>1.360 ± 0.25</td>
<td>1.527 ± 0.29</td>
<td>1.830 ± 0.17</td>
<td>2.530 ± 0.47</td>
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</tbody>
</table>

*Descending Phase*

Table 5
Dependent Variables Measured at Minimum Thigh Angle at Various Levels of Performance.
(N = 8)

<table>
<thead>
<tr>
<th>PERFORMANCE LEVEL</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIN. THIGH ANGLE (degrees)</td>
<td>1.196 ± 6.67</td>
<td>2.203 ± 6.52</td>
<td>1.926 ± 5.21</td>
<td>2.109 ± 6.67</td>
<td>5.823 ± 7.44</td>
<td>6.034 ± 8.67</td>
</tr>
<tr>
<td>TIME TO MIN. THIGH ANGLE (s)</td>
<td>1.511 ± 0.36</td>
<td>1.567 ± 0.42</td>
<td>1.668 ± 0.39</td>
<td>1.723 ± 0.39</td>
<td>1.872 ± 0.50</td>
<td>1.908 ± 0.72</td>
</tr>
<tr>
<td>% MOVEMENT TIME TO MIN. THIGH ANGLE</td>
<td>57.4 ± 5</td>
<td>56.4 ± 6</td>
<td>54.4 ± 6</td>
<td>52.9 ± 7</td>
<td>52.9 ± 8</td>
<td>42.0 ± 10</td>
</tr>
</tbody>
</table>
### Table 6
Dependent Variables Measured at Minimum Shank Angle at Various Levels of Performance. 
(N = 8)

<table>
<thead>
<tr>
<th>PERFORMANCE LEVEL</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIN. SHANK ANGLE</td>
<td>53.891</td>
<td>56.437</td>
<td>56.140</td>
<td>55.617</td>
<td>56.487</td>
<td>57.224</td>
</tr>
<tr>
<td>(degrees)</td>
<td>± 4.21</td>
<td>± 4.59</td>
<td>± 3.95</td>
<td>± 4.81</td>
<td>± 3.87</td>
<td>± 4.48</td>
</tr>
<tr>
<td>TIME TO MIN. SHANK ANGLE</td>
<td>1.553</td>
<td>1.483</td>
<td>1.696</td>
<td>1.705</td>
<td>1.629</td>
<td>1.800</td>
</tr>
<tr>
<td>(s)</td>
<td>± 0.39</td>
<td>± 0.37</td>
<td>± 0.36</td>
<td>± 0.36</td>
<td>± 0.46</td>
<td>± 0.62</td>
</tr>
<tr>
<td>% MOVEMENT TIME TO MIN. SHANK ANGLE</td>
<td>59.1</td>
<td>54.0</td>
<td>55.4</td>
<td>52.4</td>
<td>46.4</td>
<td>39.8</td>
</tr>
<tr>
<td></td>
<td>± 6</td>
<td>± 8</td>
<td>± 5</td>
<td>± 6</td>
<td>± 10</td>
<td>± 10</td>
</tr>
</tbody>
</table>

### Table 7
Dependent Variables Measured at Peak Trunk Velocity during the Descending Phase at Various Levels of Performance. 
(N = 8)

<table>
<thead>
<tr>
<th>PERFORMANCE LEVEL</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEAK NEG. VELOCITY</td>
<td>-38.45</td>
<td>-35.75</td>
<td>-38.13</td>
<td>-33.80</td>
<td>-28.88</td>
<td>-32.09</td>
</tr>
<tr>
<td>(deg./s)</td>
<td>± 10.2</td>
<td>± 11.7</td>
<td>± 12.1</td>
<td>± 9.8</td>
<td>± 10.3</td>
<td>± 10.4</td>
</tr>
<tr>
<td>TIME TO PEAK NEG. VELOCITY</td>
<td>0.392</td>
<td>0.343</td>
<td>0.350</td>
<td>0.385</td>
<td>0.267</td>
<td>0.364</td>
</tr>
<tr>
<td>(s)</td>
<td>± 0.17</td>
<td>± 0.10</td>
<td>± 0.11</td>
<td>± 0.11</td>
<td>± 0.13</td>
<td>± 0.12</td>
</tr>
<tr>
<td>% MOVEMENT TIME TO PEAK NEG. VELOCITY</td>
<td>15.1</td>
<td>12.8</td>
<td>11.5</td>
<td>12.1</td>
<td>7.9</td>
<td>8.4</td>
</tr>
<tr>
<td></td>
<td>± 6</td>
<td>± 4</td>
<td>± 3</td>
<td>± 4</td>
<td>± 4</td>
<td>± 3</td>
</tr>
</tbody>
</table>
Table 8
Dependent Variables Measured at Peak Thigh Velocity during the Descending Phase at Various Levels of Performance. (N = 8)

<table>
<thead>
<tr>
<th>PERFORMANCE LEVEL</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEAK NEG. VELOCITY (deg./s)</td>
<td>-97.30 ± 28.5</td>
<td>-88.60 ± 22.2</td>
<td>-90.72 ± 24.5</td>
<td>-82.03 ± 22.3</td>
<td>-75.96 ± 19.0</td>
<td>-80.07 ± 19.6</td>
</tr>
<tr>
<td>TIME TO PEAK NEG. VELOCITY (s)</td>
<td>0.30 ± 0.12</td>
<td>0.348 ± 0.05</td>
<td>0.250 ± 0.07</td>
<td>0.285 ± 0.09</td>
<td>0.289 ± 0.12</td>
<td>0.342 ± 0.13</td>
</tr>
<tr>
<td>% MOVEMENT TIME TO PEAK NEG. VELOCITY</td>
<td>12.3 ± 5</td>
<td>13.0 ± 3</td>
<td>8.3 ± 2</td>
<td>8.9 ± 5</td>
<td>8.4 ± 4</td>
<td>7.9 ± 3</td>
</tr>
</tbody>
</table>

Table 9
Dependent Variables Measured at Peak Shank Velocity during the Descending Phase at Various Levels of Performance. (N = 8)

<table>
<thead>
<tr>
<th>PERFORMANCE LEVEL</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEAK NEG. VELOCITY (deg./s)</td>
<td>-47.28 ± 14.6</td>
<td>-48.22 ± 18.1</td>
<td>-46.17 ± 13.8</td>
<td>-46.58 ± 13.9</td>
<td>-45.66 ± 10.9</td>
<td>-42.68 ± 8.4</td>
</tr>
<tr>
<td>TIME TO PEAK NEG. VELOCITY (s)</td>
<td>0.226 ± 0.13</td>
<td>0.310 ± 0.14</td>
<td>0.240 ± 0.08</td>
<td>0.246 ± 0.11</td>
<td>0.303 ± 0.12</td>
<td>0.251 ± 0.12</td>
</tr>
<tr>
<td>% MOVEMENT TIME TO PEAK NEG. VELOCITY</td>
<td>8.4 ± 4</td>
<td>11.8 ± 6</td>
<td>7.9 ± 3</td>
<td>7.6 ± 3</td>
<td>8.8 ± 4</td>
<td>5.8 ± 3</td>
</tr>
</tbody>
</table>
Table 10
Dependent Variables Measured at Peak Bar Velocity during the Descending Phase at Various Levels of Performance. 
(N = 8)

<table>
<thead>
<tr>
<th>PERFORMANCE LEVEL</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEAK NEG. VELOCITY (m/s)</td>
<td>-0.748 ± 0.21</td>
<td>-0.669 ± 0.18</td>
<td>-0.665 ± 0.19</td>
<td>-0.626 ± 0.19</td>
<td>-0.573 ± 0.19</td>
<td>-0.603 ± 0.18</td>
</tr>
<tr>
<td>TIME TO PEAK NEG. VELOCITY (s)</td>
<td>0.469 ± 0.20</td>
<td>0.482 ± 0.12</td>
<td>0.476 ± 0.17</td>
<td>0.428 ± 0.16</td>
<td>0.443 ± 0.18</td>
<td>0.378 ± 0.11</td>
</tr>
<tr>
<td>% MOVEMENT TIME TO PEAK NEG. VELOCITY</td>
<td>18.0 ± 6</td>
<td>18.5 ± 7</td>
<td>16.0 ± 7</td>
<td>13.6 ± 6</td>
<td>13.0 ± 6</td>
<td>8.6 ± 3</td>
</tr>
</tbody>
</table>

Ascending Phase

Table 11
Dependent Variables Measured at Minimum Trunk Angle at Various Levels of Performance. 
(N = 8)

<table>
<thead>
<tr>
<th>PERFORMANCE LEVEL</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIN. TRUNK ANGLE (degrees)</td>
<td>54.077 ± 8.94</td>
<td>53.056 ± 8.52</td>
<td>49.654 ± 10.02</td>
<td>49.131 ± 8.10</td>
<td>48.554 ± 9.29</td>
<td>46.567 ± 7.36</td>
</tr>
<tr>
<td>TIME TO MIN. TRUNK ANGLE (s)</td>
<td>1.642 ± 0.43</td>
<td>1.798 ± 0.51</td>
<td>1.913 ± 0.45</td>
<td>1.860 ± 0.31</td>
<td>2.167 ± 0.52</td>
<td>2.372 ± 0.66</td>
</tr>
<tr>
<td>% MOVEMENT TIME TO MIN. TRUNK ANGLE</td>
<td>63.0 ± 10</td>
<td>65.1 ± 11</td>
<td>62.9 ± 11</td>
<td>58.0 ± 9</td>
<td>61.5 ± 8</td>
<td>52.8 ± 9</td>
</tr>
</tbody>
</table>
Table 12
Dependent Variables Measured at Peak Trunk Velocity during the Ascending Phase at Various Levels of Performance.
(N = 8)

<table>
<thead>
<tr>
<th>PERFORMANCE LEVEL</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEAK POS. VELOCITY (deg./s)</td>
<td>51.02</td>
<td>51.11</td>
<td>47.25</td>
<td>44.84</td>
<td>38.41</td>
<td>35.25</td>
</tr>
<tr>
<td>± 17.4</td>
<td>± 13.5</td>
<td>± 10.6</td>
<td>± 9.8</td>
<td>± 7.8</td>
<td>± 13.0</td>
<td></td>
</tr>
<tr>
<td>TIME TO PEAK POS. VELOCITY (s)</td>
<td>2.284</td>
<td>2.418</td>
<td>2.788</td>
<td>2.989</td>
<td>3.103</td>
<td>4.203</td>
</tr>
<tr>
<td>± 0.45</td>
<td>± 0.55</td>
<td>± 0.49</td>
<td>± 0.43</td>
<td>± 0.45</td>
<td>± 0.66</td>
<td></td>
</tr>
<tr>
<td>% MOVEMENT TIME TO PEAK POS. VELOCITY</td>
<td>87.5</td>
<td>87.4</td>
<td>91.3</td>
<td>92.3</td>
<td>88.9</td>
<td>93.9</td>
</tr>
<tr>
<td>± 5</td>
<td>± 5</td>
<td>± 2</td>
<td>± 2</td>
<td>± 5</td>
<td>± 3</td>
<td></td>
</tr>
</tbody>
</table>

Table 13
Dependent Variables Measured at Peak Thigh Velocity during the Ascending Phase at Various Levels of Performance.
(N = 8)

<table>
<thead>
<tr>
<th>PERFORMANCE LEVEL</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEAK POS. VELOCITY (deg./s)</td>
<td>116.56</td>
<td>109.51</td>
<td>110.15</td>
<td>102.08</td>
<td>94.77</td>
<td>77.18</td>
</tr>
<tr>
<td>± 18.4</td>
<td>± 29.6</td>
<td>± 27.5</td>
<td>± 24.7</td>
<td>± 22.3</td>
<td>± 23.9</td>
<td></td>
</tr>
<tr>
<td>TIME TO PEAK POS. VELOCITY (s)</td>
<td>2.294</td>
<td>2.537</td>
<td>2.856</td>
<td>3.025</td>
<td>3.283</td>
<td>4.183</td>
</tr>
<tr>
<td>± 0.42</td>
<td>± 0.54</td>
<td>± 0.52</td>
<td>± 0.49</td>
<td>± 0.45</td>
<td>± 0.62</td>
<td></td>
</tr>
<tr>
<td>% MOVEMENT TIME TO PEAK POS. VELOCITY</td>
<td>88.1</td>
<td>91.8</td>
<td>93.4</td>
<td>93.1</td>
<td>94.0</td>
<td>93.5</td>
</tr>
<tr>
<td>± 5</td>
<td>± 2</td>
<td>± 2</td>
<td>± 2</td>
<td>± 2</td>
<td>± 2</td>
<td></td>
</tr>
</tbody>
</table>
Table 14
Dependent Variables Measured at Peak Shank Velocity during the Ascending Phase at Various Levels of Performance.
\( (N = 8) \)

<table>
<thead>
<tr>
<th>PERFORMANCE LEVEL</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEAK POS. VELOCITY (deg./s)</td>
<td>62.11 ± 19.3</td>
<td>57.13 ± 16.7</td>
<td>57.82 ± 17.8</td>
<td>56.33 ± 17.2</td>
<td>56.53 ± 15.4</td>
<td>45.11 ± 16.5</td>
</tr>
<tr>
<td>TIME TO PEAK POS. VELOCITY (s)</td>
<td>2.338 ± 0.38</td>
<td>2.553 ± 0.53</td>
<td>2.876 ± 0.51</td>
<td>3.058 ± 0.51</td>
<td>3.304 ± 0.44</td>
<td>4.251 ± 0.60</td>
</tr>
<tr>
<td>% MOVEMENT TIME TO PEAK POS. VELOCITY</td>
<td>90.1 ± 4</td>
<td>92.4 ± 2</td>
<td>94.1 ± 2</td>
<td>94.1 ± 2</td>
<td>94.6 ± 2</td>
<td>95.1 ± 2</td>
</tr>
</tbody>
</table>

Table 15
Dependent Variables Measured at Peak Bar Velocity during the Ascending Phase at Various Levels of Performance.
\( (N = 8) \)

<table>
<thead>
<tr>
<th>PERFORMANCE LEVEL</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEAK POS. VELOCITY (m/s)</td>
<td>0.954 ± 0.16</td>
<td>0.826 ± 0.16</td>
<td>0.740 ± 0.15</td>
<td>0.699 ± 0.13</td>
<td>0.583 ± 0.11</td>
<td>0.483 ± 0.15</td>
</tr>
<tr>
<td>TIME TO PEAK POS. VELOCITY (s)</td>
<td>2.257 ± 0.44</td>
<td>2.439 ± 0.52</td>
<td>2.728 ± 0.47</td>
<td>2.967 ± 0.51</td>
<td>3.100 ± 0.55</td>
<td>4.150 ± 0.63</td>
</tr>
<tr>
<td>% MOVEMENT TIME TO PEAK POS. VELOCITY</td>
<td>86.6 ± 5</td>
<td>88.3 ± 3</td>
<td>89.4 ± 4</td>
<td>91.3 ± 3</td>
<td>88.8 ± 9</td>
<td>92.8 ± 2</td>
</tr>
</tbody>
</table>
### Table 16
Temporal Measures at the Sticking Point at Various Levels of Performance. (N = 8)

<table>
<thead>
<tr>
<th>PERFORMANCE LEVEL</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIME TO STICKING POINT (s)</td>
<td>1.999 ± 0.24</td>
<td>2.233 ± 0.44</td>
<td>2.408 ± 0.42</td>
<td>2.604 ± 0.46</td>
<td>3.111 ± 0.74</td>
</tr>
<tr>
<td>% MOVEMENT TIME TO STICKING POINT</td>
<td>73.3 ± 3</td>
<td>73.4 ± 5</td>
<td>74.1 ± 5</td>
<td>74.3 ± 4</td>
<td>69.0 ± 7</td>
</tr>
</tbody>
</table>

### Table 17
Segmental Displacements at the Sticking Point at Various Levels of Performance. (N = 8)

<table>
<thead>
<tr>
<th>PERFORMANCE LEVEL</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRUNK ANGLE AT STICKING POINT (degrees)</td>
<td>53.200 ± 4.23</td>
<td>52.341 ± 9.36</td>
<td>53.255 ± 8.01</td>
<td>51.499 ± 9.06</td>
<td>51.144 ± 8.94</td>
</tr>
<tr>
<td>THIGH ANGLE AT STICKING POINT (degrees)</td>
<td>29.005 ± 6.67</td>
<td>29.449 ± 5.60</td>
<td>31.859 ± 7.37</td>
<td>34.311 ± 3.19</td>
<td>35.196 ± 7.08</td>
</tr>
<tr>
<td>SHANK ANGLE AT STICKING POINT (degrees)</td>
<td>65.981 ± 3.84</td>
<td>65.070 ± 4.46</td>
<td>65.927 ± 5.81</td>
<td>66.604 ± 5.40</td>
<td>68.192 ± 6.37</td>
</tr>
</tbody>
</table>

90
Table 18
Segmental Angular Velocities and Vertical Bar Velocity at the Sticking Point at Various Levels of Performance.
(N = 8)

<table>
<thead>
<tr>
<th>PERFORMANCE LEVEL</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>(degrees/s)</td>
<td>± 2.59</td>
<td>± 12.19</td>
<td>± 12.73</td>
<td>± 3.56</td>
<td>± 6.18</td>
</tr>
<tr>
<td><strong>THIGH VEL. AT STICKING POINT</strong></td>
<td>64.572</td>
<td>56.135</td>
<td>43.811</td>
<td>37.840</td>
<td>16.900</td>
</tr>
<tr>
<td>(degrees/s)</td>
<td>± 7.78</td>
<td>± 13.03</td>
<td>± 11.67</td>
<td>± 6.07</td>
<td>± 7.52</td>
</tr>
<tr>
<td><strong>SHANK VEL. AT STICKING POINT</strong></td>
<td>21.404</td>
<td>15.159</td>
<td>12.652</td>
<td>10.334</td>
<td>6.515</td>
</tr>
<tr>
<td>(degrees/s)</td>
<td>± 4.10</td>
<td>± 11.03</td>
<td>± 9.46</td>
<td>± 16.19</td>
<td>± 8.27</td>
</tr>
<tr>
<td><strong>BAR VEL. AT STICKING POINT</strong></td>
<td>0.515</td>
<td>0.461</td>
<td>0.373</td>
<td>0.318</td>
<td>0.120</td>
</tr>
<tr>
<td>(m/s)</td>
<td>± 0.06</td>
<td>± 0.09</td>
<td>± 0.09</td>
<td>± 0.05</td>
<td>± 0.08</td>
</tr>
</tbody>
</table>
APPENDIX B

Information and Consent Form
Information and Consent Form

Project Title:

The effects of load on the lifting characteristics of the parallel squat.

Project Purpose:

This study is a Master’s thesis conducted by Iveta Doktor in association with Dr. Wayne Marino. The purpose of the experiment is to determine the percentage of maximal load at which the sticking point occurs in the parallel squat.

This study has been approved by the ethics committee at the University of Windsor. Any questions or concerns should be directed to Dr. Wendy Rogers, University of Windsor, (519) 253-4232.

Project Outline:

The task is to perform a single repetition of the parallel squat movement at the following levels of maximal load: 50%, 60%, 70%, 80%, 90%, and 100%. The protocol of the testing will mimic competition. The use of standard powerlifting suit, powerlifting belt, and knee wraps is mandatory. Two spotters will be used to provide physical support if necessary. Testing will take place in a weightlifting gym. Joint markers will be placed on selected anatomical sites. Film data will be collected during the procedure.

A measure of each subject’s height and weight will be obtained prior to testing.
Subject Consent:

I, the undersigned, do hereby acknowledge that I:

- have willingly volunteered to participate in this experiment which requires me to perform the parallel squat movement at the following six levels of maximal load: 50%, 60%, 70%, 80%, 90%, and 100%
- understand that the experiment has minimal risk of causing physical harm
- have had the experimental protocol explained to me and understand it
- understand that the data collected during the experiment will be used to complete a Master's thesis
- understand that the data will be used in the strictest confidence during this study and any subsequent publications, and presentations, and no subjects will be identified by name
- know that I may withdraw at any time during the testing session without negative ramifications or punishment
- know that I may ask any questions, and request further information about the study at any time
- know that I may receive a summary of the results of this study upon request.

Name:__________________________________________

Signature:________________________________________

Date:____________________________________________

Signature of Researcher:________________________________________

Date:____________________________________________
VITA AUCTORIS

NAME: IVETA DOKTOR

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