Comparison of
Lumbar Spine Loads During
Back and Front Squats
by
Katherine Clancy
Submitted in Partial Fulfillment of
The Requirements of the Master of Science in Exercise Science Degree
Kinesiology Department

STATE UNIVERSITY OF NEW YORK COLLEGE AT CORTLAND

Approved:

Date ____________________________  Thesis Advisor

Date ____________________________  Thesis Committee Member

Date ____________________________  Thesis Committee Member

Date ____________________________  Associate Dean of Professional Studies
ABSTRACT

The purpose of the research was to compare the peak resultant joint torque (T), peak resultant joint compressive force (CF), and peak resultant joint shear force (SF) at the plane of the L3/L4 junction (L3/L4) between the back squat and front squat. The hypothesis was that the back squat would result in a higher peak T, peak CF, and peak SF. The participants were twenty college-aged students (males = 15, females = 5) who each performed both the back and front squat at 70% of their estimated 1RM. The lifts were video recorded and peak resultant joint torques, peak resultant joint compressive forces, and peak resultant joint shear forces were calculated using static equilibrium equations. Statistical analyses revealed that the back squat resulted in a larger peak T, peak CF, and peak SF. Additional analysis showed that both peak T and peak SF occurred for most subjects when the trunk angle was smaller than that of the front squat. Peak CF was found to occur when the heavier loads were lifted but not found to occur consistently with any given trunk angle. It was concluded that when using the same relative load, the back squat results in a larger peak T, peak CF, and peak SF acting at L3/L4 than a front squat. Results also provide evidence that peak T and peak SF occur when the trunk is less upright, and that peak CF are more likely to occur when heavier loads are lifted, rather than when the trunk is more or less upright.
ACKNOWLEDGEMENTS

I would like to thank my thesis advisor, Dr. Peter McGinnis. This project would not have been possible without his unwavering support and guidance. I would also like to thank Dr. Wendy Hurley and Dr. Joy Hendrick for their continuous advisement throughout the entire thesis process.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ABSTRACT</strong></td>
<td>ii</td>
</tr>
<tr>
<td><strong>ACKNOWLEDGEMENTS</strong></td>
<td>iii</td>
</tr>
<tr>
<td><strong>TABLE OF CONTENTS</strong></td>
<td>iv</td>
</tr>
<tr>
<td><strong>LIST OF TABLES</strong></td>
<td>vi</td>
</tr>
<tr>
<td><strong>LIST OF FIGURES</strong></td>
<td>vii</td>
</tr>
</tbody>
</table>

1. **INTRODUCTION**
   - Statement of the Problem | 1
   - Significance of the Study | 2
   - Hypothesis | 3
   - Delimitations | 3
   - Limitations | 3
   - Assumptions | 3
   - Definition of Terms | 4

2. **LITERATURE REVIEW**
   - Trunk Inclination and Torque and Forces | 7
   - Back Squat and Front Squat Compared | 10
   - Inverse Dynamic Analysis | 13
   - Summary | 15

3. **METHODS AND PROCEDURES**
   - Participants | 16
   - Procedures | 16
   - Video Recording Set-up | 19
   - Digitizing Procedure | 21
   - Data Filtering and Coordinate Transformations | 21
   - Virtual Points | 22
   - Anthropometric Model | 23
   - Inverse Dynamic Analysis | 26
   - Computation of Joint Forces and Torque at L3/L4 | 26
   - Statistical Analysis | 28

4. **RESULTS AND DISCUSSION**
   - Results | 29
   - Discussion | 33

5. **SUMMARY, CONCLUSIONS, IMPLICATIONS, AND RECOMMENDATIONS**
   - Summary | 37
   - Conclusions | 37
   - Implications | 38
# LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Body Segments and Their Associated Endpoints and Relevant Anthropometric Data</td>
</tr>
<tr>
<td>2.</td>
<td>Peak Resultant Joint Torque and Corresponding Trunk Angles</td>
</tr>
<tr>
<td>3.</td>
<td>Peak Resultant Joint Compressive Forces and Associated Trunk Angles</td>
</tr>
<tr>
<td>4.</td>
<td>Peak Resultant Joint Shear Forces and Associated Trunk Angles</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Bar positioning during the back squat</td>
<td>4</td>
</tr>
<tr>
<td>2. Bar positioning using a clean grip during the front squat</td>
<td>5</td>
</tr>
<tr>
<td>3. Bar positioning using a cross grip during the front squat</td>
<td>5</td>
</tr>
<tr>
<td>4. Plan view of the laboratory set-up</td>
<td>20</td>
</tr>
<tr>
<td>5. Schematic models</td>
<td>25</td>
</tr>
<tr>
<td>6. Change in peak resultant joint torque versus change in load lifted</td>
<td>32</td>
</tr>
<tr>
<td>7. Change in peak resultant joint compressive force by change in load</td>
<td>32</td>
</tr>
<tr>
<td>8. Change in peak resultant joint shear force versus change in load</td>
<td>33</td>
</tr>
</tbody>
</table>
CHAPTER 1
INTRODUCTION

Sometimes called the “king of all weightlifting exercises” (O’Shea, 1985), the squat has been described as a functional (Flanagan & Salem, 2007), multi-joint (Gullett, Tillman, Gutierrez & Chow, 2009), closed-chain exercise (Braidot, Brusa, Lestussi, & Parera, 2007; Stuart, Meglan, Lutz, Gowney, & An, 1996). The squat is a widely popular exercise among physical therapists, athletes, and recreational exercisers, used to strengthen the legs and trunk (Braidot et al., 2007, Cappozzo, Felici, Figura, & Gazzani, 1985; Escamilla, Fleisig, Lowry, Barrentine, & Andrews, 2001; Gullett et al., 2009) for the purposes of enhancing athletic ability and activities of daily living (Braidot et al., 2007; Dionisio, Almeida, & Duarte, et al., 2008; Russell & Phillips, 1989).

Many investigations have been carried out on the kinematics, kinetics, and muscular firing patterns of the squat (Braidot et al., 1985; Escamilla et al., 2001; Gullett et al., 2009, McLaughlin, Dillman, & Lardner, 1977; McLaughlin, Lardner, & Dillman, 1978). As with any exercise, there is a potential risk of injury when performing the squat (Cappozzo et al., 1985; Wretenberg, Feng, Lindberg, & Arborelius, 1993). Research regarding the forces and torques acting on the lumbar spine during the squat is more limited than knee research (Walsh, Quinlan, Stapleton, Fitzpatrick, & McCormack, 2007), and is extensive for lifting low-lying objects (e.g. squat lifting, stoop lifting). Findings have indicated the posture of the lumbar spine dictates the magnitude of forces and torques acting on the lumbar spine (Holmes, Damaser, & Lehman, 1992; Lee, 2004; Russell & Phillips, 1989) in both performance of manual lifting and squatting exercises. More specifically, findings have indicated that a more upright trunk results in lower

Traditionally, to load the squat, a bar is placed across the back of the shoulders, posterior to the body. The front squat is a variation which places the bar anterior to the body across the anterior deltoids. The difference in bar placement tends to require a more upright trunk posture for the front squat (Fry & Kraemer, 1990; Russell & Phillips, 1989, 1990), and because of this, the front squat is commonly thought to be less strenuous to the low back and therefore safer than a back squat (Russell & Phillips, 1989). However, due to the bar’s location anterior to the body’s center of gravity, there is a longer moment arm to the lumbar spine (Russell & Phillips, 1989). Possibly to compensate for the longer moment arm, and thus larger torque produced, the one-repetition maximum (1RM) load is less than that of a 1RM for a back squat (Gullett et al., 2009; Fry & Kraemer, 1990; Russell & Phillips, 1990) but whether the smaller absolute load used and more upright trunk in a front squat actually results in less torque and forces than the back squat is unclear.

Statement of the Problem

The purpose of this study was to compare the peak resultant joint torque, peak resultant joint compressive force, and peak resultant joint shear force at the plane of the L3/L4 junction between the back squat and front squat.

Significance of the Study

While it is commonly thought that a front squat requires less muscular force than a back squat (Gullett et al., 2009; Russell & Phillips, 1989), only three studies to date have examined this (Braidot et al., 2007; Gullet et al., 2009; Russell & Phillips, 1989), and their findings were
not consistent. This study helped to elucidate findings of peak forces and torques in the lumbar spine during the back and front squats.

_Hypotheses_

1. There will be a larger peak resultant joint torque in the back squat than front squat at the plane of the L3/L4 junction.
2. There will be a larger peak resultant joint shear force in the back squat than front squat.
3. There will be a larger peak resultant joint compressive force in the back squat than front squat.

_Delimitations_

This study was delimited to:

1. Healthy male and female college-aged students recruited from exercise science courses at SUNY Cortland
2. Weight lifters who had at least one year of experience performing both types of squats
3. Weight lifters who could front squat at least a 20 kg bar

_Limitations_

The limitations of this study include:

1. The accuracy of the self-reported loads used to estimate 70% 1RM
2. Participant effort and intention during testing
3. Participant honesty regarding training age
4. The assumption that the squat will be bilateral
5. Modeling the squat as a purely sagittal plane movement
6. Trunk angle data were not statistically analyzed

_Assumptions_

Several assumptions were made for this study:
1. Accelerations will be very small and thus negligible

2. For the purposes of inverse dynamic analysis, the body was modeled of three rigid segments with moveable, frictionless hinge joints between each segment

*Operational Definition of Terms*

The following terms are operationally defined for this study:

1. Back squat: Parallel squatting exercise with a bar resting on the upper back (as illustrated in Figure 1).

![Figure 1. Bar positioning during the back squat.](image)

2. Clean grip: A type of grip used in the front squat. The bar rests on the anterior deltoids, fingers curled under the bar, palms facing upward (as illustrated in Figure 2).
4. Cross grip: A type of grip used in the front squat. The bar rests on the anterior deltoids, arms crossed over, hands palm-down on the bar (as illustrated in Figure 3).

5. Front squat: Parallel squatting exercise with a bar resting on the anterior deltoids; as illustrated in Figures 2 and 3.

6. Inverse dynamic analysis: The process by which forces and moments of force (torques) are
computed from the kinematics and inertial properties of moving bodies (Robertson, Caldwell, Hamill, Kamen, & Whittlesey, 2004).

7. L3/L4: The transverse plane that passes through the intervertebral disc between the 3rd and 4th lumbar vertebrae. This plane is the analysis plane where the computed resultant joint torque, resultant joint compressive force, and resultant joint shear force act.

8. Moment arm: The perpendicular distance between the line of action of a force and the axis about which a moment of force or torque is being measured (McGinnis, 2005).

9. Quasi-static inverse dynamic analysis: An inverse dynamic analysis that omits the acceleration terms based on the assumption that the accelerations are small enough to be considered negligible and are thus ignored in computations.

10. Shear force: The peak resultant joint shear force acting at the analysis plane of the L3/L4 junction.


13. Torque: The product of force and moment arm; the peak resultant joint torque acting at the analysis plane of the L3/L4 junction.

14. Training age: The number of years an individual has been performing a strength training program.
CHAPTER 2
REVIEW OF LITERATURE

The purpose of this study was to compare the peak resultant joint torque, peak resultant joint compressive force, and peak resultant joint shear force at the plane of the L3/L4 junction during a back squat and front squat. The literature reviewed was limited to studies specifically investigating the trunk, lumbar spine, and hips while lifting objects and squatting. This chapter concludes with a review of research regarding inverse dynamic analysis.

Trunk Inclination and Trunk Torque and Forces

Posture is a risk factor for low back pain that is influenced by strategy of lifting (Shin & Mirka, 2004), and while still a topic of debate, it is often recommended to lift low-lying objects using a lordotic posture (Holmes et al, 1992; Lee, 2004; Yeung & Ng, 2000). Holmes et al. (1992) filmed and recorded electromyographical (EMG) data of 12 subjects performing a squat-lift from both a kyphotic and lordotic posture. A kyphotic lift results from flexing the spine, while a lordotic lift results in a more upright trunk posture. Electromyographical recordings were made of the erector spinae, quadriceps femoris, and gluteals, and the body was modeled into seven links for inverse dynamic analysis. It was found that while torques about the L3 vertebrae were similar in both lifting postures, the EMG showed that the erector spinae were highly active at the beginning of the lordotic lift and nearly silent at the beginning of the kyphotic lift. This means that since the torques about L3 were nearly identical, the erector spinae bear much of the load during the lordotic lift, whereas the torque in the kyphotic lift “can only be countered by passive restraints of structures supporting the highly flexed spine” (Holmes et al., 1990, p. 330). They concluded that forces and moments acting on the lumbar spine, and erector spinae activity,
may be posture-dependent, rather than load-dependent, and that lordotic lifting is therefore preferred, so that the erector spinae may reduce strain on sensitive tissues. Maintaining an upright torso reduces shear force on the lumbar spine (Lee, 1994), including specifically the L4/L5 joint (Cholewicki et al., 1991) and L5/S1 (Schipplein et al., 1990) due to shortening the distance between the center of mass of the weight and the joint (i.e. shorter moment arm), and as such, should be considered within safe lifting practices (Schipplein et al., 1990). While squat lifting is not the same thing as squatting with the load on the back, this information lends insight into the kinetics and muscular activity of the trunk while inclined.

Similar conclusions have been drawn regarding maintaining upright posture while back squatting. Spinal compression increases linearly with increasing load, its distance in front of the feet, and the degree to which the exerciser extends the lumbar spine beyond neutral loading. In their motion analysis of the lumbar spine during back squatting, Walsh et al. (2007) had 47 university athletes experienced with lifting perform the back squat using 40%, 60%, and 80% of their 1RM, with and without the use of a weight belt. Using a Zebris 3D motion analysis system, they found that the subjects hyperextended their lumbar spine significantly at the 60% and 80% loads. The researchers observed that as the subjects descended into the squat, there was a flexor torque acting on the lumbar spine that would pull the subject forward, causing the heels to lift off the ground. In order to regain stability, the subjects would hyperextend their spine in order to move the load back over the spine, thus allowing the heels to return to the floor so they could complete the lift. No significant differences were found with the use of the weight belt.

Cappozzo et al. (1985) investigated the compressive load acting on L3/L4 during a half-squat exercise with the bar placed on the back of the shoulders using 4 subjects experienced with weight-training. Loads used ranged from 0.8 to 1.6 times body weight, and shims (20 mm) were
placed under the subject’s heels. Electromyography recordings were made of the erectors spinae, rectus abdominus, and obliquus externus, and markers were placed on key joint centers to permit calculation of kinematics and kinetics of joints. They found consistently that the more upright the posture, the smaller the compressive load on L3/L4, and observed that the heavier the barbell load, the more the subjects tended to have an erect trunk while performing the half-squat. Trunk extensor contraction force was predicted to be between 30 and 50% of the maximal isometric force that can be exerted on the trunk at lumbar level, which they reference as 4800N (+/- 1800N). Compressive loads acting on L3/L4 varied from approximately 6 to 10 times body weight. Resultant compressive loads were not reported. They concluded that the magnitude of trunk flexion had the most influence on spinal compression load.

McLaughlin et al. (1978) investigated the kinetics of a back squat. Twelve national and world class powerlifters were filmed squatting and an inverse dynamic analysis was performed to calculate resultant moments of force and resultant joint reaction forces. Trunk and thigh torques were extensor-dominant for all subjects, and it was found that the highly skilled subjects had the smallest trunk torques (including one subject who weighed the most of all subjects and lifted the largest load) and greatest thigh torques. The researchers observed that trunk torques did not increase linearly as a function of the subject’s body weight or total load lifted, but did increase linearly as trunk angle decreases (i.e. forward lean). The data appeared to suggest that highly skilled subjects sought to use leg extensors more so than the less skilled, and accomplished this via maintaining a more upright posture.

Various values have been found for torques in the lumbar spine and hip joint while squatting, whereas reported values for both compressive and shear forces were more limited. It is difficult to compare one to another, as both methodologies and loads used vary greatly across the
literature. In summary, for a squatting exercise with the bar either placed on the back or the front, peak hip joint torques ranging from 150 – 785 N·m, with the greatest values coming from powerlifters using competitive 1RM loads (Escamilla et al., 2000). McLaughlin et al. (1978) reported a peak trunk torque of 705 N·m during a back squat. Russell and Phillips (1989) reported a peak trunk torque of 784 N·m during a front squat and 587.9 N·m during a back squat. Considering Cholewicki et al. (1990) reported an average L4/L5 torque of up to 988.3 N·m and an average hip torque of up to 1,046.6 N·m in national powerlifting championship competitors while deadlifting, this range of torques is likely a safe range for the lumbar spine. In the same study, Cholewicki et al. (1990) reported an average compressive force on L4/L5 of 12,641 N and an average shear force of 2,832 N for men, and an average compressive force on L4/L5 of 6,400 N and an average shear force of 1,666 N for women.

*Back Squat and Front Squat Compared*

While not as frequently used as the back squat, the front squat is often prescribed in strength and conditioning programs. A front squat requires a more upright trunk posture (Fry & Kraemer, 1990), has a lower 1RM than a back squat (Gullett et al., 2009; Fry & Kraemer, 1990, Russell & Phillips, 1989), and due to the position of the bar being in front of the body’s line of gravity, the bar has a longer moment arm to the trunk (Russell & Phillips, 1989). Based on these observations, it is thought that the front squat is safer for the lower back (Russell & Phillips, 1989), due to less muscular force used in the lower back (Gullett et al., 2009; Russell & Phillips, 1989), despite little empirical evidence supporting these claims.

Gullett et al. (2009) measured the EMG activity of the rectus femoris, vastus lateralis, vastus medialis, biceps femoris, semitendinosus, and erector spinae during back and front squats in fifteen subjects experienced in both exercises. Net joint reaction forces and joint moments of
force for the lower extremities were computed using inverse dynamic analysis. A relative weight of 70% 1RM of each squat type was used (average loads for back squat and front squat were 88.3 kg and 69.2 kg, respectively). The researchers hypothesized that due to the difference in bar position, there would be increased knee extensor and decreased back extensor activity in the front squat. Gullett et al. also found that there was no significant difference in muscle activity between the two lifts. The researchers comment that “[t]he similarity in EMG activity between bar positions is an intriguing result” (p. 291). A similar study by Stuart et al. (1996) comparing back and front squats also found no significant difference in muscular activity of the quadriceps and hamstrings between the two lifts. However, Stuart et al. (1996) used the same absolute load for both squat variations (22.7 kg), resulting in the back squat being tested at a relatively lighter load than the front squat. Therefore, the similarity of results found is especially interesting, considering Gullett et al. (2009) used a relative load and Stuart et al. (1996) used an absolute load for both squat types.

Russell and Phillips (1989) calculated the forces and torques acting on the low back during back and front squats. Eight males experienced in both lifts were filmed performing each squat variation while wearing a weight belt. After normalizing data to body weight (unit is percent of system mass), they found larger lumbar compressive forces in the back squat than the front squat ($M = 111.36\%$ for back squat, $M = 105.62\%$ for front squat). Larger lumbar shear forces were found for the front squat than the back squat ($M = 67.34\%$ for back squat, $M = 69.13\%$ for front squat). Mean maximal trunk extensor torques for the back squat and front squat were 444.64 N·m and 478.48 N·m, respectively. They reported that it seemed trunk inclination had a greater influence on lumbar shear forces than squat variation. Specifically, as trunk flexion decreased (i.e. more upright posture), there was greater compressive force and decreased shear
force. It should be noted for this study that a statistical analysis was not conducted, so differences found may or may not be significant.

Fry and Kraemer (1990) noted some research flaws in Russell and Phillips’ (1989) research. Russell and Phillips (1989) used the end of the bar to approximate the location of the center of the shoulder joint when making calculations, and any error in doing so was considered constant. While this assumption has been made before in back squat research (McLaughlin et al., 1978), due to the more upright posture of the front squat and the different bar position distances relative to the shoulder joint, the actual shoulder joint location may vary by as much as 7-15cm between squat types (Fry & Kraemer, 1990). Russell and Phillips (1990) responded that upon inspection of the performances, the difference between the end of the bar and the shoulder joint center was approximately 2-4cm in both exercises, and that any resulting calculation error appeared to be within measurement error. Fry and Kraemer also criticized the use of the same absolute load across both exercises, given that the typical 1RM load of a front squat is less than that of a back squat. Russell and Phillips responded that using a larger load in a back squat may have resulted in larger absolute forces and torques, which may or may not be due to the larger absolute load used. They further noted that tissue is injured due to absolute loads, not relative ones, and a primary focus of their research was risk of injury. This ‘discussion’ illustrates the importance of variations in research designs, and the need for repeated research efforts in this area.

Braidot et al. (2007) calculated hip torque in 10 experienced subjects performing back and front squats. A load of 50% of 1RM for their back squat was used for both exercises (the exact load was not reported). They used the end of the bar to approximate the location of the center of the shoulder joint as Russell and Phillips (1989) did. No significant difference was
found between squat variants for hip torque. Actual values were not reported, making it difficult to compare this study to others in the literature. The comments of Fry and Kraemer (1990) apply to this study by Braidot et al. (2007), as their research design was similar to that of Russell and Phillips (1989).

Comparison between these three studies must be undertaken carefully. Gullett et al. (2009) used relative loads of 70% of the 1RM for the back squat and the front squat, while Russell and Phillips (1989) and Braidot et al. (2007) used an absolute load of 75% of the 1RM of the front squat for both squat types, and 50% of the 1RM of the back squat for both squat types, respectively. Therefore, Russell and Phillips (1989) and Braidot et al. (2007) tested the back squat at a relatively lighter load than the front squat. Given that the front squat also has a longer moment arm to the spine, one might expect to see larger trunk torque values in the front squat than the back squat when using the same absolute load, and it is interesting that while Russell and Phillips (1989) observed this, Braidot et al. (2007) did not, and Gullett et al. (2009) also did not but while using relative loads. While Russell and Phillips used the same absolute load purposely so that any differences found could not be due to the higher absolute load, this may actually be confusing matters more.

Inverse Dynamic Analysis

An inverse dynamic analysis is a method used to quantify forces and moments acting on moving bodies. Using kinematic and anthropometric data, forces and moments can be indirectly calculated using equations based on Newton’s 2nd law of motion. Much research has been devoted to acquiring accurate anthropometric data (i.e. segment lengths, masses, and radii of gyration), usually from cadavers and more recently, living bodies, for the purposes of conducting biomechanical analyses on human movement. This method for determining forces and moments
has been used extensively in squat and lifting tasks research (Braidot et al., 2007; Cappozzo et al., 1985; Cholewicki et al., 1990; Dionisio et al., 2008; Escamilla et al., 2000).

A quasi-static analysis of a human motion assumes accelerations are small enough to be considered negligible, as they do not contribute very much to overall forces and/or torques. However, disregarding acceleration results in smaller calculated forces and moments than perhaps what they truly are, and there has been disagreement whether this assumption is appropriate for human motion, and if a dynamic analysis including accelerations and inertia is more appropriate (Bush-Joseph, Schipplein, Anderrson, & Andriacchi, 1988; Buseck, Schipplein, Anderrson, & Andriacci, 1987; Tsuang, Schipplein, Trafimow, & Anderrson, 1992;). It has been noted that more research is needed on this topic (Bush-Joseph et al., 1988), and the use of heavier loads tends to cause the lifter to move with less acceleration than lighter loads (Tsuang et al., 1992). The use of static or quasi-static equilibrium models in squat and lifting task research continues to be common (Braidot et al., 2007; Cholewicki et al., 1990; Escamilla et al., 2000, Gullett et al., 2009; Holmes et al., 1990; McLaughlin et al., 1977; McLaughlin et al., 1978; Plamondon, Gagnon, & Desjarins, 1994; Russell & Phillips, 1989; Wretenberg et al., 1993).

There are limitations to inverse dynamic analyses. The results of an inverse dynamic analysis give only an estimation of resultant joint forces and moments acting at a particular joint, and these resultants represent the sum of the effects of all the muscles and ligaments crossing that particular joint. It is not possible through this method alone to differentiate what specific muscle groups are working, or how much force they may be providing to the sum total. Furthermore, because the results are resultants, the actual force or moment acting in a particular direction are underestimated.
Summary

The current body of research indicates that maintaining an upright posture while back squatting has numerous benefits. Walsh et al. (2007) found that maintaining an upright posture minimizes hyperextension of the lumbar spine, which increases stability of the exercise and decreases risk of injury to the lumbar spine. Cappozzo et al. (1985) found that the magnitude of trunk flexion has the most impact on compressive forces acting on L3/L4. McLaughlin et al. (1978) observed that their highly skilled subjects exhibit the most upright trunks, lowest hip torques, and highest thigh torques, and that trunk torque increases linearly with less upright posture. While it has been anecdotally observed that a front squat results in a more upright posture than a back squat, it also results in a larger moment arm to the lumbar spine. Of the four studies reviewed comparing back and front squats, Gullett et al. (2009) and Stuart et al. (1990) found no difference in muscular activity between the two lifts. Russell and Phillips (1989) found larger lumbar compressive forces in back squat than front, larger lumbar shear forces in front squat than back, and smaller mean maximal trunk extensor torques for back than front squat. They observed that trunk inclination has a greater influence on lumbar shear forces than squat variation, and that as trunk flexion decreased, there was greater compressive force and decreased shear force (Russell & Phillips, 1989). Braidot et al. (2007) found no significant difference in the mean hip torque. The sum of the body of research on back and front squats indicates that trunk posture has the biggest influence on trunk torque and forces, but the impact of the location of the bar on trunk torques and forces remains unclear.
Chapter 3

METHODS AND PROCEDURES

The purpose of this study was to compare the peak resultant joint torque, peak resultant joint compressive force, and peak resultant joint shear force at the plane of the L3/L4 junction during a back squat and front squat. This chapter includes description of the subjects, the testing procedures and the statistical treatment of the data.

Participants

Twenty-one participants were recruited from exercise science courses during the spring 2010 semester at SUNY Cortland. This number exceeds estimated sample size for a power of .80 using estimated effect size of .45 (based on Russell & Phillips’ 1989 data), using G*Power (Faul, Erdfelder, Buchner, & Lang, 2009). Students registered for these classes were verbally invited to participate by the lead researcher. The lead researcher informed students as to what their participation would involve, including risks and benefits involved with this study. Potential participants were required to be experienced weight lifters with at least one year of experience in both the back and front squat, and free of any injuries for at least 30 days.

A total of 21 students participated in this study, but one participant was eliminated due to a joint marker being obscured by the weight plates. Of the remaining participants, there were 15 males and 5 females. Participant characteristics are displayed in Appendix A.

Procedures

Prior to testing all procedures were approved by the SUNY Cortland Institutional Review Board. The lead researcher offered to read aloud an informed consent to the participant (see Appendix B). The participant then had the opportunity to read it and sign it if in agreement. Following this, participants were asked to complete a Physical Activity Readiness Questionnaire
(PAR-Q) (see Appendix C). Participants’ height, weight, gender, age, estimated weightlifting experience in years, and maximal load for X# of repetitions for each squat type were recorded (see Appendix D). Based on this load, their 1RM was estimated using the National Strength and Conditioning Association’s 1RM calculator (NSCA, n.d.), and 70% of this estimated 1RM was used for the experimental trials.

The participant was asked to warm up on a stationary bike at a self-selected intensity for 5 minutes. Following this, spherical reflective markers with a diameter of 2cm were placed on the right side of the body on the tip of the longest toe (TTIP) (first or second toe), the heel, lateral malleolus (LMAL), knee joint center (KJC), and hip joint center (HJC). A marker with a diameter of 4cm was placed on the end of the bar. These were the endpoints of the body segments used in later calculations. Two additional markers with a diameter of 2cm were placed in equidistant locations slightly anterior and posterior to the shoulder joint center (SJC), so that the location of the shoulder joint relative to the hip joint and the bar end could be determined for later trunk angle calculations. The participant then performed a warm-up set of 5 repetitions of the back squat, followed by 5 repetitions of the front squat, with a standard 20 kg bar. In addition to warming up the participants, the purpose of this warm-up set was to capture the shoulder joint on video. Locating the center of the shoulder joint during squat exercises is a complication in squat research, as any plates on the bar block the view of the shoulder in the sagittal plane (Russell & Phillips, 1989; Russell & Phillips, 1990).

A SONY miniDV recorder (SONY DV1000) recorded the video signal from a JVC video camera (model #GR-DF550U) with a sagittal view of the participant during the warm up squats. More detail regarding the camera set up is described later in this chapter and depicted in Figure 4.
After the warm up sets were completed and recorded, the JVC video camera and SONY miniDV recorder were used to record the experimental lifts and a force platform was used to measure ground reaction forces (Bertec #K00606, type 4060-10, Columbus, OH, with dimensions of 40 x 60 cm). The appropriate load was secured onto the bar in between the warm up set and experimental set, which took approximately 45 seconds. Each participant was instructed to stand with their right foot lined up along the right edge of the force platform closest to the camera, so that the field of view was the same for all participants. While standing with both feet on the force platform, each participant was video recorded performing one set of three repetitions per squat type, and the order of squat type was randomized per participant. The load used was 70% of their estimated 1RM for their back and front squat. Rest of approximately 4 minutes was given between trials and during this time the load was changed. The total time requirement of each participant was approximately a half-hour. The load, repetitions, and rest periods were similar to those used by Gullett et al. (2009).

When a “Go” command was given to the participant, the researcher simultaneously triggered a handheld button, which caused a signal to be recorded in the form of a white rectangle on the upper left-hand corner of the video image. This visual aid allowed the researcher to manually synchronize the data from the force platform with the video images. The Peak Motus software was set to pre-record for 1 second prior to the trigger and record for 13 seconds following the trigger, for a total of 14 seconds per set. The analog output from the force platform was amplified and converted to digital form before recorded as a digital data file by the Peak Motus software. The video signal from the camera was first transmitted to the video input of the Peak Motus event and video control unit (E&VCU). The video output of the E&VCU, which
included the video signal from the camera with the synchronization signal overlaid in the upper left corner was then recorded on a mini DV tape using a SONY DV1000 miniDV recorder.

*Video Recording Set-up*

A diagram of the experimental set-up and camera view is given in Figure 4. The camera was set up 1.11 m and 9.14 m to the right of the participant, perpendicular to the sagittal plane. The camera recorded at a rate of 60 fields per second with a shutter speed of 1/250th of a second. In order to maximize the vertical field of view, the camera was rotated 90 degrees and the lens length adjusted to a field of view of 2.43m. The wall on the far side of the participant from the camera was marked to indicate the edges of the camera’s field of view so that the lens length was consistent per trial. Markers with a diameter of 2.6 cm were placed close to the corners of the force platform nearest the camera and in line with the participant’s right foot. Positioned directly below the camera was a 300 W light, so that the reflective markers were more visible. The camera was calibrated to focus on a field of view level with the force platform where participants were located.
Figure 4. Plan view of the laboratory set-up.
**Digitizing Procedure**

Prior to digitizing the participants, the force platform was digitized. For the warm-up sets, the reflective markers on the TTIP, heel, LMAL, KJC, HJC, SJC (back squat warm-up only), the end of the bar, and the corners of the force platform closest to the camera were digitized. By digitizing the force platform corners, the force platform could be located relative to the coordinate system of the participant. With this information, locating the point of application of the ground reaction force on the participant’s foot was possible. For the warm-up trial front squat, the location of the SJC was estimated and digitized, as the SJC was visible but the marker located anterior to the SJC was obscured. For both of the warm-up trials (back squat and front squat), the SJC was digitized in the initial upright standing position, and at the bottom of the squat.

For the experimental trials, the reflective markers on the TTIP, heel, LMAL, KJC, HJC, and the corners of the force platform closest to the camera were digitized. The coordinates of a virtual point for L3/L4 and the SJC were also computed as described in detail below.

**Data Filtering and Coordinate Transformations**

Raw coordinate data were smoothed using a second-order Butterworth filter to reduce random noise produced during the digitizing process. The filtered coordinate data were then transformed to real life coordinates using the ratio of the known distance between the front and back of the force platform and the computed distance between the filtered coordinates of these two points as a multiplier. The coordinate system was then translated to position the origin at the top front edge of the force platform, and the coordinate system was then rotated 90° clockwise to produce an upright view of the participant.
Virtual Points

The anthropometric data of Zatsiorsky as adjusted by de Leva (1996) were used for the determination of segment endpoints and body segment parameters (BSPs). Two points needed for calculations were not visible from the side during the squat: the SJC, and L3/L4, because the only landmark given by de Leva and Zatsiorsky was the omphalion (navel), which lies in the same transverse plane as L3/L4 (Lariviere & Gagnon, 1999), and is best viewed from the front and not the side. The location of the SJC and L3/L4 were computed using anthropometric data reported by de Leva (1996) and the coordinate data of digitized points.

The virtual point representing the SJC was created using the spatial relationship between the digitized points of the SJC, HJC, and end of the bar from the warm-up trial. These points create a triangle and it was assumed that the angles of this triangle remained unchanged during a squat. The coordinate data of the SJC, HJC, and bar end when the subject was in the squat position during the warm up trials were used to develop equations that defined the x and y coordinates of the SJC using only the coordinates of the HJC and bar. These equations were subsequently used in the experimental trials to compute the coordinates of the SJC. The equations are as follows:

\[
x_{\text{SJC}} = x_{\text{HJC}} + c(HB)\cos(\phi - \theta) \tag{1}
\]

\[
y_{\text{SJC}} = y_{\text{HJC}} + c(HB)\sin(\phi - \theta) \tag{2}
\]

Where \(x_{\text{SJC}}\) is the horizontal coordinate of the SJC, \(y_{\text{SJC}}\) is the vertical coordinate of the SJC, \(x_{\text{HJC}}\) is the horizontal coordinate of the HJC, \(y_{\text{HJC}}\) is the vertical coordinate of the HJC, \(c\) is the distance from the HJC to the SJC in the warm up trial divided by the distance from the HJC to the bar in the warm up trial, \(HB\) is the distance from the HJC to the bar, \(\phi\) is the angle from right horizontal to the line from the HJC to the bar, and \(\theta\) is the angle between the line from the HJC
to the SJC and the line from the HJC to the bar in the warm up trial. In these equations, the terms \( c \) and \( \theta \) are computed using data from the warm up trials and the terms \( x_{\text{HJC}}, y_{\text{HJC}}, \text{HB}, \) and \( \phi \) are derived from the experimental trials.

Using the data of Zatsiorsky as adjusted by de Leva (1996), the model was customized to create a virtual point for L3/L4 as follows. The endpoints for the entire trunk are the HJC and SJC. The distance between these points is 515.5 mm for the average male used by Zatsiorsky (as cited in de Leva, 1996). The end points for the lower part of the trunk (LPT) are the omphalion and the point midway between the HJC (MIDH). This distance is 145.7 mm for the average male used by Zatsiorsky (as cited in de Leva, 1996), and the MIDH and HJC lie on the same plane. The location of the omphalion, and thus L3/L4, is therefore 28.26\% \( ([145.7 \text{ mm} / 515.5 \text{ mm}] \times 100 \%) \) of the trunk length from the HJC. For the average female used by Zatsiorsky (as cited in de Leva, 1996), the length of the entire trunk is 497.9 mm and the length of the LPT is 181.5 mm, so the location of L3/L4 is 36.45\% of the trunk from the HJC (de Leva, 1996).

**Anthropometric Model**

Due to a computer malfunction, data were lost from the force platform, so a top-down analysis was utilized. This required anthropometric modeling of body segments above the L3/L4 plane. The body parts above L3/L4 were modeled into the following three segments: the middle trunk, upper trunk, and head; the upper arm; and the forearm and hand. The defining endpoints of these segments are respectively as follows: L3/L4 to the SJC for the middle trunk, upper trunk, and head segment; the SJC to the EJC for the upper arm segment; and the EJC to the bar for the forearm and hand segment. Data of Zatsiorsky as adjusted by de Leva (1996), were used to compute the center of gravity locations for these segments relative to their endpoints. For the two compound segments, the forearm and hand and the middle trunk, upper trunk, and head, the
relative masses and relative locations of each of the elemental segments were used to compute
the relative mass and relative center of gravity location for the compound segment.

The segments and their associated endpoints and relevant anthropometric data are
presented in Table 1. The schematic model used for computations is presented in Figure 5.

Table 1

Body Segments and Their Associated Endpoints and Relevant Anthropometric Data.

<table>
<thead>
<tr>
<th>Segment</th>
<th>Endpoints</th>
<th>Mass (%)</th>
<th>Longitudinal CM position (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Origin</td>
<td>Other</td>
<td>F</td>
</tr>
<tr>
<td>Trunk and head</td>
<td>L3/L4</td>
<td>SJC</td>
<td>36.78</td>
</tr>
<tr>
<td>Upper arm</td>
<td>SJC</td>
<td>EJC</td>
<td>2.55</td>
</tr>
<tr>
<td>Forearm, hand and bar</td>
<td>EJC</td>
<td>MET3</td>
<td>1.94</td>
</tr>
</tbody>
</table>

Note. CM = center of mass, SJC = shoulder joint center, EJC = elbow joint center, MET3 = third metacarpale
Figure 5. Schematic models of (a) the model used to compute resultant joint forces and torque at L3/L4, and (b) resultant joint torque and resultant shear and compressive joint forces acting on lower body at L3/L4.
Inverse Dynamic Analysis

Resultant joint torques and resultant joint forces were calculated using position data obtained from the video analysis. A static model was used in calculations based on static equilibrium equations. The accelerations and inertia were assumed to be negligible, and equations of static equilibrium were used to calculate resultant joint forces and torques. For each calculation, the sum of the forces in a given direction, or torques, was set equal to zero.

Computation of Resultant Joint Forces and Torque at L3/L4

The schematic model, as seen in Figure 5, was used to calculate resultant joint torques and forces at L3/L4. The trunk angle and resultant joint forces were used to compute the resultant joint shear and compressive forces at L3/L4. The computations used to determine these forces and torques follow.

Vertical reaction force at L3/L4:

\[ R_y = W_{\text{trunk}} + W_{\text{upper arm}} + W_{\text{arm}} + W_{\text{bar}} \]  

(3)

Where \( R_y \) is the vertical reaction force at L3/L4, \( W_{\text{trunk}} \) is the weight of the middle trunk, upper trunk and head, \( W_{\text{upper arm}} \) is the weight of the upper arm, \( W_{\text{arm}} \) is the weight of the arm, \( W_{\text{bar}} \) and \( W_{\text{hand}} \) is the weight of the bar and hand.

Resultant torque at L3/L4:

\[ T_{L3/L4} = W_{\text{trunk}} (x_{\text{trunk}} - x_{L3/L4}) + W_{\text{upper arm}} (x_{\text{upper arm}} - x_{L3/L4}) + W_{\text{arm}} (x_{\text{arm}} - x_{L3/L4}) + \]
\[ W_{\text{bar}} (x_{\text{bar}} - x_{L3/L4}) \] (4)

Where \( T_{L3/L4} \) is the torque about L3/L4, \( W_{\text{trunk}} \) is the weight of the middle trunk, upper trunk and head, \( x_{\text{trunk}} \) is the horizontal coordinate of the trunk center of gravity, \( x_{L3/L4} \) is the horizontal coordinate of L3/L4, \( W_{\text{upper arm}} \) is the weight of the upper arm, \( x_{\text{upper arm}} \) is the horizontal coordinate of the upper arm center of gravity, \( W_{\text{arm}} \) is the weight of the forearm and hand, \( x_{\text{arm}} \) is the horizontal coordinate of the forearm and hand center of gravity, \( W_{\text{bar}} \) and is the weight of the bar, and \( x_{\text{bar}} \) and is the horizontal coordinate of the bar.

Compressive force at L3/L4:

\[ F_c = R_y \sin \theta \] (5)

Where \( F_c \) is the resultant joint compressive force at L3/L4, \( R_y \) is the vertical reaction force at L3/L4, and \( \theta \) is the trunk angle.

Shear force at L3/L4:

\[ F_s = R_y \cos \theta \] (6)

Where \( F_s \) is the resultant joint shear force at L3/L4, \( R_y \) is the vertical reaction force at L3/L4, and \( \theta \) is the trunk angle.
Statistical Analysis

A one-way multivariate analysis of variance (MANOVA) was used to evaluate results, incorporating a within subjects design, with repeated measures to compare squat types. The dependent variables were the peak compressive forces, peak shear force, and peak resultant force at the plane of the L3/L4 junction. Statistical analysis was conducted at the .05 significance level to reveal effects of the treatment. Follow-up ANOVAs for each individual dependent variable was conducted using a Bonferroni adjusted alpha level of .017. Statistical analyses were run using PASW (SPSS) version 17 for Windows.
CHAPTER 4

RESULTS AND DISCUSSION

The purpose of this study was to compare the peak resultant joint torque (T), peak resultant joint compressive force (CF), and peak resultant joint shear force (SF) at the plane of the L3/L4 junction (L3/L4) during a back squat and front squat. Participants were video recorded performing back and front squats. Torque and forces were computed using static equilibrium equations.

Results

A one-way within-subjects multivariate analysis of variance (MANOVA) was used to compare squat types. After verification for satisfying requirements for colinearity and sphericity, a significant effect of the type of squat (back versus front) on the combined dependent variable was found, $F(3,17) = 17.4, p < .0005$, Wilks’ Lambda = .2. Partial eta squared = .756, meaning 76% of the variability in the combined variable is explained by the different squat types. Using a Bonferroni adjusted alpha of .017 (.05/3) for each individual dependent variable, analysis of the peak T ($F(1,19) = 8.38, p = .01$, partial eta squared = .30), peak CF ($F(1,19) = 40.28, p < .0005$, partial eta squared = .68), and peak SF ($F(1,19) = 39.71, p < .0005$, partial eta squared = .68) showed that all three dependent variables differed significantly between the back squat and front squat. Specifically, it was found that the peak T was higher in the back squat ($M = 236$ N·m) than the front squat ($M = 192$ N·m), the peak CF was higher in the back squat ($M = 1208$ N) than the front squat ($M = 918$), and the peak SF was higher in the back squat ($M = 736$ N) than the front squat ($M = 494$ N), as shown in Tables 2, 3, and 4. Data for all participants are displayed in Appendices E, F, and G.
Table 2

Peak Resultant Joint Torque and Corresponding Trunk Angles \((n = 20)\)

<table>
<thead>
<tr>
<th>Torque (N·m)</th>
<th>Trunk angle (°) at maximal torque</th>
<th>Minimum trunk angle (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back</td>
<td>Front</td>
<td>Back</td>
</tr>
<tr>
<td>Mean</td>
<td>236</td>
<td>53</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>98</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 3

Peak Resultant Joint Compressive Forces and Associated Trunk Angles \((n = 20)\)

<table>
<thead>
<tr>
<th>Compressive force (N)</th>
<th>Trunk angle (°) at maximal compressive force</th>
<th>Maximum trunk angle (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back</td>
<td>Front</td>
<td>Back</td>
</tr>
<tr>
<td>Mean</td>
<td>1208</td>
<td>80</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>356</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 4

Peak Resultant Joint Shear Forces and Associated Trunk Angles \((n = 20)\)

<table>
<thead>
<tr>
<th>Shear force (N)</th>
<th>Trunk angle (°) at maximal shear force</th>
<th>Minimum trunk angle (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back</td>
<td>Front</td>
<td>Back</td>
</tr>
<tr>
<td>Mean</td>
<td>736</td>
<td>53</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>233</td>
<td>7</td>
</tr>
</tbody>
</table>

All participants lifted a heavier load in the back squat \((M = 88 \text{ kg})\) than the front squat \((M = 57 \text{ kg})\); see Appendix A). To account for the difference in loads between squat types, the change in load between squat types, including bodyweight, was calculated as a percentage for each participant as follows:

\[
\text{Percent change in load} = \left( \frac{\text{back squat load} - \text{front squat load}}{\text{back squat load} + \text{subject body weight}} \right) \times 100\% \]  
(7)
The change in peak T, peak CF, and peak SF between squat types were also calculated similarly:

\[
\text{Percent change in dependent variable} = \left( \frac{\text{back squat value} - \text{front squat value}}{\text{back squat value}} \right) \times 100\% \quad (8)
\]

The percent change in load for the squat types was plotted against the percent change in each of the dependent variables. The graph for percent change in load versus percent change in T (Figure 6) shows a positive linear relationship. \(R^2 = .52\), meaning the change in load accounted for 52% of the change in T, indicating a moderate relationship between change in load and T.

The graph for percent change in load versus percent change in CF (Figure 7) shows a positive linear relationship. \(R^2 = .97\), meaning the change in load accounted for 97% of the change in CF, indicating a strong relationship. The graph for percent change in load versus percent change in SF (Figure 8) shows a positive linear relationship. \(R^2 = .64\), meaning the change in load accounted for 64% of the change in SF, indicating a moderate relationship.
Figure 6. Change in peak resultant joint torque versus change in load lifted. The regression line indicates to predict change in peak torque from change in load, $Y = 1.61x - 14.9$, $R^2 = .52$.

Figure 7. Change in peak resultant joint compressive force by change in load. The regression line indicates to predict change in peak compressive force from change in load, $Y = 1.27x - .04$, $R^2 = .97$. 
Figure 8. Change in peak resultant joint shear force versus change in load. The regression line indicates to predict peak compressive force from load, $Y = 1.50x - 4.85$, $R^2 = .64$.

Discussion

The results of the current study were limited by a relatively small sample size, the accuracy of participant self-report (for load and experience), and the inherent modeling assumptions underlying the use of three rigid segments with moveable, frictionless hinge joints between each segment. Trunk angle data were not statistically analyzed. Additionally, results were limited to the scope of the analysis which was static and occurred in a top-down fashion due to unforeseeable software overwrites that erased previously collected force data (this is explained in a note in the results section).

The results of this study indicated that in the population sampled, a back squat resulted in a higher peak T, peak CF, and peak SF acting at L3/L4 than a front squat. The strong positive
linear relationship found to exist between increase in load lifted and increase in peak CF suggested that CF was strongly influenced by load magnitude.

The moderate positive linear relationship found between increase in load lifted and increase in peak T and peak SF suggested that while T and SF are influenced by the magnitude of load used, perhaps other factors may influence these variables. It can be reasoned that one such factor may be trunk angle (see Figure 5). The peak T and peak SF of the back squat and the peak T and peak SF of the front squat occurred at the smallest trunk angle for all participants. Fifty percent of participants’ trunks \((n = 10)\) were less upright when they experienced maximal peak T, regardless of squat type. Sixty-five percent of participants’ trunks were less upright \((n = 13)\) when they experienced maximal peak SF, regardless of squat type. All participants experienced maximal peak compressive force during the back squat, and 60% of participants’ trunks \((n = 12)\) were slightly less upright when experiencing peak CF during the back squat \((M = 80°)\) than when experiencing peak CF during the front squat \((M = 82°)\). However, the larger peak CF found in the back squat is probably more due to the heavier load lifted in the back squat than the small increase in trunk flexion, given that the trunk angles show the participants were standing mostly upright (see Table 4).

The larger peak T found in the back squat is not supported by previous research. Russell and Phillips (1989) reported larger mean maximal trunk torques acting at L3/L4 in a front squat than back squat. Braidot et al. (2007) reported no significant difference in mean hip torque between a back and front squat. However, both studies used the same absolute load for both squat types, and Russell and Phillips (1989) noted that each subject experienced the largest torques when the trunk was the least upright, and that this trunk inclination had a greater influence on maximal torque than squat type. In their research on back squats, McLaughlin et al.
(1978) reported that trunk torque increased linearly with a decrease in trunk angle, but it did not increase linearly with bodyweight or load lifted. The current study used a heavier absolute load for the back squat than front squat, and most participants’ trunks were less upright during the back squat. Of the participants (participants 5, 9, 10, and 11) who experienced a larger peak torque in the front squat, one had a smaller trunk angle in their front squat when compared to their back squat. Of the participants \( n = 14 \) who experienced a larger peak torque in the back squat, nine had a smaller trunk angle in their back squat when compared to their front squat. The remaining two participants (participants 4 and 7) had virtually identical peak torques and trunk angles in their back and front squats. Ten participants experienced a larger peak torque at their smallest trunk angle, nine participants experienced a larger peak torque with little difference in trunk angle, and one participant (participant 14) experienced a larger peak torque with a larger trunk angle. Overall, these results are supported by other researchers that have reported greater trunk and spine torques with smaller trunk angles.

The larger peak resultant joint compressive forces found in the back squat are supported by Russell and Phillips (1989), who found larger mean maximal compressive forces in a back squat than a front squat. Cappozza et al. (1985) reported that magnitude of trunk flexion has the largest impact on spinal compressive forces. More specifically, Russell and Phillips (1989) reported that with more upright posture, spinal compressive forces increased. In the current study, all participants experienced maximal compressive forces during the back squat, yet twelve subjects (60%) had slightly less trunk flexion when they experienced the peak compressive force of the front squat. Walsh et al. (2007) reported that spinal compressive forces increase linearly with load, and as the compressive force is the vector component of the system load (bar load plus
bodyweight) projected along the trunk, it may be expected to see larger compressive forces when the bar load is heaviest and the trunk is upright.

The larger peak resultant joint shear forces found in the back squat are not directly supported by Russell and Phillips (1989), who found slightly larger maximal shear forces during the front squat than back. However, they specified that trunk angle had more of an impact on shear forces in the lumbar spine than squat type, and that a more upright trunk angle resulted in reduced shear forces. In the current study, all participants but one (participant 9) experienced a larger peak shear force during the back squat and had either less upright posture \((n = 13)\) or virtually the same trunk angle \((n = 6)\) in the back squat than the front squat at the instant of peak shear force. Interestingly, the loads lifted by participant 9 only differed by 2 kg, suggesting that trunk angle had a large influence on peak torque. Thus, these results are supported by Russell and Phillips (1989) in that more upright posture resulted in reduced shear forces.

Results showed that when performed using the same relative load, the back squat resulted in a larger peak resultant joint torque, peak resultant joint compressive force, and peak resultant joint shear force acting at the plane of the L3/L4 junction than the front squat. For most participants, the peak resultant joint torque and peak resultant joint shear force of the back squat occurred at smaller trunk angles than those of the front squat. The peak resultant joint compressive force did not always occur with smaller trunk angles but did always occur with heavier absolute loads. These findings are consistent with most current research regarding the connection between trunk inclination and peak torque and peak shear force, and the connection between bar load and peak compressive force.
CHAPTER 5

SUMMARY, CONCLUSIONS, IMPLICATIONS AND RECOMMENDATIONS

Summary

The purpose of the research was to compare the peak resultant joint torque (T), peak resultant joint compressive force (CF), and peak resultant joint shear force (SF) at the plane of the L3/L4 junction (L3/L4) between the back squat and front squat. The hypothesis was that the back squat would result in a higher peak T, peak CF, and peak SF. The participants were twenty college-aged students (males = 15, females = 5) who each performed both the back and front squat at 70% of their estimated 1RM. The lifts were video recorded and peak resultant joint torques, peak resultant joint compressive forces, and peak resultant joint shear forces were calculated using static equilibrium equations. Statistical analyses revealed that the back squat resulted in a larger peak T, peak CF, and peak SF. Additional analysis showed that both peak T and peak SF occurred for most subjects when the trunk angle was smaller than that of the front squat. Peak CF was found to occur when the heavier loads were lifted but not found to occur consistently with any given trunk angle.

Conclusion

Results of this study provide evidence which suggests that when using the same relative load, the back squat results in a larger peak T, peak CF, and peak SF acting at L3/L4 than a front squat. Results also provide evidence that peak T and peak SF occur when the trunk is less upright, and that peak CF are more likely to occur when heavier loads are lifted, rather than when the trunk is more or less upright.
Implications

The implications of the current study suggest that findings could be of relevance for strength and conditioning professionals. Specifically, it could be reasoned that strength and conditioning professionals should be cautious when using the back squat because of evidence of larger peak T, peak CF, and peak SF acting at L3/L4 during the back squat than the front squat. Similarly, professionals should pay close attention to trunk position since the current study found that with a less upright trunk peak T and peak SF are more likely to occur.

Recommendations

Future research could be conducted to further elucidate the combined impact of load and trunk angle on the torque and forces experienced by the spine during back and front squats. Limited research has been conducted comparing these squat types. Of those reviewed, efforts were made to control for the effects of load, either by using an absolute or relative load. While using a relative load may result in larger forces and torques in the back squat due to load alone and thus may not seem appropriate to use, using an absolute load would result in the front squat being tested at a relatively lighter load. As athletes may employ different lifting strategies when using heavier loads, even for the same exercise, comparing squat types with an absolute load may not be appropriate research design (Fry & Kraemer, 1990). Using an absolute load may also be less applicable to the field of strength and conditioning, as coaches generally prescribe exercises with a specific intensity.

In addition to comparing the peak torque and forces between squat types, EMG activity of the trunk musculature could also be compared. Gullett et al. (2009) found no difference in activity of the erector spinae between back and front squats performed at relative loads of 70% of 1RM. However, peak torque and forces of the trunk were not calculated. This study also used a
relative load of 70% of 1RM and found a significantly larger peak torque in the back squat.

While these combined findings may help explain why the 1RM of a front squat is less than that of a back squat, future research should further explore both the trunk resultant torque and forces, and the muscles responsible for supporting the trunk.
REFERENCES

1 RM Calculator. (n.d.). Retrieved from National Strength and Conditioning Association Web site: 
http://www.nsca-lift.org/fly%20solo%20program/onearm.asp


dynamic factors and external loads on the moment at the lumbar spine in lifting. Spine, 
13, 918-921.

Cappozzo, A., Felici, F., Figura, F., & Gazzani, F. (1985). Lumbar spine loading during half- 
squat exercises. Medicine & Science in Sports & Exercise, 17, 613-620.

extremely heavy weights. Medicine & Science in Sports & Exercise, 23. 1179-1186.

patterns during downward squatting. Journal of Electromyography and Kinesiology, 18, 
134-143.

of Biomechanics, 29, 1223-1230.

biomechanical analysis of the squat varying stance widths. Medicine & Science in Sports 
& Exercise, 33, 984-998.

G*Power 3.1: Tests for correlation and regression analyses. Behavior Research Methods, 
41, 1149-1160.

Flanagan, S.P, & Salem, G.J. (2007). Bilateral differences in the net joint torques during the 

Fry, A.C., & Kraemer, W.J. (1990). Comment on a preliminary comparison of front and back 
squat exercises (Russell & Phillips, 1989). Research Quarterly for Exercise and Sport, 
61, 210-211.

comparison of back and front squats in healthy trained individuals. Journal of Strength


## APPENDIX A

### Participant Characteristics with Means and Standard Deviations

<table>
<thead>
<tr>
<th>Participant</th>
<th>Gender</th>
<th>Age</th>
<th>Training Age</th>
<th>Height (m)</th>
<th>Body Mass (kg)</th>
<th>Front squat grip</th>
<th>Back</th>
<th>Front</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>22</td>
<td>7</td>
<td>1.78</td>
<td>84</td>
<td>Cross</td>
<td>88</td>
<td>57</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>20</td>
<td>3.5</td>
<td>1.80</td>
<td>83</td>
<td>Clean</td>
<td>113</td>
<td>54</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>20</td>
<td>5</td>
<td>1.78</td>
<td>82</td>
<td>Clean</td>
<td>82</td>
<td>41</td>
</tr>
<tr>
<td>4</td>
<td>F</td>
<td>21</td>
<td>6</td>
<td>1.63</td>
<td>59</td>
<td>Clean</td>
<td>48</td>
<td>32</td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>22</td>
<td>4</td>
<td>1.68</td>
<td>62</td>
<td>Clean</td>
<td>43</td>
<td>36</td>
</tr>
<tr>
<td>6</td>
<td>M</td>
<td>22</td>
<td>12</td>
<td>1.65</td>
<td>67</td>
<td>Cross</td>
<td>64</td>
<td>52</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>22</td>
<td>7</td>
<td>1.75</td>
<td>93</td>
<td>Clean</td>
<td>84</td>
<td>68</td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>21</td>
<td>8</td>
<td>1.85</td>
<td>88</td>
<td>Clean</td>
<td>118</td>
<td>95</td>
</tr>
<tr>
<td>9</td>
<td>F</td>
<td>26</td>
<td>1</td>
<td>1.73</td>
<td>70</td>
<td>Clean</td>
<td>25</td>
<td>23</td>
</tr>
<tr>
<td>10</td>
<td>M</td>
<td>21</td>
<td>5</td>
<td>1.75</td>
<td>75</td>
<td>Clean</td>
<td>88</td>
<td>77</td>
</tr>
<tr>
<td>11</td>
<td>M</td>
<td>21</td>
<td>8</td>
<td>1.88</td>
<td>125</td>
<td>Cross</td>
<td>88</td>
<td>66</td>
</tr>
<tr>
<td>12</td>
<td>F</td>
<td>21</td>
<td>5</td>
<td>1.63</td>
<td>66</td>
<td>Clean</td>
<td>70</td>
<td>34</td>
</tr>
<tr>
<td>13</td>
<td>M</td>
<td>34</td>
<td>5</td>
<td>1.78</td>
<td>84</td>
<td>Cross</td>
<td>100</td>
<td>54</td>
</tr>
<tr>
<td>14</td>
<td>M</td>
<td>21</td>
<td>6</td>
<td>1.68</td>
<td>82</td>
<td>Cross</td>
<td>175</td>
<td>113</td>
</tr>
<tr>
<td>15</td>
<td>F</td>
<td>20</td>
<td>3</td>
<td>1.52</td>
<td>57</td>
<td>Cross</td>
<td>64</td>
<td>57</td>
</tr>
<tr>
<td>16</td>
<td>M</td>
<td>20</td>
<td>6</td>
<td>1.60</td>
<td>67</td>
<td>Cross</td>
<td>100</td>
<td>54</td>
</tr>
<tr>
<td>17</td>
<td>M</td>
<td>21</td>
<td>8</td>
<td>1.91</td>
<td>93</td>
<td>Cross</td>
<td>104</td>
<td>64</td>
</tr>
<tr>
<td>18</td>
<td>M</td>
<td>18</td>
<td>4</td>
<td>1.78</td>
<td>71</td>
<td>Clean</td>
<td>100</td>
<td>48</td>
</tr>
<tr>
<td>19</td>
<td>M</td>
<td>21</td>
<td>5</td>
<td>1.78</td>
<td>73</td>
<td>Cross</td>
<td>127</td>
<td>54</td>
</tr>
<tr>
<td>20</td>
<td>M</td>
<td>33</td>
<td>10</td>
<td>1.83</td>
<td>88</td>
<td>Clean</td>
<td>82</td>
<td>64</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>22</td>
<td>5.9</td>
<td>1.74</td>
<td>78</td>
<td></td>
<td>88</td>
<td>57</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td></td>
<td>4.1</td>
<td>2.5</td>
<td>0.10</td>
<td>16</td>
<td></td>
<td>33</td>
<td>21</td>
</tr>
</tbody>
</table>
APPENDIX B

State University of New York College at Cortland

Informed Consent

The research in which you have been invited to participate is being conducted by graduate student Katherine Clancy of the Kinesiology Department at SUNY Cortland. The researcher requests your informed consent to be a participant in the project described below. This project has the purpose of comparing the spinal loads during a back squat and front squat. Please feel free to ask about the project, its procedures, or objectives.

You will be asked to perform the back squat and front squat. You will be lifting 70% of your calculated 1 repetition maximum (1RM). The lead researcher will place markers on your right heel, toe, ankle joint, hip joint, and shoulder joint. Your performance will be videotaped. This will take place in one session that will last approximately an hour. The opportunity to participate in this study will be made available to approximately 20 students from several classes at SUNY Cortland.

The risks associated with your participation in this study are minimal. However, there is always a risk of injury associated with engaging in physical activity. Only the researcher will have access to your videotaped performances. Your videotaped performances will be saved on a flash drive containing your subject ID#. This flash drive and all other data will be stored in a locked cabinet in the lead researcher’s office for no more than 3 years, upon which all videos will be deleted and all paper documents will be shredded. At no time will your name be associated with the data results. Only group aggregate scores will be reported.

You are free to withdraw consent at any time without penalty. Additionally, at any time, you may ask the researcher to destroy all videotape recordings of your performances, as well as any other data or information collected.

From participating in this study, you should expect to come to a better understanding of the way in which research is conducted. You will also earn extra credit from the class in which you were recruited.

If you have any questions concerning the purpose or results of this study, you may contact Katherine Clancy at (607) 745-4903 or at katherine.clancy@Cortland.edu. Other contacts include: Dr. Peter McGinnis, Professor of Kinesiology at Van Hoeson, C119L, or peter.mcginnis@Cortland.edu. For questions about research at SUNY Cortland or questions/concerns about participant rights and welfare, you may contact Amy Henderson-Harr, IRB Administrator, PO Box 2000, Cortland, NY, 13045 (phone (607) 753-2511 or email irb@cortland.edu). In the event of an injury please contact the SUNY Cortland Counseling Center in room B-44 Van Hoesen Hall (607) 753-4728, and/or SUNY Cortland Health Center in room B-26 of Van Hoesen Hall at (607) 753-4811.
I (print name) ___________________________________ have read the description of the project for which this consent is requested, understand my rights, and I hereby consent to participate in this study.

Signature: ___________________________________ Date: __________________

This form was approved by the SUNY Cortland IRB on 05-06-2010 and is in effect until 05-05-2011. The IRB protocol number is 091045.
APPENDIX C

Physical Activity Readiness Questionnaire (PAR-Q)

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer YES or NO for each.

Y  N  Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?

Y  N  Do you feel pain in your chest when you do physical activity?

Y  N  In the past month, have you had chest pain when you were not doing physical activity?

Y  N  Do you lose your balance because of dizziness or do you ever lose consciousness?

Y  N  Do you have a bone or joint problem that could be made worse by a change in your physical activity?

Y  N  Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?

Y  N  Do you know of any other reason why you should not do physical activity?

If you answered YES to one or more of these questions, talk to your doctor by phone or in person before you start becoming more physically active or before you have a fitness appraisal. Tell your doctor about the PAR-Q and the questions to which you answered YES.

If you answered NO to all PAR-Q questions, you can be reasonably sure that you can: start becoming more physically active – begin slowly and build up gradually.

I have read the above information or had it explained to me and understand that I am completely liable for any injury as well as my personal well-being while participating in this study.

____________________________________________________               _________________
Signature                                           Date
APPENDIX D

Participant Information

Please complete this questionnaire to the best of your ability. If you do not wish to answer a question, please leave it blank. Your responses will be treated in a confidential manner.

Subject #_______

Have you suffered an injury in the last 30 days? (Circle one): YES NO

Gender (Circle one): Male Female

Age: _______

Height: _______

Weight: _______

Estimated weightlifting experience in years: _______

Estimated maximum load for ___ repetitions for back squat: _______

Estimated maximum load for ___ repetitions for front squat: _______

To be filled out by researcher:

Calculated 1RM for back squat: _______

Calculated 1RM for front squat: _______

70% of 1RM for back squat in pounds: _______

70% of 1RM for front squat in pounds: _______
### APPENDIX E

**Peak Resultant Joint Torque and Corresponding Trunk Angles**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Torque (Nm)</th>
<th>Trunk Angle (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Back</td>
<td>Front</td>
</tr>
<tr>
<td>1</td>
<td>182</td>
<td>180</td>
</tr>
<tr>
<td>2</td>
<td>434</td>
<td>207</td>
</tr>
<tr>
<td>3</td>
<td>205</td>
<td>194</td>
</tr>
<tr>
<td>4</td>
<td>92</td>
<td>93</td>
</tr>
<tr>
<td>5</td>
<td>108</td>
<td>127</td>
</tr>
<tr>
<td>6</td>
<td>188</td>
<td>166</td>
</tr>
<tr>
<td>7</td>
<td>249</td>
<td>250</td>
</tr>
<tr>
<td>8</td>
<td>384</td>
<td>294</td>
</tr>
<tr>
<td>9</td>
<td>107</td>
<td>135</td>
</tr>
<tr>
<td>10</td>
<td>249</td>
<td>266</td>
</tr>
<tr>
<td>11</td>
<td>235</td>
<td>162</td>
</tr>
<tr>
<td>12</td>
<td>138</td>
<td>93</td>
</tr>
<tr>
<td>13</td>
<td>297</td>
<td>150</td>
</tr>
<tr>
<td>14</td>
<td>310</td>
<td>290</td>
</tr>
<tr>
<td>15</td>
<td>144</td>
<td>137</td>
</tr>
<tr>
<td>16</td>
<td>194</td>
<td>171</td>
</tr>
<tr>
<td>17</td>
<td>349</td>
<td>226</td>
</tr>
<tr>
<td>18</td>
<td>275</td>
<td>224</td>
</tr>
<tr>
<td>19</td>
<td>215</td>
<td>107</td>
</tr>
<tr>
<td>20</td>
<td>368</td>
<td>276</td>
</tr>
<tr>
<td>Mean</td>
<td>236</td>
<td>192</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>98</td>
<td>66</td>
</tr>
</tbody>
</table>
APPENDIX F

Peak Resultant Joint Compressive Forces and Corresponding Trunk Angles

<table>
<thead>
<tr>
<th>Subject</th>
<th>Compressive Force (N)</th>
<th>Trunk Angle (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Back</td>
<td>Front</td>
</tr>
<tr>
<td>1</td>
<td>1267</td>
<td>952</td>
</tr>
<tr>
<td>2</td>
<td>1456</td>
<td>931</td>
</tr>
<tr>
<td>3</td>
<td>1095</td>
<td>791</td>
</tr>
<tr>
<td>4</td>
<td>729</td>
<td>575</td>
</tr>
<tr>
<td>5</td>
<td>678</td>
<td>625</td>
</tr>
<tr>
<td>6</td>
<td>938</td>
<td>835</td>
</tr>
<tr>
<td>7</td>
<td>1248</td>
<td>1073</td>
</tr>
<tr>
<td>8</td>
<td>1513</td>
<td>1320</td>
</tr>
<tr>
<td>9</td>
<td>553</td>
<td>522</td>
</tr>
<tr>
<td>10</td>
<td>1230</td>
<td>1118</td>
</tr>
<tr>
<td>11</td>
<td>1437</td>
<td>1228</td>
</tr>
<tr>
<td>12</td>
<td>985</td>
<td>625</td>
</tr>
<tr>
<td>13</td>
<td>1374</td>
<td>938</td>
</tr>
<tr>
<td>14</td>
<td>2036</td>
<td>1432</td>
</tr>
<tr>
<td>15</td>
<td>786</td>
<td>780</td>
</tr>
<tr>
<td>16</td>
<td>1299</td>
<td>857</td>
</tr>
<tr>
<td>17</td>
<td>1462</td>
<td>1062</td>
</tr>
<tr>
<td>18</td>
<td>1293</td>
<td>756</td>
</tr>
<tr>
<td>19</td>
<td>1595</td>
<td>883</td>
</tr>
<tr>
<td>20</td>
<td>1186</td>
<td>1047</td>
</tr>
</tbody>
</table>

Mean  | 1208  | 918    | 80    | 82     |
Std. Dev.  | 356   | 245    | 7     | 7      |
# APPENDIX G

## Peak Resultant Joint Shear Forces and Corresponding Trunk Angles

<table>
<thead>
<tr>
<th>Subject</th>
<th>Shear Force (N)</th>
<th>Trunk Angle (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Back</td>
<td>Front</td>
</tr>
<tr>
<td>1</td>
<td>603</td>
<td>400</td>
</tr>
<tr>
<td>2</td>
<td>1004</td>
<td>294</td>
</tr>
<tr>
<td>3</td>
<td>881</td>
<td>496</td>
</tr>
<tr>
<td>4</td>
<td>382</td>
<td>271</td>
</tr>
<tr>
<td>5</td>
<td>413</td>
<td>370</td>
</tr>
<tr>
<td>6</td>
<td>607</td>
<td>342</td>
</tr>
<tr>
<td>7</td>
<td>641</td>
<td>563</td>
</tr>
<tr>
<td>8</td>
<td>1053</td>
<td>854</td>
</tr>
<tr>
<td>9</td>
<td>375</td>
<td>393</td>
</tr>
<tr>
<td>10</td>
<td>723</td>
<td>671</td>
</tr>
<tr>
<td>11</td>
<td>926</td>
<td>780</td>
</tr>
<tr>
<td>12</td>
<td>410</td>
<td>258</td>
</tr>
<tr>
<td>13</td>
<td>784</td>
<td>344</td>
</tr>
<tr>
<td>14</td>
<td>1186</td>
<td>908</td>
</tr>
<tr>
<td>15</td>
<td>617</td>
<td>476</td>
</tr>
<tr>
<td>16</td>
<td>784</td>
<td>377</td>
</tr>
<tr>
<td>17</td>
<td>782</td>
<td>542</td>
</tr>
<tr>
<td>18</td>
<td>924</td>
<td>576</td>
</tr>
<tr>
<td>19</td>
<td>700</td>
<td>318</td>
</tr>
<tr>
<td>20</td>
<td>923</td>
<td>653</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shear Force (N)</td>
<td>736</td>
<td>233</td>
</tr>
<tr>
<td>Trunk Angle (degrees)</td>
<td>494</td>
<td>195</td>
</tr>
<tr>
<td></td>
<td>53</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>58</td>
<td>8</td>
</tr>
</tbody>
</table>