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Back stress and assistance exercises in extreme weightlifting

Adam J. Beard
Edith Cowan University

Back Stress and Assistance Exercises in Extreme Weightlifting

By

Adam J. Beard

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ABSTRACT

The purpose of this study was to test the suitability of selected assistance exercises to strengthen the low back for the Olympic lifts in elite weightlifters. Four subjects were filmed by a five-camera Motion Analysis system operating at 120Hz. The subjects completed both of the Olympic lifts (Snatch and Clean) at a near one repetition maximum and four assistance exercises (Bent-over Row, Clean Pull Deadlift, Romanian Deadlift, and Good Morning) at an intensity typically performed at a routine training session. Peak moments, compressive and shear forces about the L5/S1 intervertebral joint were calculated via a top-down inverse dynamics model.

Comparisons were made between the lifts using a one way ANOVA with repeated measures and post-hoc differences between the means were calculated via Least Squared Differences. Significant differences ($p<0.05$) were found when comparing the assistance exercises to that of the Olympic lifts for peak moments, compressive and shear force. Further, significant differences ($p<0.05$) were also found between lifts when these measures were normalised for bar mass and body weight above L5/S1. This study demonstrated that the assistance exercises may all be suitable for conditioning the low back for the two Olympic lifts

USE OF THESIS

DECLARATION

I certify that this thesis does not, to the best of my knowledge and belief:

(i) incorporate without acknowledgment of any material previously submitted for a degree or diploma in any institution of higher education;

(ii) contain any material previously published or written by another person except where due reference is made in the text; or

(iii) contain any defamatory material.

Signature....[redacted]

Date......14-03-02

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1.0 INTRODUCTION

1.1 Background

Olympic Weightlifting consists of two disciplines, they being the Snatch and the Clean and Jerk. As well as being a sport in itself, the so-called "Olympic lifts" are routinely used in strength and conditioning programs at the elite level, and to a lesser degree in the recreational fitness industry.

The Snatch exercise requires an athlete to lift a barbell from the floor to above the head in one continuous motion. The bar must be seen to be an arm's length above the lifters head to be judged a successful lift (Drechsler, 1998). The Clean and Jerk is separated into two distinct movements. The Clean requires that the athlete pull the bar from the floor to the shoulders in one continuous lift (Garhammer, 1984). Once the athlete has successfully lifted the bar onto his/her shoulders from the floor, the Clean segment of the lift is complete and lifter must jerk the bar above the head. The Jerk is completed by the athlete making a shallow dip followed by a powerful knee and hip extension that will allow the athlete to jerk the bar over head. Whilst the bar is being jerked overhead the athlete will split the feet to allow the body to get under the bar (receiving position). The lifter will then proceed to return the feet to the starting position while maintaining the bar over head (Drechsler, 1998; Walsh, 1990).

Previous research (Garhammer, 1978) has identified Olympic lifting as an activity which produces very high power outputs. Power is the product of force and velocity, thus can be computed knowing the weight of the bar and the speed in which it travels (Enoka, 1994). Results have shown that lifters have produced power values for the 'Snatch lift' of 1300 Watts in the 52kg class and up to 3000 Watts in the unlimited class (Garhammer, 1980). Garhammer (1993) has estimated the maximum weight lifted in a Snatch lift as about 80% of that lifted for a maximal Clean, therefore it is typically a faster and more dynamic lift. Total average power output values, however, tend to be very similar for a given athlete for the Snatch and clean movements. The Jerk drive movement of the Clean and Jerk also was noted to produce the highest total output when compared to both the Snatch and Clean (Garhammer, 1980).

The Snatch and the Clean and Jerk both require powerful contractions from the large muscle groups responsible for hip and knee extension, and plantar flexion of the ankle. The arms act as links and do not play a major part in further exerting force on the bar once full extension is reached by the lifter (Garhammer, 1980).

Performance in many sports requires the rapid application of mass. This may come in the form of a powerful serve in tennis, a fast run in rugby or a spectacular mark above the pack in football. All of these skills require powerful movements by the large muscle groups of the body, to allow rapid change in direction to occur when needed.

A kinetic analysis of sprinting conducted by Mann (1981) showed that the highest joint torques were generated by the hip extensor / knee flexor group. These muscle groups can be trained in a specific manner via the Olympic lifts and their variations. Furthermore, their use in conditioning programs is based upon being very time-effective as it is a composite lift, that is, a majority of the body's muscles are conditioned in a single burst of activity.

Correct technique in the Olympic lifts is of paramount importance to maximise power output to the desired musculature. When preparing to lift the barbell from the floor, the shoulders should be slightly in front of the bar. When the bar is being lifted from the floor to the level of the knee (this phase is called the first pull), good technique demands that the shoulders remain ahead of the bar. The athlete should have the feeling of only opening the knee joint whilst keeping the trunk at a constant angle relative to the horizontal. For this reason, Enoka (1979) reported that the beginning of the lift was the most demanding on the lower back. Therefore, for the athlete to be capable of adopting good technique when approaching near maximal efforts, the low back must have sufficient strength to keep the trunk in the correct position described above. The risk of back injury is high in these lifts if the lower back is not sufficiently conditioned. Exercises, which prepare the lower back for impending higher loads, are termed "assistance exercises".

Further, good technique demands that the low back adapt a neutral, or lordotic posture, whilst the bar is being pulled to hip level. The lordotic posture is important as this minimises the contribution of the lumbar posterior ligaments to support the extensor moment (Cholewicki & McGill, 1992). Rather, the lumbar musculature is recruited which potentially reduces the compressive penalty on the lumbar spine due to its larger moment arm when compared to the lumbar posterior ligaments.

Assistance exercises can be performed with greater weight on the bar but the potential for these assistance exercises to provide a greater demand on the low back in preparation for loading in the Olympic lifts is unknown to date. Estimates of the loading on the lumbar spine during lifting can be made at one of the lower lumbar intervertebral joints via a computer modelling approach. Variables typically examined are compressive and shear forces, which are derived from the reactive moment.

Assistance exercises that will be used in this study are the Clean Pull Deadlift (CPD), Bent-over Row (BOR), Good Morning (GM) and the Romanian Deadlift (RDL). The CPD is generally performed using a pronated (over hand) grip, instead of the alternate grip utilised in the conventional powerlifting version of the deadlift (Graham, 2000).

The RDL differs from the conventional Deadlift in that it requires the lifter to maintain the knees at a slightly flexed position throughout the lift. This shifts the emphasis of the work completed further from the hip extensors seen in the conventional deadlift more towards the back musculature required in the RDL (Frounfelter, 2000). It should be noted that the back must maintain its lordotic curve when performing the RDL to maximise the

recruitment of the back musculature. The BOR is performed by starting at a position that requires the lifter to flex at the hips, so the torso is parallel to the floor. The back is maintained in a neutral position while the bar is pulled vertically towards the navel. The GM exercise is performed by placing a barbell behind the neck, the lifters' legs are fixed with the knees flexed at about 15^0. From this position the lifter flexes at the hips while keeping the back a lordotic spine, the lifter then extends back to the starting point (Drechsler, 1998).

1.2 Purpose of the Study

The purpose of this research was to assess the suitability of commonly used assistance exercises to develop back strength in athletes performing the Olympic lifts. Suitability of the assistance exercises is based on developing low back strength for performance (high peak moments about L5/S1), while decreasing the risk of injury to the low back (minimising compressive and shear forces about the L5/S1). To the investigators best knowledge, such an assessment has never been undertaken and this would provide an objectively based rationale on what the best exercises to perform at various developmental levels. Currently, this is done via the coaches' "gut feel".

1.3 Significance of the Study

This project will contribute to a longer-term research plan by developing a two-dimensional, dynamic model suitable for lifting analysis. In this project, the emphasis was on lifting extremely heavy weights and there is paucity of literature on preparing the low back to lift heavy loads. Not only has this project application to the exercise and sport science field, it will have application in the field of ergonomics.

1.4 Research Question

i) What is the relationship between the reactive moments and the compressive and shear forces at the L5/S1 intervertabral joint experienced in the assistance exercises to those of the Olympic lifts?

1.5 Hypothesis

The hypothesis for this study is:

i) The assistance exercises (BOR, GM, RDL and CPD) will show greater peak L5/S1 moments, compressive and shear forces than that displayed for the two Olympic lifts (Snatch and Clean).

1.6 Definition of Terms

i) Kinematics: The study of the time and space factors of motion of a system.

ii) Displacement: The change in a body's location in space in a given direction.

iii) Velocity: The speed and direction of a body.

iv) Acceleration: The change in velocity (speed or direction or both) per unit of time.

v) Kinetics: The study of the forces acting on the body that influence its movement.

vi) Force: That which causes or tends to cause a change in a body's motion or shape.

vii) Moment Arm: The perpendicular distance between the line of action of the force and the axis of rotation.

viii) Torque/Moment of Force: The turning effect of a force

ix) Moment of Inertia: The resistance of a body to angular motion.

x) Statics: The study of factors associated with nonmoving systems.

xi) Dynamics: The study of mechanical factors associated with systems in motion.

xii) Inverse Dynamic Analysis: The analysis of mechanical factors acting on the human body whilst moving. The formulae used in this process are:

$$\sum F_x = ma_x \quad (1)$$

where F_x = horizontal force; m = segment mass a_x; = horizontal acceleration.

$$\sum F_y = ma_y \quad (2)$$

where F_y = vertical force; m = segment mass a_y; = vertical acceleration.

$$\sum T = I_o \alpha \quad (3)$$

where T = torque; I_o = segment moment of inertia; α = angular acceleration.

xiii) Cinematography: Motion picture photography.

xiv) Sagittal: Refers to plane that divides a body or segment into right and left portions.

xv) Spatial: Refers to a set of planes and axes defined in relation to three-dimensional space.

xvi) Technique: A particular type, or variation, of the performance of the same skill.

2.0 REVIEW OF LITERATURE

2.1 Introduction

The review of the literature that is significant to this study will be firstly addressed by investigating prior findings on the methods and models used in the measurement of back stress. The first section in review of literature will address the following: -

2.2 Measuring Back Stress
2.2.1 Direct measurement
2.2.2 Electromyography
2.2.3 Computer Modelling
2.2.4 Inverse Dynamics

The next section reviews the different methods used for the inverse dynamic modelling approach, static and dynamic modelling, as well as the top-down and bottom-up methods are discussed in relevant detail under the headings:-

2.3 Static and Dynamic Inverse Dynamics Modelling
2.4 Top-down and Bottom-up Inverse Dynamic Models

The final section will address intra-Abdominal Pressure (IAP) and its role in lifting tasks. The role of weight lifting belts and muscle mechanic concerns associated to spinal loads while lifting will also be reviewed.

2.5 Intra-Abdominal Pressure
2.5.1 Weight Lifting Belts

2.2 Measuring Back Stress

2.2.1 Direct Measurement

Direct measurements for calculating stress on the spine have been studied using cadaver (in-vitro) experiments (Adams & Dolan, 1996; Adams, McNally, Chinn & Dolan, 1994; Gordon, Yang, Mayer, Mace, Kish, & Radin, 1991; Keller, Hansson, & Holm, 1989) and in vivo studies using animal models (Buttermann, Schendel, Kahmann, Lewis & Bradford, 1991). The cadaver studies all concentrated on the lumbar spine, Adams et al. (1996), and Adams et al. (1994) each used a lumbar segment consisting of two vertebrae and the intervening disc and ligaments. The lumbar segments were attached to a computer driven hydraulic materials testing machine, which applied specific loads to the specimens.

It was reported that cadaver experiments are unreliable due to poor repeatability (Keller, et al., 1989), due to intervertabral discs becoming dehydrated (Adams et al., 1994). However in vitro studies can be used to evaluate the extent of damage caused by extreme forces that would not be able to be applied to living human subjects (Hsiang, Brogmus, & Courtney, 1996).

The in vivo animal model (Buttermann et al., 1991) implanted a strain gauge to measure the facet joint loads of canine lumbar spines, this method is not widely practiced and is restricted to animal studies due to ethical reasons. This study conducted by Buttermann et al. (1991) must also be questioned in regards to its transfer to human spinal models. The study tested the loads on the canine lumbar spine which primarily runs horizontally, this allows for (the canines) quadruped locomotion. Whereas the human spine runs vertically

allowing for bipedal locomotion, this points to different forces acting on canine and human spinal structures, therefore reducing the studies carryover.

2.2.2 Electromyography

Electromyography (EMG) is the technique used to record changes in the electrical potential of the muscle when it is caused to contract by a motor nerve impulse. EMG is used either indwelling (intramuscular) or on the surface of the muscle being recorded (Nigg & Herzhog, 1999).

Estimates of load on the lower back may also be made via electromyography (EMG). This data has been previously been used, in addition to videographic data to input to an anatomically complex, EMG driven lower back model outlined by McGill and Norman, (1986). This model was used to assess muscle use and passive structure loading.

EMG has also been used to predict lower back stability whilst performing various lifting tasks (Nelson, Walmsley & Stevenson, 1995; Cholewicki, Adams & Simons, 2000). These studies have used EMG to measure contractions of the flexor and extensor musculature. Lifting tasks are performed in a dynamic nature, which can cause many different changes in back curvature that will ultimately influence the moments about the low back. This problem has been addressed by combining EMG with other biomechanical techniques (Cholewicki, McGill & Norman, 1995; Mitnitski, Yahia, Newman, Gracovetsky & Feldman, 1998).

EMG allows the researcher to account for the moments contributed by the passive elastic tissues and the inertial segments during lifting. This is thought to reduce error in the reactive moment calculations (Mitnitski et al., 1998). Further, EMG can be used to measure an individuals load share pattern more accurately than an optimisation method for evaluating spinal function in lifting tasks (Potvin & Norman, 1993). This may be important in injury assessment in light of tissue failure in lifting tasks (Cholewicki et al., 1995).

2.2.3 Computer Modelling

Computer modelling is an engineering method that researchers use to calculate loads on the spine. The models are based on numerical data, which is simulated on a geometrical representation of the spines motion segments. Computer tomography scans of the spine are used to give geometrical representations of the motion segment, which increases the accuracy of the computer models. Shirazi-Adl, Ahmed and Shrivastava (1986) used a finite element model to analyse the effects of sagittal plane moments on the lumbar spine. This model allowed the researchers to test for the stress and strain fields that would not be able to be tested in direct measurement methods.

EMG has also been combined with inverse dynamic modelling to create a computer driven model for estimating muscle forces and joint loads (Cholewicki et al., 1995). The EMG assisted model was used to validate predicted tissue loads that were unable to be measured directly on human subjects, whereas an indirect computer modelling approach can help estimate the stress experienced about the segments of the spine without having to resort to invasive methods.

2.2.4 Inverse Dynamics

Back stress can be measured from estimations of the reactive moment to calculate compressive and shear forces typically experienced during lifting tasks involving loads. A compressive force acts on the spine by pushing two adjacent vertebrae together, whereas a shear force creates a sliding of two adjacent surfaces (Kreighbaum & Barthels, 1996). Research has pointed towards the spine being able to tolerate much higher compressive forces than shear forces (Adams, et al., 1994). Cholewicki, McGill and Norman (1991) reported L5/S1 compressive and shear loads of up to 18,449 N and up to 3539 N respectively for the Deadlift exercise performed by powerlifters in the Canadian national championships.

Research has shown that the lumbar vertebrae are subjected to the greatest mechanical loads during lifting (Kumar, 1996). Schipplein, Trafimow, Andersson and Andriacchi (1990) indicated that if a back injury from mechanical causes were to occur during lifting, the likelihood of its occurrence would depend upon the magnitude of the moment acting about the back during lifting.

The moment acting about the lumbar spine can be calculated using Newtonian mechanics. The reactive moments between the segments are summed from starting at one end of the segment chain model. This allows the researcher to conveniently work out the individual reactive forces experienced at the joint by applying Newton's third law, there is an equal and opposite force acting at each (hinge) joint in the chain (Winter, 1990; de Looze, Kingma, Bussmann & Toussaint, 1992).

The inverse dynamic modelling approach is the most practical of all the above methods for estimating back stress in human subjects. The model can be applied in the field via a top-down approach and in a controlled setting such as a laboratory using a force plate for a bottom- up approach. Inverse dynamics can also be combined with the EMG model to estimate the passive tissue contribution to the joint moments (Cholewicki, et al., 1995; Mitnitski et al., 1998).

2.3 <u>Static and Dynamic Inverse Dynamics Modelling</u>

There are two distinct methods used to predict physical stress from lifting tasks, these methods are either termed static or dynamic analyses. The static model predicts stress due to gravity, but ignores the inertial effects due to accelerations of the load and the body. Dynamic modelling however considers both types of effects, which can be an advantage in estimating the reactive moment in lifting tasks, as they are also dynamic in nature.

Static modelling of lifting tasks has revealed an underestimation of forces and moments about the lumbar intervertebral joint of interest when compared to dynamic analysis (McGill & Norman, 1985., Tsuang, Schipplein, Trafimow & Anderson, 1992).

Dynamic modelling requires that the moment of inertia and the angular acceleration of the limbs is calculated, therefore in Olympic lifting where extremely heavy weights are lifted with great speed, the potential for extreme loading on the lower back is obvious.

2.4 Top-down and Bottom-up Inverse Dynamic Models

There are a further two types of models that use inverse dynamics for obtaining estimates of loads applied to the lumbar spine during lifting tasks. These are either conducted in a "bottom-up" or "top-down" manner. The bottom-up analysis requires the use of a force plate to calculate ground reaction forces and the centre of pressure (Winter, 1990). The centre of pressure is a product from the resultant force vector that acts from the subject's bodyweight in a vertical direction. This is noted by a line of action of the force vector passing through a point on the force plate between the subject's two feet (Nigg & Herzog, 1999).

Research conducted by McGaw and DeVita (1995) using the "bottom-up" approach found that a slight shift in the centre of pressure posteriorly, increased both hip and ankle moments while decreasing the moment at the knee. Kabada, Ramakrishnan, Wootten, Gainey, Gorton and Cochran (1989) also found that force ground reaction values used in the bottom up analysis produced a high repeatability in both single day tests (0.953 – 0.997) and between day tests (0.942 – 0.995).

Research conducted by de Looze et al. (1992) showed that there was a high correlation (r = 0.99) for moments about the L5/S1 calculated by the top-down and bottom-up approach. However, it must be noted that de Looze et al. (1992) reported that spinal averaged and peak moments were 4.9 N m (3.6%) and 22.8 N m (10.9%) higher when calculating from the hands rather than calculating from the feet.

The top-down approach does not need to measure ground reaction forces to calculate spinal loads. This gives the top-down approach a field-based advantage as it could be applied more readily to tasks that are based outside facilities that have a force plate installed (de Looze et al., 1992).

2.5 Intra-Abdominal Pressure

Much controversy surrounds intra-abdominal pressure (IAP) and it's role in lifting tasks, such as weight training exercises. IAP is where full inspiration is completed, followed by a forced exhalation against a closed glottis causing a rapid in pressure. This voluntary act performed by the lifter is termed a valsalva manoeuvre (McArdle, Katch & Katch, 1996). Preforming the valsalva manoeuvre causes the viscera to push upward into the diaphragm and downward into the pelvic floor, creating IAP (Chek, 1996).

IAP has been shown to aid the spines stiffening effect, but for IAP to be most effective in stabilising the spine it has been found that it needs to be applied together with the co-activation of the erector spinae musculature (Cholewicki, Juluru & McGill, 1999). It has been also reported that IAP reduces the compressive forces applied to the spinal disc when lifting (Lander, Bates & DeVita, 1986; Morris, Lucas & Bresler, 1961). McGill (1997) explained that IAP contributes to stiffening of the spine to reduce failure or buckling occurring when lifting and not the reduction of spinal compression.

2.5.1 Weight Lifting Belts

Weight belts have been used predominantly by weightlifters and powerlifters however, they are being used more frequently throughout the community to reduce injury while lifting (Zink, Whiting, Vincent & McLane, 2001). Weight lifters and powerlifters predominantly use belts to both reduce injury and to increase lifting performance, through increasing the stability of the spine (Lander, Simonton & Giacobbe, 1990).

The weight belt when used in weight lifting is thought to create a greater stability of the spine through the increase of IAP (Lander, Hundly & Simonton, 1992; Lander et al., 1990). It has been found that IAP rises earlier when wearing a belt compared to not wearing a belt before performing a lift (Zink et al., 2001). However, continual use of the weight belt may contribute to altered neuro-muscular patterns for generating IAP, through the detraining of the transverse abdominous and the internal oblique musculature (Harman et al., 1989; Chek, 1996).

3.0 MATERIALS AND METHODS

3.1 Subjects

Four male nationally ranked weightlifters (mean age = 21.5 years, mean height = 172.2 cm and mean mass = 94.1 kg) were recruited for this study. All subjects were in good physical health at the time of testing and had no prior history of low back pain or other physical impairment. Individual subject data are displayed in Table 1.

Ethical approval was granted by the Edith Cowan University Ethics Committee. To ensure anonymity of all subjects with the write up of this study each subject will be referred to A through to D.

Table 1

Age, height and mass of subjects

	Age (Years)	Height (cm)	Mass (kg)
Subject A	17	178.0	86.6
Subject B	25	170.0	100.1
Subject C	22	174.0	99.2
Subject D	22	167.0	90.2

3.2 Experimental Protocol

To ensure that the experimental protocol replicated real competition and training conditions, the subjects were given access to a standard warm up. Rest periods between the lifts were between two and five minutes for assistance exercises and five and seven minutes for the Olympic lifts (Fleck & Kraemer, 1997; Bompa, 1983; Ozolin, 1971). This allowed sufficient rest between each set of exercises to prevent unnecessary lower back injury and help maximise lifting performance of the subjects.

Each subject performed the Olympic lifts (Snatch and Clean) at a near one repetition maximum, followed by the four assistance exercises at an intensity typically performed during a routine training session. The assistance exercises that were performed were the CPD, BOR, the RDL and the GM. This constituted 24 trials in total (4 subjects x 6 lifts/subjects). Subjects performed the snatch and clean in sequence, this was followed by the assistance exercises being tested in a randomised order. Mass on the bar was recorded for each trial. The analysis of all lifts was conducted using a top-down inverse dynamics model.

3.3 Examination of Video Based Digitisation to Calculate Acceleration Data in Lifting

The purpose of the pilot study was to assess the reliability of measuring the acceleration-time data about the knee, hip and the bar, using the Ariel Performance Analysis System (APAS). Acceleration data is needed to be accurate so the estimations of stress acting on the lumbar spine are calculated using Newtonian mechanics, are accurate. This is needed because if the acceleration data is incorrect the summed reactive moments will be erroneous.

The data for this study was obtained from standard video footage taken at the 2001 Weightlifting Western Australian Telstra masters and seniors competition. One male subject who was nationally ranked was marked at two points on the right side of the body at predetermined joint locations using texture outline prior to testing. The landmarks that were identified were the knee, hip and the centre of the bar.

A video camera recorder operating at 50 fields per second filmed a Snatch lift from a sagittal view as the lift was assumed to be symmetrical. The major knee, hip and centre of the bar were digitised four times over the course of the first pull in the snatch lift using the APAS. Put simply, this system converts video images into a computer 'pixel map' and the location of selected points are identified as an x-y pixel location. The conversion of image size to real world size was done by digitising an object of known size prior to filming the trials of interest. The data was smoothed using a digital filter at a cut-off frequency of 5 Hz.

3.3.1 Results of APAS Pilot Test

A comparison of acceleration data for trials one to four that were digitised using the APAS system are shown for the Knee x-axis (Figure 1), Hip x-axis (Figure 2), Bar x-axis (Figure 3), Knee y-axis (Figure 4), Hip y-axis (Figure 5), the Bar y-axis (Figure 6).

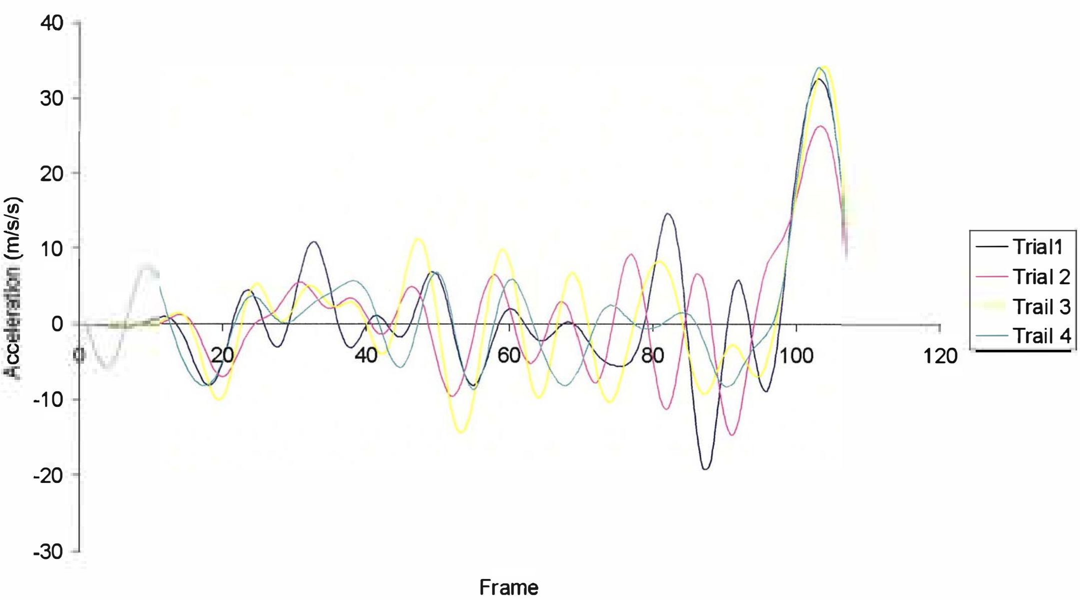

Figure 1. Knee x-axis acceleration data using APAS in four trials.

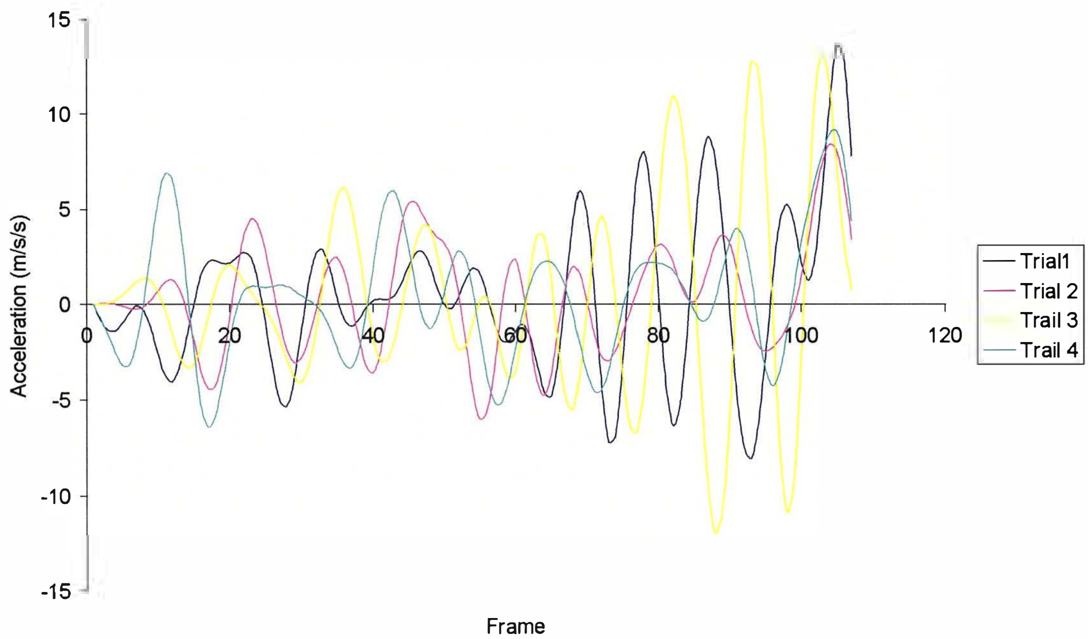

Figure 2. Hip x-axis acceleration data using APAS in four trials.

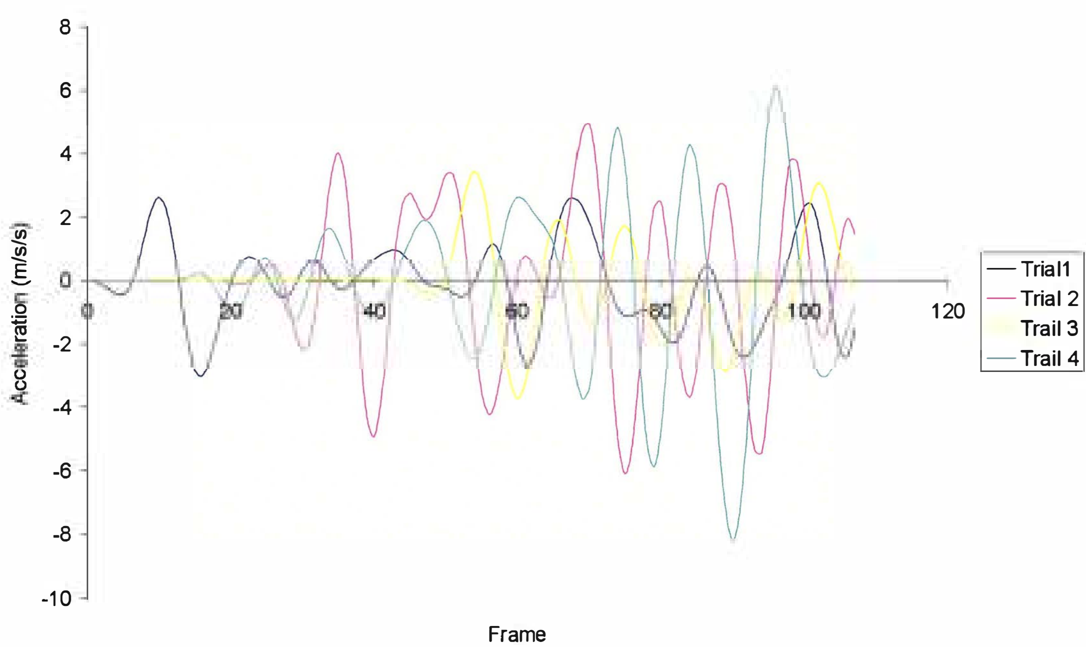

Figure 3. Bar x-axis acceleration data using APAS in four trials.

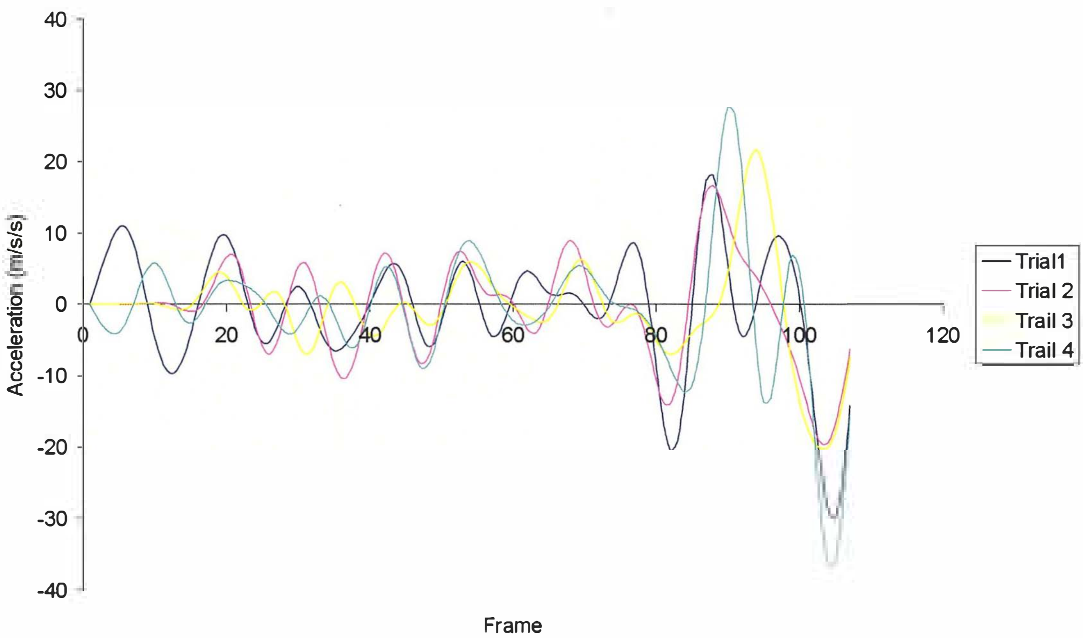

Figure 4. Knee y-axis acceleration data using APAS in four trials.

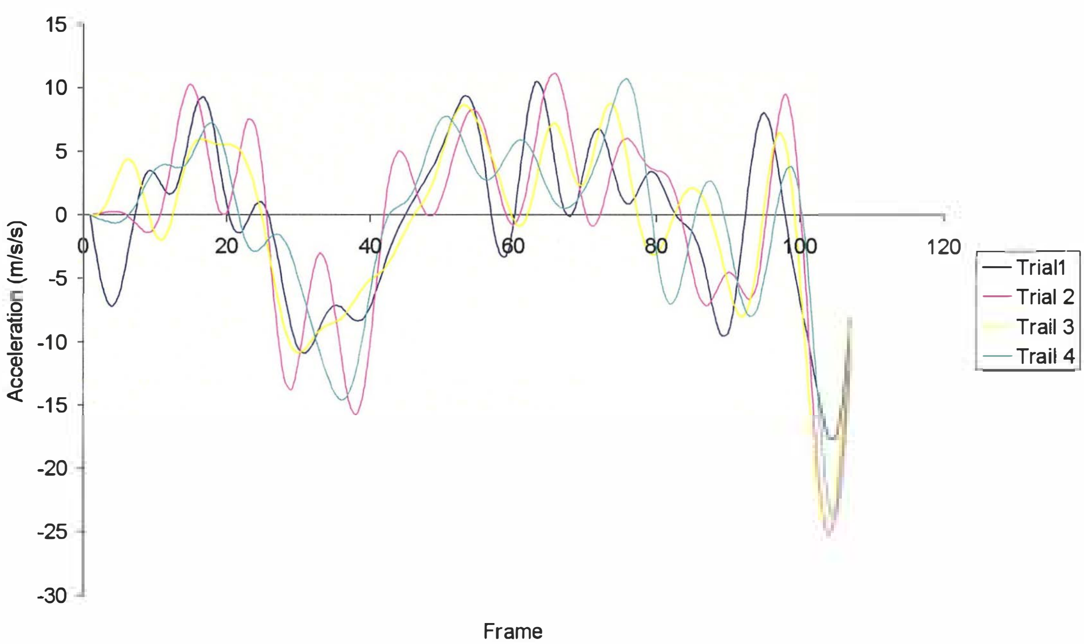

Figure 5. Hip y-axis acceleration data using APAS in four trials.

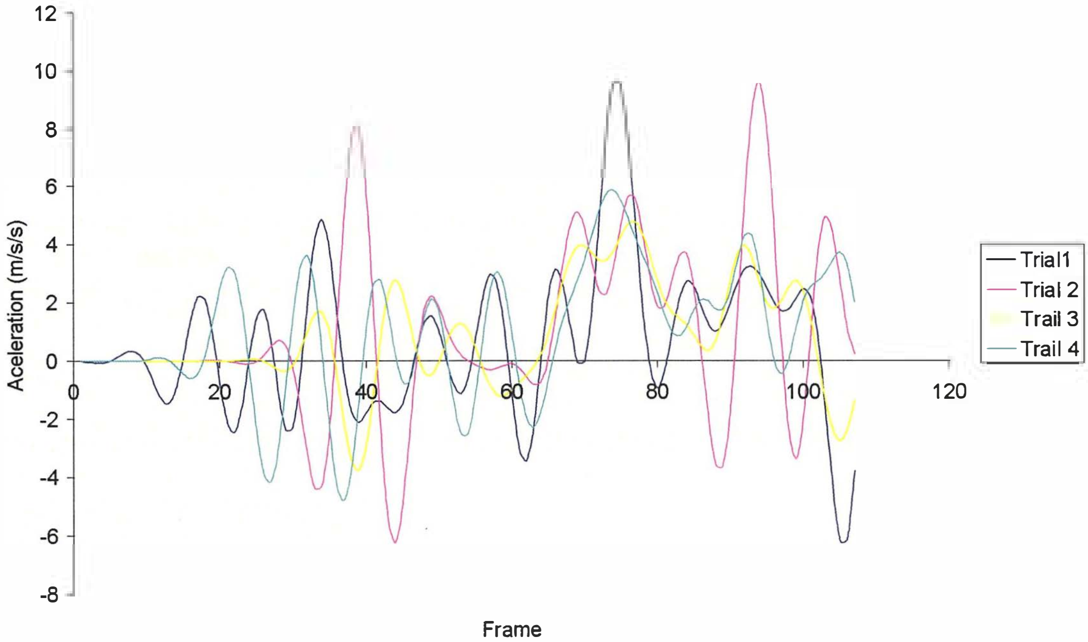

Figure 6. Bar y-axis acceleration data using APAS in four trials.

The corresponding values of the adjusted coefficient of multiple determination (CMD) depicting the similarity between waveforms for acceleration data is shown in Table 2 below.

Table 2

The coefficient of multiple determination (CMD) for acceleration data over four trials using the APAS digitising system

Acceleration	Mean CMD over four trials
Knee x- axis	0.513
Knee y- axis	0.903
Hip x- axis	0.857
Hip y- axis	0.766
Bar x- axis	0.300
Bar y- axis	0.586

3.3.2 Discussion of APAS Pilot Test

Acceleration data was derived from four digitised trials using the APAS. The repeatability of acceleration in this study was represented by the similarity between the waveforms of trial one to four, which was depicted by the CMD. The coefficient is the number that represents the similarity of the acceleration data waveforms across repeated trials. The coefficient is always between 0 and 1, the closer the CMD is towards 1 the higher the correlation, or in this case, repeatability of the APAS method to calculate acceleration (Kabada et al., 1989).

Table 2 shows the CMD for acceleration data in repeated trials using the APAS. The CMD for the knee acceleration in the y- axis showed the highest repeatability, whereas the bar acceleration in the x- axis showed the lowest repeatability. The range of the CMD over the four trials was 0.300 to 0.903, while the mean of the CMD was 0.654. This shows a low repeatability for deriving acceleration data from the use of the APAS.

These findings show that acceleration data derived through the use of the APAS is not reliable for analysis of repeated measurements. However, it should be noted that research has shown APAS to accurately and consistently obtain static linear and angular measurements (Klein & DeHaven, 1995).

3.4 Data Collection

Each subject was marked at nine points on the right side of the body at predetermined joint locations using reflective marker balls prior to testing. The landmarks that were identified were shoe tip, heel, ankle, knee, hip, seventh cervical vertebra (C7), shoulder, elbow and the centre of the bar. The marking scheme is shown in Figure 7 below.

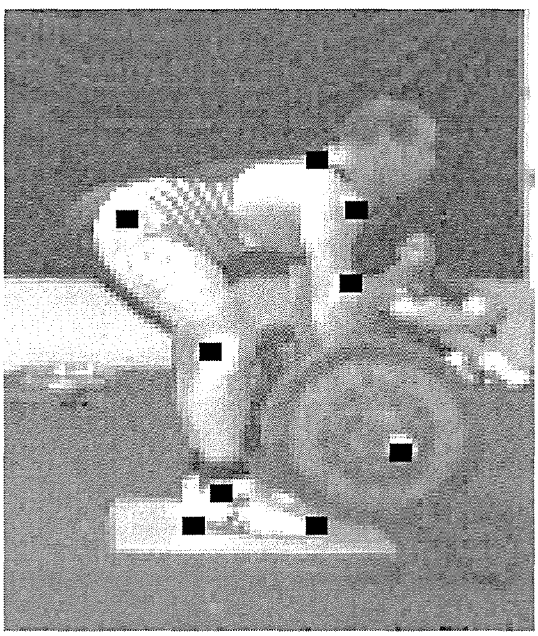

Figure 7. Anatomical landmarks.

To provide known 3-D control points, a calibration frame with dimensions of approximately 2.0 m x 2.0 m x 2.5 m was centred over the desired lifting area. The control point configuration satisfied the condition that these points should surround the activity to avoid errors associated with extrapolation to unknown points outside the control point distribution space (Wood & Marshall, 1986; Challis & Kerwin, 1992).

Subjects were filmed performing the Olympic lifts and the assistant exercises by a five camera opto-electronic Motion Analysis System (Motion Analysis Corporation, 2000) operating at 120Hz. The cameras were positioned so the locus of movement of the major joint markings on the body were central to the photographic plane of all cameras, and such that at least two cameras could track these landmarks throughout the lifting movement. Data was collected for five seconds over which time the exercises were performed.

Following the identification of joint markers, video records were automatically digitised and the 3-D points reconstructed using EVA 6.0 software (Motion Analysis Corporation, 2000). Data was then saved to a file for later analysis.

3.4.1 Model Description and Calculations

Kinetics about the L5/S1 joint were calculated via a top-down link segment model. The model was a nine-segment inverse dynamics model similar in many respects to that described by Brown and Abani (1985). The exception with this model was that it divided the trunk into three segments as described later in this section.

The top-down model was dynamic in nature and was based upon Newtonian equations of motion as follows: -

$$F_X = m.a_X$$
$$F_Y = m.a_Y$$
$$T = I\alpha$$

The assumptions implicit in this model were: -

- The lifter and bar systems were bilaterally symmetrical.
- Body segments were treated as rigid bars.
- Joints were frictionless and pinned.
- The shoulder/C7 connection was treated as a massless segment, which transfers force and torque.
- Mass of the hands was added to the bar mass.
- There was no Intra-abdominal Pressure (IAP) contribution (Cholewicki et al. 1991)
- The head was considered to be in line with the trunk and had a set length of 0.248m (McConville, Churchill, Kaleps, Clauser & Cuzzi, 1980).
- Erector Spinae force was considered to be from a single equivalent muscle model with 6 cm moment arm and acting at 5^{o} to the compressive axis of the spine (Cholewicki et al. 1991).

Due to the dynamic nature of these calculations, segmental moment of inertia data had to be calculated. Segment anthropometric and moment of inertia data was taken from deLeva (1996). These figures were derived from those produced by Zatsiorsky and Seluyanov (1983) and makes it more user friendly due to it's similarity to Dempster's data. (ie for use in calculations). This data is shown in Table 3 below.

Table 3

Anthropometric data used in the top-down link segment model

Segment	Origin	Other	Length (mm)	Norm Length	Norm Mass	2-D Mass	CM Norm	K Norm
Forearm	Elbow	Wrist	268.9	0	0.016	0.032	0.457	0.265
Upper Arm	Shoulder	Elbow	281.7	0	0.027	0.054	0.577	0.269
Head	Cervicale	Vertex	242.9	0	0.069	0.069	0.499	0.315
UPT	Cervicale	Xiphoid	242.1	0.401	0.156	0.156	0.507	0.320
MPT	Xiphoid	Omphalion	215.5	0.357	0.163	0.163	0.450	0.383
LPT	Omphalion	Mid Hip	145.7	0.241	0.112	0.112	0.611	0.551
Thigh	Hip	Knee	422.2	0	0.142	0.284	0.409	0.329
Shank	Knee	Ankle	434.0	0	0.043	0.086	0.446	0.249
Foot	Heel	Longest Toe	258.1	0	0.014	0.028	0.442	0.245

Notes: UPT, MPT and LPT represent the upper middle and lower portion of the trunk respectively. Norm stands for normalised segment length. CM and K represent Centre of Mass and Radius of Gyration respectively.

It should be noted that not all points defined by this model were actually digitised. For example, the head was defined by the cervicale (C7) and the vertex. The vertex was not digitised but the line of the trunk and set length (0.248 m) was used to define the vertex's position. Furthermore, only the cervicale (C7) and the mid hip were digitised in defining UPT, MPT and LPT. Once the segment length was calculated the positions of the xiphoid and omphalion were calculated by knowing the length between C7 and the mid hip and knowing segment angle defined by these positions.

For each of model's segments, the Moment of Inertia about the centre of mass has to be calculated via the following equation: -

$$I_o = m.(l.k)^2$$

where I_o – Segmental Moment of Inertia ($kg.m^2$)
m – Segment Mass (kg)
l – Segment Length (m)
k – Radius of Gyration (% of length)

For each of the defined segments, F_X, F_Y and Torque was calculated. This was necessary, as calculations for the subsequent segment required these data. The L5/S1 joint was located using the data of Nemeth and Ohlsen (1989) who found using CT scans that the L5/S1 joint was located 6.1% of standing height above the mid hip. The derivation of the L5/S1 compressive and shear forces was performed as described below.

The sacral cutting angle (angulation of the surface of the vertebrae) was necessary to convert the F_X and F_Y forces into components of compressive and shear and was calculated as follows (Chaffin & Anderson, 1991): -

$$\alpha = -17.5 - 0.12T + 0.227K + 0.0012\,TK + 0.005T^2 - 0.0007K^2 + 40$$

where α - Sacral cutting angle (°)

T – Trunk segment angle with respect to the vertical (°)

K – Knee angle (°)

The moment arm of the erector spinae group was 6 cm and the erector spinae line of action was set to be 5° with respect to the compressive axis of the spine (Cholewicki et al. 1991). The Erector Spinae Force (F_{ES}) was derived from the L5/S1 torque via the following equation: -

$$F_{ES} = T_{L5/S1} \,/\, (0.06 \cos 5°)$$

The L5/S1 compressive and shear forces (F_C and F_S respectively) were determined by the following equations: -

$$F_C = F_{ES} + F_Y \cos \alpha - F_X \sin \alpha$$

$$F_S = F_X \cos \alpha + F_Y \sin \alpha$$

3.5 Data Analysis

The above equations were included into a customised software program written in LabVIEW Version 5.1 (National Instruments, USA). Raw displacement data from the Motion Analysis System was saved to a file for input into the LabVIEW program.

This above program calculated all segment angles, segment inertia data as well as acceleration data required for the inverse dynamic analysis.

End point and segment acceleration data were calculated via finite differences with the digitised displacement acting as the inputs (Winter, 1990). The formula for end point acceleration data was: -

$$a_i = s_{(i+1)} - 2s_{(i)} + s_{(i-1)} / (\Delta t)^2$$

where:-

a – acceleration (m/s^2)

s – displacement (m)

t – time (s)

I – i^{th} sample

Data was then imported into an Excel file, which was then manually sorted for peak moments, peak compression and peak shearing forces for each lifter in all six lifts.

Normalisation of Moment, Compressive and Shear Force data was calculated to account for each subject's differing body mass and mass lifted on the bar for each individual lift. Normalisation of all variables were calculated to reduced inter-subject differences, Plamondon, Gagnon and Desjardins (1995) reported that the top-down model such as this model adopted for this study, the hands and segmental weights contributed to 70% of the net reactive moments at the L5/S1 joint. Therefore by accounting for the individual segment mass above the L5/S1 joint along with the Mass lifted, the normalisation of the values allows a more accurate method of comparing between the lifts.

Normalisation of the Moment data was calculated via the formula: -

$$\text{Normalised Moments} = \frac{\text{L5/S1 Moments}}{(0.474 \times \text{Subject Mass}) + \text{Bar Mass}}$$

A similar procedure was used to calculate the Compressive and Shear Force data. The units derived from the normalisation equation are arbitrary units.

3.6 Statistical Analysis

Dependant variables for the study were the L5/S1 moments, compressive and shear forces. The independent variables for this study are the exercise type, which is divided into six levels as follows:

1) Snatch 2) Clean, 3) CPD, 4) BOR, 5) RDL and 6) GM.

A One-Way ANOVA with repeated measures was performed at an alpha level of $p=< 0.05$ through the use of the computer software package Statistical Package for Social Sciences (SPSS). Post-hoc differences between means were calculated via Least Squared Differences.

4.0 RESULTS

4.1 Load Lifted

Each of the four weightlifters individually set the mass on the bar to be lifted for each exercise during testing. The Olympic lifts (Snatch and Clean) were instructed to be as close to the lifter's one repetition maximum (1RM), while the assistance exercises were set at the lifter's three-repetition maximum (3RM). The Olympic lifts were set at a 1 RM to simulate competition and the assistant exercises were set at a 3RM to simulate typical training loads. The mass lifted by each lifter can be seen in Figure 8 below.

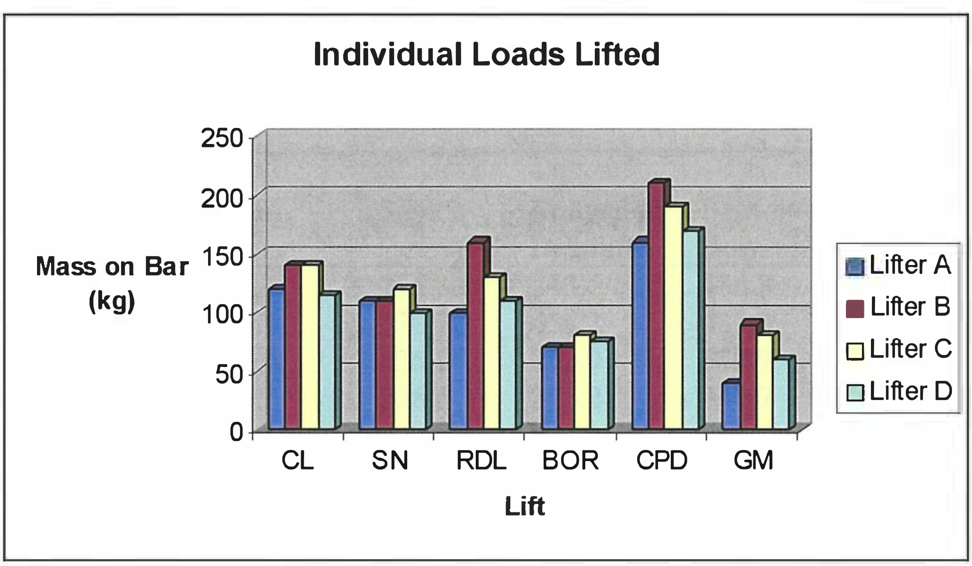

Figure 8. Loads lifted (kg) by each lifter for six lifts. CL = Clean, SN = Snatch, RDL = Romanian Deadlift, BOR = Bent-over Row, CPD = Clean Pull Deadlift, GM = Good Morning.

4.2 L5/S1 Moments

Table 4 presents data for the peak moments of force acting about the L5/S1 intervertabral joint for each lifter and also the total group mean in all six lifts. The highest group means ranged from 340.5 N·m for the to 495.9 N·m. Further, there was a significant difference ($p<0.05$) between the Snatch when compared to the Clean and significant differences ($p<0.05$) were also found when comparing the CPD to the Snatch, RDL and the GM.

Table 4

Mean peak moments of force (N·m) acting about the L5/S1 intervertebral joint for each lift

	Clean	Snatch	Romanian Deadlift	Bent-over Row	Clean Pull Deadlift	Good Morning
Lifter A	361.1	255.3	243.6	436.8	426.1	298.4
Lifter B	478.5	370.7	458.2	483.3	545.5	438.4
Lifter C	583.6	425.8	353.9	372.7	533.1	379.3
Lifter D	356.6	328.6	306.2	346.7	478.8	301.6
Group Mean	444.9	345.1[a]	340.5	409.9	495.9[b,c,d]	354.4

[a] denotes a significant difference when compared to the Clean ($p<0.05$).
[b] denotes a significant difference when compared to the Snatch ($p<0.05$).
[c] denotes a significant difference when compared to the Romanian Deadlift ($p<0.05$).
[d] denotes a significant difference when compared to the Good Morning ($p<0.05$).

4.2.1 Normalised L5/S1 Moments

Table 5 presents data for the normalised moments to body weight above the L5/S1 joint and mass on the bar for each lifter and also the group means for all six lifts. Mean figures for normalised moments ranged from 0.21 for the CPD to 0.34 for the BOR. There were significant differences (p<0.05) when comparing the Clean against the RDL, BOR and the GM. Significant differences (p<0.05) also existed when comparing the Snatch to the RDL, BOR and the GM.

Table 5

Normalised moments to body weight above L5/S1 and bar mass acting on the about the L5/S1 intervertabral joint for each lift

	Clean	Snatch	Romanian Deadlift	Bent-over Row	Clean Pull Deadlift	Good Morning
Lifter A	0.22	0.16	0.16	0.37	0.20	0.34
Lifter B	0.26	0.24	0.22	0.42	0.21	0.32
Lifter C	0.31	0.25	0.20	0.29	0.22	0.30
Lifter D	0.22	0.22	0.19	0.28	0.22	0.28
Group Mean	0.25	0.22	0.19[a,b]	0.34[a,b]	0.21	0.31[a,b]

[a] denotes a significant difference when compared to the Clean (p<0.05).
[b] denotes a significant difference when compared to the Snatch (p<0.05).

4.3 L5/S1 Compressive Force

Table 6 presents data for the peak compressive force (N) acting on the L5/S1 intervertebral joint for each lifter and also the group means for all six lifts. Mean compressive forces ranged from 6700.8 N for the RDL to 9829.9 N for the CPD. There were significant differences ($p<0.05$) when comparing the Clean against the Snatch and the GM. Significant differences ($p<0.05$) were also found when comparing the Snatch, RDL, BOR and GM with the CPD.

Table 6

Mean peak compressive force (N) acting on the L5/S1 intervertabral joint for each lift

	Clean	Snatch	Romanian Deadlift	Bent-over Row	Clean Pull Deadlift	Good Morning
Lifter A	7077.0	5277.0	4913.1	8232.6	8737.0	5564.9
Lifter B	9453.0	7365.6	8667.0	8975.5	10850.0	8263.6
Lifter C	10717.0	8787.5	7089.6	7014.8	10396.0	7243.9
Lifter D	7028.4	6648.0	6134.0	6525.5	9336.6	5778.6
Group Mean	8568.7	7019.5[a]	6700.8	7687.1	9829.9[b,c,d,e]	6712.7[a]

[a] denotes a significant difference when compared to the Clean ($p<0.05$).
[b] denotes a significant difference when compared to the Snatch ($p<0.05$).
[c] denotes a significant difference when compared to the Romanian Deadlift ($p<0.05$).
[d] denotes a significant difference when compared to the Bent-over Row ($p<0.05$).
[e] denotes a significant difference when compared to the Good Morning ($p<0.05$).

4.3.1 Normalised L5/S1 Compressive Forces

Table 7 presents data for the L5/S1 compressive forces normalised to body weight and mass on the bar for each lifter and also the total group mean in all six lifts. Mean figures for normalised compression ranged from 3.92 for the RDL to 5.97 for the GM. There were significant differences ($p<0.05$) when comparing the Clean against the RDL, and when comparing the BOR against the RDL and the CPD. A significant ($p<0.05$) difference also existed when comparing the GM to the CPD.

Table 7

Normalised compressive force to body weight above L5/S1 and bar mass acting on the L5/S1 intervertabral joint for each lift

	Clean	Snatch	Romanian Deadlift	Bent-over Row	Clean Pull Deadlift	Good Morning
Lifter A	4.31	3.42	3.40	7.15	4.29	6.49
Lifter B	5.14	4.77	4.26	7.80	4.30	6.13
Lifter C	5.83	5.35	4.07	5.61	4.46	5.80
Lifter D	4.41	4.60	3.97	5.44	4.38	5.49
Group Mean	4.92	4.53	3.92[a]	6.50[b]	4.35[c]	5.97[d]

[a] denotes a significant difference when compared to the Clean ($p<0.05$).
[b] denotes a significant difference when compared to the Romanian Deadlift ($p<0.05$).
[c] denotes a significant difference when compared to the Bent-over Row ($p<0.05$).
[d] denotes a significant difference when compared to the Clean Pull Deadlift ($p<0.05$).

4.4 L5/S1 Shear Force

Table 8 presents data for the peak shear force acting on the L5/S1 intervertabral joint for each lifter and also the group means for all six lifts. Mean shear forces ranged from 1064.9 N for the Snatch to 2338.5 N for the CPD. There were significant differences ($p<0.05$) when comparing the Clean against the RDL and the CPD, the GM showed a significant difference ($p<0.05$) when compared to the CPD. A significant ($p<0.05$) difference also existed when comparing the Snatch to the RDL, BOR and the CPD.

Table 8

Mean peak shear force (N) acting on the L5/S1 intervertabral joint for each lift

	Clean	Snatch	Romanian Deadlift	Bent-over Row	Clean Pull Deadlift	Good Morning
Lifter A	1012.6	1032.7	2026.7	1234.2	1304.8	861.3
Lifter B	1252.2	957.9	2371.8	1183.4	3136.9	1474.5
Lifter C	1438.9	1223.1	2240.0	1643.3	2587.9	1423.0
Lifter D	998.3	1046.0	1209.3	1529.4	2324.5	1152.5
Group Mean	1175.5	1064.9	1961.9[a,b]	1397.6[b]	2338.5[a,b]	1227.8[c]

[a] denotes a significant difference when compared to the Clean ($p<0.05$).
[b] denotes a significant difference when compared to the Snatch ($p<0.05$).
[c] denotes a significant difference when compared to the Clean Pull Deadlift ($p<0.05$).

4.4.1 Normalised L5/S1 Shear Forces

Table 9 presents data for the normalised shearing force to body weight and mass on the bar for each lifter and also the groups mean for all six lifts. Mean figures for normalised shearing force ranged from 0.67 for the Snatch to 1.16 for the BOR. There were significant differences ($p<0.05$) when comparing the Clean against RDL, BOR and the GM. A significant difference ($p<0.05$) also existed when comparing the Snatch to the RDL, BOR and the GM.

Table 9

Normalised shear force to body weight above L5/S1 and bar mass acting on the L5/S1 intervertabral joint for each lift

	Clean	Snatch	Romanian Deadlift	Bent-over Row	Clean Pull Deadlift	Good Morning
Lifter A	0.61	0.66	1.40	1.07	0.64	1.00
Lifter B	0.68	0.62	1.16	1.02	1.24	1.09
Lifter C	0.78	0.74	1.28	1.31	1.11	1.13
Lifter D	0.62	0.72	0.78	1.27	1.09	1.09
Group Mean	0.67	0.68	1.15[a,b]	1.16[a,b]	1.02	1.07[a,b]

[a] denotes a significant difference when compared to the Clean ($p<0.05$).
[b] denotes a significant difference when compared to the Snatch ($p<0.05$).

5.0 DISCUSSION

5.1 Introduction

This study has aimed to analyse the suitability of the assistance exercises for the low back to that of the Olympic lifts, they being the Snatch and the Clean. It was hypothesised that the assistance exercises (BOR, GM, RDL and CPD) would show greater peak L5/S1 moments, compressive and shear forces than that displayed for the two Olympic lifts.

The top-down model used in this study could not account for the eccentric phase of lifting and this is a limitation of the model (Kingma, Baten, Dolan, Toussaint, Diee, de Looze and Adams, 2001). EMG may have been a more appropriate method to examine the eccentric phase of lifting. The eccentric (lowering) phase of lifting tasks has been estimated to account for higher compressive forces and lower shear forces acting about the low back (Davis, William & Waters, 1998).

5.2 L5/S1 Moments

The hypothesis postulated that all assistance exercises would display a greater peak moment about the L5/S1 than that of the two Olympic lifts (Snatch and Clean). Results showed that only the CPD (assistance exercises) showed significantly higher ($p<0.05$) peak moments when compared to that of the Snatch (Olympic lifts). The Clean displayed the second highest peak moment. This indicated that all assistance exercises except for the CPD displayed lower peak moments than that of the clean, resulting in the rejection of this hypothesis.

The study showed that all lifts from the floor displayed peak moment values just off the floor or in the first pull (bar to knee level), which supports research conducted on the pull in Weightlifting by Enoka (1979). Brown and Abani (1985) further explained that at lift-off in the Deadlift all subjects studied displayed the largest moment arms from the hip to the bar (which is the dominant mass) which produces torque about the L5/S1 joint. Cholewicki et al. (1991) reported peak moments of 538.8 N·m in the Deadlift for a load on the bar of 190 kg, which compares closely with results found in this study with the CPD of 495.9 N·m with a load of 182.2 kg.

When comparing the values for the peak moments, the CPD's value was significantly higher ($p<0.05$) than that of the Snatch, RDL and GM exercises. This would be due to the direct relation to this lift having more (mean) mass on the bar when compared to above-mentioned lifts (Cholewicki et al., 1991). However, it was found that the Clean and BOR lifts displayed similar peak moments to that of the CPD with much less mass on the bar, especially in the BOR exercise.

The mean load lifted for the BOR was 73.3 kg, which resulted in producing peak moments of 409.9 N·m about the L5/S1 joint compared to 495.9 N·m with a load of 182.2 kg for the CPD. The difference in loads lifted and moments that were produced between the BOR and the CPD may have been a result of the larger moment arm of the BOR when compared to that of the CPD. This can be shown in Figure 9 below.

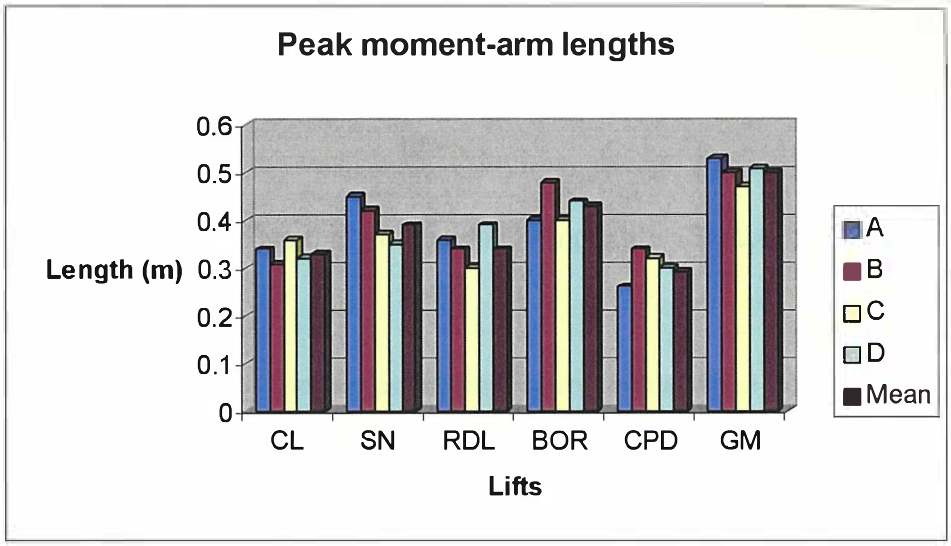

Figure 9. Peak moment arm lengths (m) displayed for each of the six lifts. CL = Clean, SN = Snatch, RDL = Romanian Deadlift, BOR = Bent-over Row, CPD = Clean Pull Deadlift, GM = Good Morning.

When completing the CPD the athlete pulls the bar closer to the body than when completing the BOR. Consequently, the moment arm of the CPD is shortened throughout the entire lift compared to that of the BOR. The BOR also requires the lifter to create high reactive moments at the L5/S1 intervertebral joint to keep the spine in a horizontal (neutral) position, this position is necessary to be able to perform the lift correctly.

Examination of the peak moments displayed in the Clean showed similar values to that of the CPD and the BOR. This may be a result of the higher velocity nature of the Clean when compared to that of the CPD. Hall (1985) found peak moments in the Clean and Jerk resulted in lifts with a higher percentage of the lifter's one-repetition maximum and that were performed at faster velocities when compared to slower velocity trials.

5.2.1 Normalised L5/S1 Moments

Upon examination of the differences between the normalised L5/S1 moments, it was found that all of the assistance exercises, except for the CPD displayed significant differences ($p<0.05$) to that of the two Olympic lifts (Snatch and Clean).

The BOR displayed the largest normalisation value when compared to that of the other lifts and this was followed by the GM, Clean, Snatch, CPD and the RDL showing the lowest value. The BOR and the GM may have resulted in higher values due to them both having longer moment arms when compared to the other lifts. A larger moment arm would therefore require a higher extensor force to maintain position for example the BOR or aid in completing the lift for example the GM. Furthermore, both the BOR and GM lifts are performed with minimal utilisation of the lower extremity, which would require the L5/S1 to produce higher reactive moments to complete the lifts. These above results support findings that lifts that primarily use the back, produce greater moments than lifts involving the lower extremities such as the squat lift (Lestinnen, Stalhammer, Kuorinka & Troup, 1983).

Schipplien et al. (1990) reported that the upper body always contributed more to the L5/S1 moment than did the weight (5 kg - 25.5 kg), the study also indicated that flexed positions produced higher moments at lift-off compared with the average moments for the entire lift. Although the mass on the bar for this study was far higher, it demonstrates the importance of normalising data in lifting tasks, as it accounts for upper body mass as well as the mass on the bar.

The low normalisation moment values displayed by the RDL may be a result of this study having to focus on the concentric phase of the lift only. It is estimated that the RDL would produce higher stress on the erector spinae for the eccentric phase (Kingma et al., 2001), as a large flexor moment would be present with a large mass on the bar. This would require a large reactive extensor moment to eccentrically control the lowering of the weight.

5.3 L5/S1 Compression Force

The hypothesis in this study stated that the assistance exercises would show greater peak L5/S1 compressive forces than that displayed for the two Olympic lifts. Statistical analysis of results demonstrated the CPD as the only assistance exercise to show significantly higher ($p<0.05$) compressive forces about the L5/S1 when compared to the Snatch in the Olympic lifts. Results showed that the Clean displayed the second highest value for compressive forces, therefore all assistance exercises except the CPD displayed lower compressive forces about the L5/S1 than that of the Clean, resulting in the rejection of the hypothesis.

Compression force acts on the spine by applying stress perpendicular to the surface of a vertebra that acts to compress the intervertebral disc towards the underlying vertebra. Ultimate compression strength in cadaver models, has been estimated at 4360 N (Jager & Luttmann, 1989), however Hsiang et al. (1996) reported that anatomical differences in the low back may enable individuals to exceed this value in real life subjects.

Granhed, Johnson and Hansson, (1986) reported compressive forces that acted on L3 ranged from 18400 – 36200 N for the Deadlift with loads on the bar ranging from 212 – 335 kg. Granhed et al. (1986) also found that when two lifters with different moment arm lengths (L3 to bar), lifted the same load compressive forces varied by almost 1000 N.

The CPD displayed the highest compression force on the L5/S1 intervertebral joint with a mean value of 9829.9 N. Cholewicki et al. (1991) reported an average L4/L5 compressive force of 9316.0 N using a quasi-static model in the Deadlift for a bar mass of 190 kg. McGill and Norman (1985) reported that static modelling of lifting tasks underestimated forces and moments about the lumbar intervertebral joint. As this study utilised a dynamic model, higher values would be expected in this study with everything else being equal.

When comparing L5/S1 compression forces the CPD showed significantly higher ($p<0.05$) values than that of the Snatch, RDL, BOR and GM. This may have resulted from higher loads being lifted in the CPD, when compared to the other lifts tested in this study. Further, it was also found that the peak moment arm for the CPD (0.29 m) was the shortest when compared to the other lifts in the study (Figure 8).
This may point to the line of pull and the magnitude of the mass on the bar to be the main contributors of compressive force on the L5/S1 joint. Figure 10 shows the moment arm from L5/S1 during the CPD below.

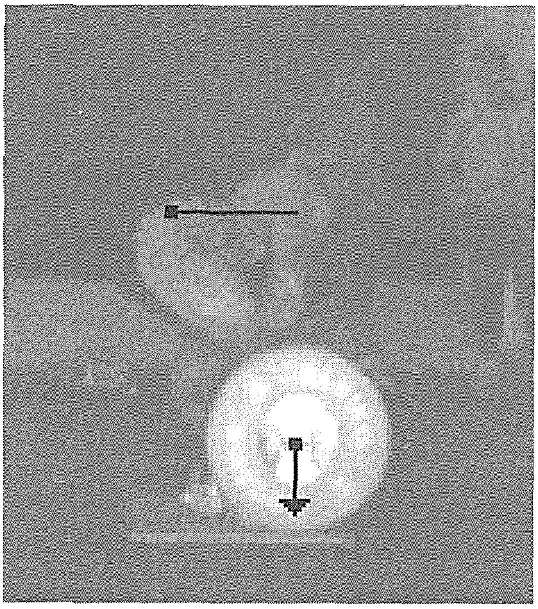

Figure 10. Clean Pull Deadlift performed during the study with moment arm acting from L5/S1 to the line of action of mass on bar (180 kg).

It was also found that the Clean displayed significantly higher compression forces when compared to the Snatch and GM. The GM may have shown a significantly lower compressive force than that of the Clean due to the lower mass on the bar and the slower velocity compared to the Clean. However, the significantly lower compressive force of the Snatch when compared to that of the Clean may be due to the large differences in load lifted rather than velocities lifted and similar moment arms.

5.3.1 Normalised L5/S1 Compressive Forces

Upon examination of the differences between the normalised L5/S1 compressive forces, it was found that the BOR and GM displayed significantly higher ($p<0.05$) values than that of the CPD and had a higher value than all other lifts tested. This may point to the moment arm from the L5/S1 to the bar in addition to trunk position being the major contributor to the higher values displayed by the BOR and GM.

The GM had a peak moment arm of 0.50 m, which was present between 90^0 and 110^0 of trunk incline, which was just after the subject reached the bottom position in the eccentric phase of the lift. The BOR had a peak moment arm of 0.43 m, which was present when the subject had close to full extension of the arms. This was while trunk angle of between 90^0 and 100^0 was maintained. The above peak moment arms for the BOR and GM was much higher than 0.29 m displayed for the peak moment arm of the CPD.

The BOR and the GM also requires the trunk to maintain a predominantly flexed position. This greatly increases the reactive moments needed to counter the large flexor moments at the L5/S1 due to the external load and it's distance from the L5/S1 joint (Cholewicki et al. 1991; Lee & Chen, 2000; Harman, 1994).

Research has shown that as the load becomes heavier in lifting tasks, contribution from the legs tend to decrease which increases the effort required by the spinal extensors (Schipplein et al., 1990; Bejjani, Gross & Pugh, 1984). Stobbe (1982) explained that the erector spinae musculature has a larger moment arm than that of the quadriceps, therefore giving the lifter a mechanical advantage in producing the required extensor moments for

lifting heavy loads. This may point to why the GM and BOR both displayed the highest compression force values once normalised, as they both do not use the legs (knee) to aid in lifting the bar.

5.4 <u>L5/S1 Shear Force</u>

The hypothesis postulated that the assistance exercises would show greater peak L5/S1 shear forces than that displayed for the two Olympic lifts. Results for shear forces indicated that the RDL and CPD both showed significantly higher ($p<0.05$) shear forces than that displayed by the Snatch and Clean. The BOR showed significantly higher ($p<0.05$) L5/S1 shear forces than that of the Snatch lift only. Therefore, resulting in the hypothesis being rejected. However, the assistance exercises were found to display a trend of non significant ($p<0.05$) higher shear forces than that displayed by the two Olympic lifts.

Shear force acts on the spine by applying a load parallel to the surface of the vertebrae structure. This can cause deformation to structures such as the facet joints and the intervertabral disc, if the muscles are not able to counter these forces with reactive torques that will enable appropriate stabilisation to occur. Kreighbaum et al. (1996) indicated that the magnitude of shear forces acting on the spine are caused by the mass that is lifted, the distance that the weight is held from the vertebral column (moment arm) and the amount of trunk flexion while lifting. Cholewicki et al. (1991) further explained that the length of the torso will greatly influence the length of the moment arm about the low back, which will increase the moment necessary to support the weight when lifting.

van Dieen, van der Burg, Raaijmakers and Toussaint (1998) reported that shear forces occurred about the spine mainly as a result of gravity acting on the upper body and that of muscular forces. Further, the moment arm from the L5/S1 intervertebral joint to that of the force vector of the bar mass would greatly influence the magnitude of the shear force acting on the L5/S1

Shear forces about the L5/S1 for the six exercises ranged from 1064.9 to 2338.5 N. The RDL displayed significantly higher ($p<0.05$) shear forces acting about the L5/S1 when compared to that of the Snatch and Clean. Typically, the lifts that averaged more mass on the bar displayed higher shear forces, this is shown below for the averaged lifts (Snatch, Clean, GM, BOR, RDL and CPD) in Figure 11 below.

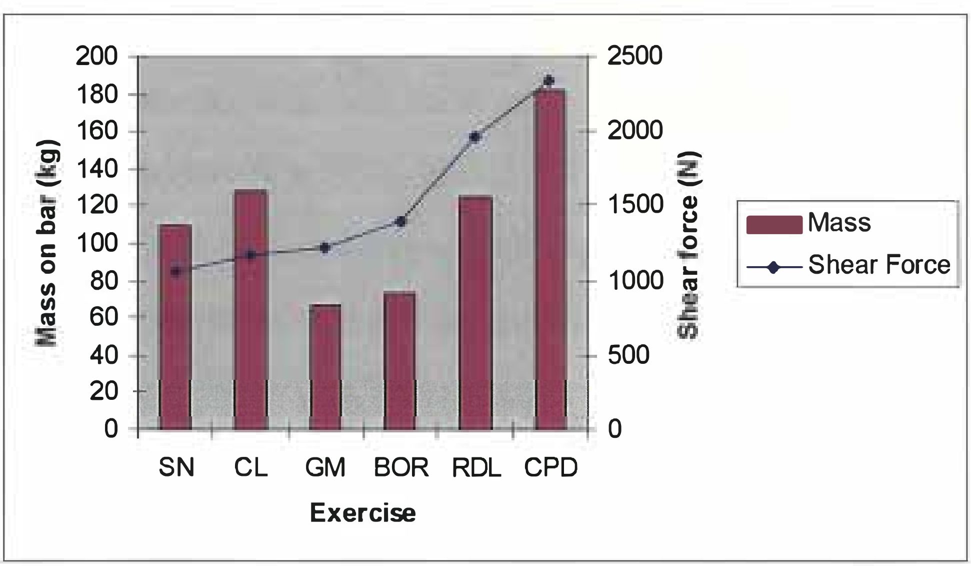

Figure 11. Peak L5/S1 shear force and bar mass relationship. Snatch =110kg, CL = 128.3 kg, GM = 67.2 kg, BOR = 73.3 kg, RDL = 125 kg, CPD = 182.2 kg.

However, despite this trend the BOR and GM showed higher values than both of the Olympic lifts, with the BOR showing significantly higher shear forces than the Snatch. This may be due to the BOR and the GM both having large moment arms, and because they are performed over a longer period when the peak moment arm is evident.

Further, both the BOR and GM initially require the lifter to lower the trunk to around 90^0. This lengthens the moment arm or distance from the mass on the bar to that of the L5/S1 fulcrum. This serves to increase the extensor moment required to stabilise and/or pull the trunk back to a vertical position. The moment arms for the Snatch and BOR are shown below in Figures 12 and 13.

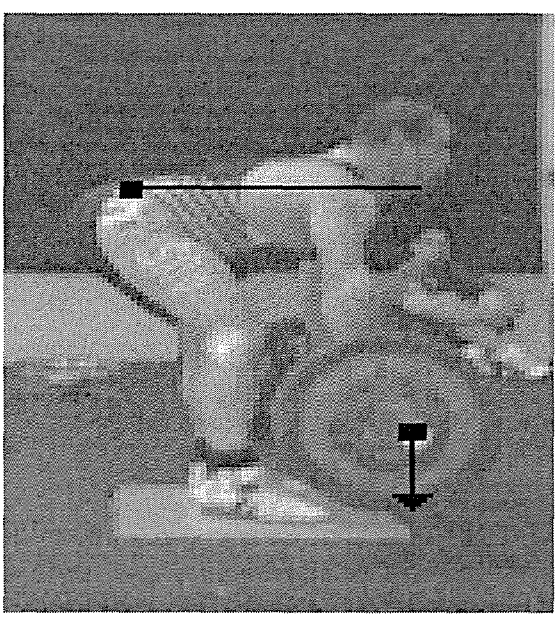

Figure 12. Bent-over Row performed during the study with moment arm acting from L5/S1 to line of action of mass on bar (80 kg).

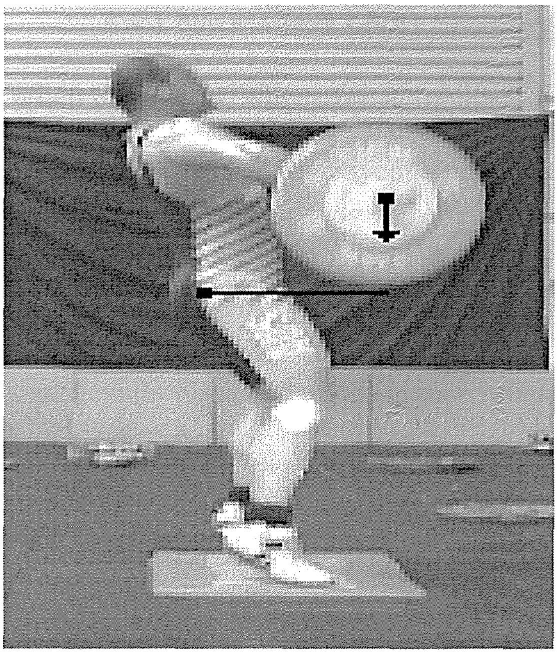

Figure 13. Snatch performed during the study with moment arm acting from L5/S1 to line of action of mass on bar (110 kg).

The more upright posture of the Snatch when compared to that of both the BOR and GM reduced the extensor moment through the later phases of the Snatch. This reduced the need for the spine to extend due to the low flexion moment reducing the shear forces place upon it to complete the lift (Cholewicki et al., 1991).

Farfan (1973) estimated that the shear force on the lumbar spine for a subject performing a Deadlift with a mass on the bar of 205kg to be around 2400 N. This compared favourably to results found in this study with an average shear force of 2338.5 N for a Deadlift of 182.2 kg.

5.4.1 Normalised L5/S1 Shear Forces

When comparing values for normalised L5/S1 shear forces it can be seen that the BOR, RDL and the GM displayed significantly higher ($p<0.05$) values than both of the Olympic lifts (Snatch and Clean). These results show a trend in lifts that require the lifter to flex forward at the hip to a horizontal position (BOR, RDL and GM), show significantly higher ($p<0.05$) higher values than that displayed by the Snatch and Clean.

Peak moment arm values were 0.43 m for the BOR, 0.34 m for the RDL and 0.50 m for the GM. The BOR displayed the highest normalisation shear force value, this may have been a direct result of the subjects having to maintain close to the peak moment arm value of 0.43 m over a longer time period than that of other lifts tested in this study. Further the BOR must maintain a trunk position close to a horizontal position while the bar is lowered and pulled back towards the body. Whereas the other lifts that displayed significantly high ($p<0.05$) values, were able to change the length of the moment arms by extending the trunk back to a vertical position which helps in pulling the bar closer to the L5/S1 fulcrum. Which may have contributed in the normalised shear force to be lower in lifts that did not have to maintain a horizontal position as in the BOR.

Upon further examination of the normalised shear force values, it was noted that the RDL showed no significant difference when compared to the BOR, CPD and GM. Interestingly, the RDL displayed a similar value to that of the BOR, this may be due to both the mean mass on the bar (125.0 kg) compared to that of the BOR (73.3 kg), and also the faster velocity that the trunk returns to an extended position than the BOR.

5.5 Conclusions

From the results and within the limitations of this study it was found that the assistance exercises examined showed significant differences ($p<0.05$) when compared to the Olympic lifts for L5/S1 moments of force, compressive force and shear force. Further, significant differences ($p<0.05$) were also found between lifts when these measures were normalised to bar mass and body weight above L5/S1. However, the assistance exercises (BOR, RDL, GM and CPD) only displayed a trend of non significant ($p<0.05$) higher L5/S1 shear forces than that displayed for the two Olympic lifts. Resulting in the rejection of the hypothesis for both the L5/S1 moments and compressive forces and shear forces. All results in this study are only applicable to elite weightlifters and should not be over generalised towards other populations.

Further biomechanical analysis of assistance exercises and their suitability to the Olympic lifts. A more comprehensive analysis needs to be adopted to account for muscular contributions to reactive moments, compressive force and shear force acting about the L5/S1 intervertebral joint. A 2-D bottom-up inverse dynamics model used in this study that is synchronised with EMG recordings would add significantly to the literature.

5.6 Practical Applications

This study has produced results that a coach could use to both increase performance and reduce the injury potential of an athlete. Having information concerning the suitability of assistance exercises for the low back and the Olympic lifts will allow the coach to make more informed discussions when prescribing appropriate training programs.

Results in this study have shown that the CPD is a lift that is used with a high mass on the bar, therefore, it resulted in high values for reactive moments, compressive and shear forces about the L5/S1 joint. This lift would be best used with a high mass on the bar as demonstrated in this study, which would be predominantly used for a strength phase of conditioning or with a lower weight on the bar performed with a higher velocity for power phases of conditioning.

The CPD is also a good exercise for conditioning the low back for the Olympic lifts, as it is also performed in the same line of action to that of the Clean and Snatch. It can also be used to teach lifters the correct technique of the first pulling phases in the Clean with a heavier mass on the bar.

The CPD can also be modified to start from above the knees (hang position) for beginner lifters, or lifters that need to strengthen the low back before attempting to lift the bar from the floor. As results from this study support findings by Enoka (1979) that indicate that the highest peak moment occurs early in the lift, and mainly just off the floor. Performing the CPD from the hang position would serve to reduce injury in the developing weightlifter as well as reduce the constant high stresses that occur early in the lift.

The RDL is a lift that is also a good exercise for conditioning of the Olympic lifts as it relies on the back extensors rather than the knee extensors to pull the bar from the floor in the first pull. Results in this study showed that the peak moment arm was displayed at the bottom of the lift (trunk close to horizontal). Although the RDL displayed a peak moment arm value lower than all other lifts except the CPD, it still rated the highest shear force behind the CPD. Therefore, the RDL must be classed as an advanced exercise that may be prescribed for elite weightlifters or athletes that have had some prior back conditioning.

The GM and BOR are also exercises that are excellent back conditioners, they both produce high moments and require small loads to be lifted in comparison to other lifts. Yet, again they must be added to a program with caution as results have shown that even with a light mass on the bar high stresses on the L5/S1 joint are produced. The BOR could be broken into two lifts, the conventional version (bar pulled closer to hips and lowered close to the legs) and the advanced version (bar pulled vertically to the chest). The conventional BOR could be used as a first up version of the BOR, this version reduces the distance from the L5/S1 to that of the bar mass, which may reduce the magnitude of the reactive moments needed to complete the lift. The conventional BOR may also be used in the specific phase of conditioning as it more closely replicates the line of action of the bar, in both the Clean and Snatch. The advanced BOR would increase the moment arm from the L5/S1 to that of the bar mass, which may increase the reactive moments, required to perform the lift. The advanced BOR would be a good back conditioning exercise in terms of strength. However, weightlifters are more focused on

functional strength gains in a specific sequence of actions, which is altered dramatically with the advanced BOR.

The GM is another assistance exercise that must be prescribed carefully as it can produce high reactive moments while using relatively small loads on the bar. The GM may be used by the coach for a lifter that is predominantly stronger in the upper extremities than the torso as the GM takes the use of the arms and legs (to a large extent) out of the lift. The trunk extensors must produce high reactive moments to counter the load on the bar without the added help of the upper extremities.

These practical applications are recommendations only, coaches must always prescribe exercises on an individual athlete basis to ensure both performance and injury prevention is maximised. However, this study has hopefully aided the coach in choosing the appropriate lift for low back conditioning to suit the phase or development stage of the weightlifter.

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