Original Article

The effect of increasing loading on powerlifting movement form during the squat and deadlift

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ABSTRACT

Spencer, K., & Croiss, M. (2015). The effect of increasing loading on powerlifting movement form during the squat and deadlift. *J. Hum. Sport Exerc., 10*(3), pp.764-774. Strength based sports, such as powerlifting, are characterized by distinct movements where competitors endeavor to move the maximum weight possible. Powerlifting is characterized by three distinct movements: the squat, the deadlift, and the bench press. The resulting total of all lifting event is used as a measure of overall lifting performance and strength (Garhammer, 1993). For each of the core powerlifting movements, there are several rules pertaining to movement form that an athlete must adhere to in order to obtain a successful lift. The basis of which is to standardize difficulty between competitors, such as the squat reaching adequate depth, or the deadlift reaching adequate height. The study compares the effect of increasing loads on technical form during the squat and deadlift among different standards of competitor. **Key words**: INCLUSIONS, INJURY, TRAINING, LUMBAR, WEIGHTLIFTING.

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INTRODUCTION

Once thought to be a high-risk sport, recent studies have alluded that powerlifting may represent a low to moderate risk sport in comparison to other more dangerous sporting endeavors (Siewe et al., 2011). Despite this, there is always invested interest in decreasing injury risk; particularly for lower level athletes who appear to be at the greatest risk of injury (Keogh, Hume, & Pearson, 2006). Unfortunately, the few studies that have investigated injury prevalence feature differing methodologies, sample sizes, and underestimated results which render findings near incomparable (Brown & Kimball, 1983; Haykowsky & Warburton, 1999; Keogh et al., 2006; Keogh & Pearson, 2003; Raske & Norlin, 2002; Siewe et al., 2011). Most authors conclude, however, that powerlifting appears to cause both acute and chronic injuries (Keogh & Pearson, 2003; Raske & Norlin, 2002) arising from disparate causes (Reeves, Laskowski, & Smith, 1997, 1998). The studies conclude that lower back injuries comprise a very high prevalence of injuries for powerlifting athletes of between 33 - 47% of total injuries (Keogh et al., 2006; Raske & Norlin, 2002; Siewe et al., 2011). Additionally, shoulder capsule injuries are particularly high in powerlifting athletes (approximately 30% of total injuries); however these are thought to be resultant from the nature of the movement itself, rather than technical issues (Keogh et al., 2006; Keogh & Pearson, 2003; Siewe et al., 2011). Lower implement related injuries, particularly lumbar spinal incursions (Cholewicki & McGill, 1992; Cholewicki, McGill, & Norman, 1991), hold high severity due to effectively rendering the athlete immobile for an extended period and possible chronic symptoms affecting quality of life in later years (Cholewicki et al., 1991; McGil, 2007). These lumbar lower limb injuries are thought to be dependent, at least in part, to the large compressive and shear forces placed on the joints and spine throughout the squat and deadlift movement (Keogh et al., 2006; Keogh & Pearson, 2003).

The current world records for powerlifting stand well in excess of 300 to 450 kg for each lift (McGowan, Talton, & Tobacyk, 1990), exceeding body weight by, in some cases, more than five times (Stone et al., 2005). These immense weights can result in extreme torques, compressive loads and sheer forces through the spine and other key joints (Brown & Abani, 1985; Cholewicki & McGill, 1992; Cholewicki et al., 1991; Escamilla et al., 1998; Escamilla et al., 2000; Escamilla, Lowry, Osbahr, & Speer, 2001). While these extreme loads represent the top percentile of elite lifters, any level of these forces can be harmful if not correctly and safely managed through correct technique; particularly, incorrect form exacerbates these forces and their effect on the body (Keogh & Pearson, 2003).

Common technical inclusions during the squat and deadlift typically occur due to posterior chain dysfunction, resulting in either lumbar or excessive thoracic spine kyphosis (Bird & Barrington-Higgs, 2010); commonly referred to as 'rounding'. As you move into this position, the lower back musculature can become deactivated, a process referred to as myoelectric silence (Fortin, 1997; McGil, 2007). When this occurs, a proportionally larger stress is applied to the spinal ligaments, neural arch, disks, and facet joints of the lumbar spine (Fortin, 1997; McGil, 2007). Rounding during the initial stages of the deadlift is thought to be reliant on inflexibilities, and rounding during fatigue is thought to be more dependent on core stability and conditioning (Keogh & Pearson, 2003). Similarly, the lower back and knees may be injured from increased moment arms putting excessive shear forces on the knee capsule and patella, or valgus collapse harming the ligaments stabilizing the joint (Escamilla, 2001; Escamilla et al., 1998; Escamilla, Lowry, et al., 2001; Fry, Smith, & Schilling, 2003; Hales, Johnson, & Johnson, 2009; Swinton, Stewart, Agouris, Keogh & Lloyd, 2011). Imbalances in muscular strength and or flexibility, often manifesting in rotational movement of the torso, can also greatly increase an athletes disposition to injury (Keogh & Pearson, 2003). It would seem, therefore, that as correct form helps properly disperse compressive forces through the joints, and aid in the reduction of harmful shear forces leading to injury, ensuring correct form throughout both submaximal and maximal lifting exertions is worthwhile.

The correct movement technique during the squat and deadlift has been covered extensively (Baechle & Earle, 2008; Costill, Wilmore, & Kenney, 2012), however it appears incorrect form is commonplace within powerlifting (Keogh et al., 2006; Keogh & Pearson, 2003; Siewe et al., 2011). Particularly, a brief incursion into powerlifting video graphic footage often illustrates elite level athletes using potentially dangerous movement form during maximal lifts. This occurrence is thought to be dependent on a number of aspects. Namely, although there are rules surrounding 'legal' movement form during powerlifting competition, as previously mentioned they are written for the purposes of standardization, rather than correct or safe movement form. This can potentially allow for dangerous movement form and technical inclusions to occur during these high load events (Keogh & Pearson, 2003). Additionally, although classic guidelines for resistance training place value in safe and correct movement form over and above total weight lifted, a reflection of the core goal of competitive powerlifting highlights a different approach; to gain the highest weight lifted possible, potentially in lieu of incorrect and arguably damaging lifting form. Moreover, as it is currently unknown the weight 'threshold' at which these inclusions occur, this attitude may not be limited to the competitive stage, and may occur throughout training. This is a major issue, as unlike many team sports powerlifters will construct the majority of their training around large volumes of the exact movements represented in the sport. Hence if incorrect form is not adhered to at training percentages, athletes could be putting themselves in undue risk of injury outside of the competitive platform. Unfortunately, the relationship between increasing load and technical inclusions, and its relation to training status and other experience related factors are inexistent (Keogh et al., 2006; Siewe et al., 2011).

The aim of this research project is to examine the effects of increasing loading on technical alterations during the squat and deadlift between individuals of similar training backgrounds in the hope of determining whether technical inclusions occur at a given percentage of maximum ability, and whether that threshold is correlated to athlete level. The results from this study may help determine an 'upper-ceiling' of training weights of correct form, and identify whether performance in one movement is indicative of performance in another. The data will aid in informing the given athlete sample of their ability to train safely at a given percentage, and may further be used to inform coaching and training practice in terms of safe training loads. Furthermore, as the deadlift and squat movements form part of the three major compound movements prescribed by coaches and strength and conditioning specialists worldwide (Bird & Barrington-Higgs, 2010), and the typical powerlifting summation of lifting performance is used as a common measure of sporting strength, this research has implications surpassing that of the competitive weightlifting community alone.

MATERIAL AND METHODS

Athletes were filmed during a peaking session of their training cycle, which was designed to mirror the events during a typical powerlifting competition. The squat and deadlift movements will were recorded, and subjects were loaded in incremental volumes, interspersed with rest, until they reached their maximum weight. Testing occurred in each athletes preferred place of training, with the majority occurring at either the Human Performance Center, or Auckland University of Technology Akoranga Gym. The data was then analysed for key performance indicators based around cues of a successful and valid 'lift', dependent on each movement, and the correct form or technique during which each lift was executed. The technical inclusions, among other measurements, were compared between loads, and between individual subjects using notational coding software.

Participants
The participants comprised of a group of strength sport athletes (*n* = 6; 20 to 27 years; body mass: 83 to 144kgs; stature: 175 to 204cms) who had at least 2 years of resistance training, with emphasis on powerlifting style and technique, and were currently competing in competing powerlifting. Additionally, all athletes held at a minimum of a Bachelors level qualification in Sports Science, and were REPS registered. All athletes provided written informed consent before participating.

Procedures
Pilot Study: The procedures and methodology following is based on a short pilot study that tested each step of protocols, setup and analysis to be used in the project. Alterations to the plan were further piloted to ensure suitability to the project design.

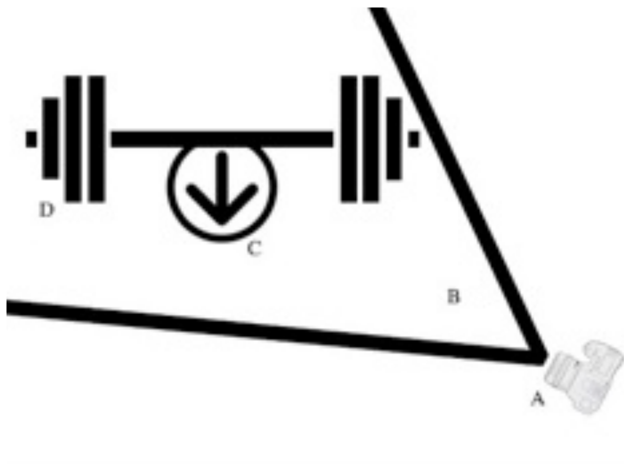

Figure 1. Illustration of equipment setup. A. Approximate camera position; B. Approximate image scope; C. Subject placement and direction; D. Position of barbell equipment.

Equipment: Subjects were recorded using a digital video camera, operating at 25fps, at a distance of approximately 3 meters. The camera was set on a tripod at a height corresponding to the subjects' center of mass, directed in a transverse plane in order to capture both sagittal plane data and frontal plane data (see Figure 1). This ensured the accurate identification of technical inclusions occurring in both these planes. The powerlifting equipment used for the testing comprised of one or more Elieko (Halmstad, Sweden) competition grade Olympic bars (dimensions specified by the International Weightlifting Federation), an Elieko squat rack, a regulation deadlift platform, and a selection of bumper plates to supply loading. The load applied to the subject was able to be increased in increments of 2.5 to 20 kg. The participants used only regulation accessories that would enable them to compete in the unequipped class of an International Powerlifting Federation (IPF) approved competition.

Testing Protocol
Each athlete's previous 1RM values were determined prior to testing, and used in order to establish the percentage-loading increments to be used during the testing. Subjects started with 50% of their predetermined maximum and work up incrementally at 10% increases until they reached their previous personal best 1RM value. At this point athletes are able to progress past this, as per a powerlifting competition. Each lift was interspersed with rest typical of powerlifting competition (< 5 minutes). Subjects

were given verbal cueing and encouragement in order to promote maximal effort and simulate a supportive environment.

Performance Indicators

Developed based on indicators outlined in the following sources: (Baechle & Earle, 2008; Cholewicki & McGill, 1992; Cholewicki et al., 1991; Costill et al., 2012; Escamilla, 2001; Escamilla, Fleisig, Lowry, Barrentine, & Andrews, 2001; Escamilla et al., 1998; Escamilla et al., 2000; Fortin, 1997; McGil, 2007; Reeves et al., 1997, 1998; Schoenfeld, 2010; Siewe et al., 2011; Swinton et al., 2011; Tremblay & Proteau, 1998).

Eccentric (squat only): From the time the athlete begins the downward lowering movement until the time they cease moving down. Amortization (squat only): Paused moment (if any) that may occur at the lowest point of the squat before the concentric phase.

Concentric: Squat; from the moment the athlete begins the drive upward from the bottom of the squat until they cease upward movement. Deadlift; from the time the athlete begins applying force to the bar, causing it to 'slack out' or bend, before the weight plates leave the ground, until the bar ceases upward movement at the completion of the lift.

Lower back rounding: As the lumbar spine moves from a neutral or slightly lordotic posture (extended) into a kyphotic (flexed) position. This gives the appearance of a 'rounded' lower back. This is to be separated from rounded thoracic extension, which is natural and safe to a large degree. This typically occurs during the concentric portion of either the squat or deadlift, but can occur as the athlete nears the bottom of the squat (and remain for the duration of the concentric period) due to imbalances or restrictions in flexibility.

Thoracic Kyphosis: As per above, the thoracic spine is naturally slightly kyphotic (rounded), however excessive rounding can be a prelude to injury. This indicator will often be seen in an athlete exhibiting lower back rounding also.

Knee internal/external collapse (left / right leg): Whether the lower limbs are naturally aligned with the knees tracking out over the toes. Any internal (valgus) or external (varrus) movement outside of natural bounds will be noted.

Data Analysis

Video-graphic data was initially cropped of any extraneous footage using video editing software (Xilisoft Ltd, Toronto, Canada), and then analysed using notational coding software (Sportscode Gamebreaker+ software, Sportec Ltd, Australia). Using a customized coding window (see Figure 2.) each lift was coded using the performance indicators listed above, and saved into a database respective of the movement type, and loading percentage. Descriptive statistics were then determined via Sportcode Gamebreaker+, and the data entered into Microsoft Excel for further statistical analysis. For the deadlift movement, output variables for each loading percentage included (in m/s unless otherwise specified): Total lift time, lumbar inclusions, thoracic inclusions, knee inclusions, total inclusions (calculated as the sum of all inclusions), and relative time of inclusions (%; calculated as total inclusions / total lift time). For the squat movement output variables for each loading percentage included (in ms unless otherwise specified): Concentric phase, amortization phase, eccentric phase, total lift time (calculated as the total of the concentric, amortization and eccentric phases), lumbar inclusions, thoracic inclusions, knee inclusions, total inclusions, and relative time of inclusions (%). A Repeated measures ANOVA was used to determine whether the above variables changed significantly changed during loading, under increasing loading. As part of the initial pilot study, this process of data analysis will be tested for inter-operator reliability using a test for intra-class correlation (ICC) and coefficient of variation (CV%) (Drinkwater, Hopkins, McKenna, Hunt, & Pyne, 2007). Statistical significance criterion was set at an alpha level of $p \leq 0.05$. Additionally, effect sizes (ES) were calculated using the following equation: ES = (High value – Low value) / ((High value SD + Low value SD) / 2). Effect sizes were described as large (ES > 1.2), moderate (0.6 < ES < 1.2), small (0.2 < ES < 0.6), and trivial (ES < 0.2) (Drinkwater et al. 2007).

RESULTS

Reliability

To assess inter-operator reliability, all athletes were coded twice under the 90% loading condition for all performance measures. Variables were assessed using an intra-class correlation (ICC) and coefficient of variation (CV%), and found to be highly reliable (see Table 1.).

Table 1: Inter-operator reliability based on intraclass correlation (ICC) and coefficient of variation (CV) for 1 change in Performance measures during squat and deadlift movements under increasing loading.

Performance Measure	ICC	CV (%)
Deadlift Movement		
Total lift time	1.00	0.2
Lumbar Inclusions	0.99	0.9
Thoracic Inclusions	0.98	0.6
Squat Movement		
Eccentric Phase	1.00	0.2
Ammortization Phase	1.00	0.3
Concentric Phase	1.00	0.3
Thoracic Inclusions	0.98	0.4
Knee Inclusions	0.99	0.7
Lumbar Inclusions	0.98	0.8

ICC= intra-class correlation, CV= Coefficient of variation

Deadlift

For the deadlift movement pattern (see Table 2.), total (concentric) lift time significantly increased under the 100% loading condition (ES = 4.17). Total time of inclusions increased significantly in both the 90% loading increment (ES = 2.78) and 100% (ES = 4.61) compared to the baseline 70% protocol. Lumbar flexion represented 90% of total inclusions (see Figure 2), and was significantly increased with loading under the 90% and 100% load (ES = 3.45 to 4.12) compared to baseline. Thoracic inclusions were observed in several participants (approximately 10% of total inclusions; see Figure 2), but were not significantly changed when compared as a group average. Additionally, although inclusions at the knee were selected to be coded, there were no instances of this observed under the deadlift movement pattern. When total inclusions were expressed as a percentage of total lift time, there were significant increases in both the 90% and 100% loading conditions (ES= 3.17 to 3.24).

Squat

For the squat pattern (see Table 2.), there was a trend for increased total lift time under the 100% loading protocol (ES = 2.22), largely resultant from a significantly increased concentric phase time (ES = 2.05). The eccentric and amortization phases were not significantly changed. All technical inclusion markers were not significantly changed by loading due largely to high levels of variance between participants. 66% of technical inclusions occurred at the lumbar spine, followed 26% at the knee, and 8% at the thoracic spine (see Figure 3). Total inclusions, both absolute and expressed as a percentage of total lift time, likewise were not significantly changed.

DISCUSSION

As previously noted, to the best of the author's knowledge there has been no previous research into the area of loading and its relationship with dangerous technical inclusions in power lifters (Keogh et al. 2006).

Table 2. Change in performance measures during squat and deadlift movements under increasing loading.

	Loading Increments			
Performance Measure	70%	80%	90%	100%
Deadlift Movement				
Total lift time (ms)	121.0 ± 18.0	151.0 ± 19.2	167.0 ± 16.2	311.5 ± 73.4*
Lumbar Inclusions	0.0 ± 0.0	27.7 ± 20.6	59.0 ± 34.1*	95.3 ± 46.3*
Thoracic Inclusions	0.0 ± 0.0	0.0 ± 0.0	5.5 ± 13.5	13.7 ± 21.4
Total Inclusions (ms)	0.0 ± 0.0	27.7 ± 20.6	64.5 ± 46.4*	109.0 ± 47.3*
Relative time of inclusions (%)	0.0 ± 0.0	17.9 ± 11.3	37.7 ± 23.8*	39.1 ± 24.1*
Squat Movement				
Eccentric Phase (ms)	132.2 ± 17.4	149.7 ± 43.0	166.7 ± 21.7	160.8 ± 47.6
Ammortization Phase (ms)	16.5 ± 10.4	18.7 ± 11.2	22.0 ± 7.3	12.7 ± 2.5
Concentric Phase (ms)	133.0 ± 24.6	165.7 ± 21.1	211.3 ± 44.9	237.7 ± 69.6*
Total lift time (ms)	281.7 ± 35.2	334.0 ± 54.8	400.0 ± 61.5	411.2 ± 91.4#
Thoracic Inclusions	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	8.8 ± 21.6
Knee Inclusions	0.0 ± 0.0	0.0 ± 0.0	8.0 ± 14.5	18.2 ± 24.7
Lumbar Inclusions	9.3 ± 22.9	8.8 ± 21.6	8.3 ± 20.4	47.7 ± 79.6
Total Inclusions (ms)	9.3 ± 22.9	14.3 ± 23.1	16.3 ± 26.6	74.7 ± 95.4
Relative time of inclusions (%)	3.1 ± 7.6	4.1 ± 7.1	4.0 ± 6.6	18.7 ± 25.0

*Significant to 70% loading protocol (P<0.05), *Trend for significant results over 70% loading protocol (P=0.052).

The findings presented in the current study are novel, and therefore will be discussed in such a manner, relating as much as possible to previous research. Potentially dangerous technical inclusions appear to be a regular occurrence at high loading powerlifting competitions (Keogh & Pearson, 2003); therefore the investigation of high occurrence negative technique markers with increasing load is key to injury prevention both during competition and training.

During the deadlift, both total and relative inclusions increased largely under the 90% and maximal loading protocols. Approximately 90% of all inclusions observed occurred at the lumbar spine - a troubling statistic given the large capacity for both acute and chronic injury as a result of this inclusion (Alexander, 1985;

Cholewicki & McGill, 1992; Cholewicki, McGill, & Norman, 1991; McGill, McDermott, & Fenwick, 2009). Based on the results of both relative and total inclusions not significantly changing below 90% loading, it could be interpreted as a threshold for technical inclusions in athletes of these same characteristics. However, given the high levels of variability and small sample size observed in this study, this recommendation should not be taken at face value. It is instead recommended that each athlete be screened and assessed for inclusions at each weight level, and a combination of technique correction and possible safe training cap be implemented. All athletes presented excellent lifting form, void of technical inclusions, under the 'baseline' 70% load.

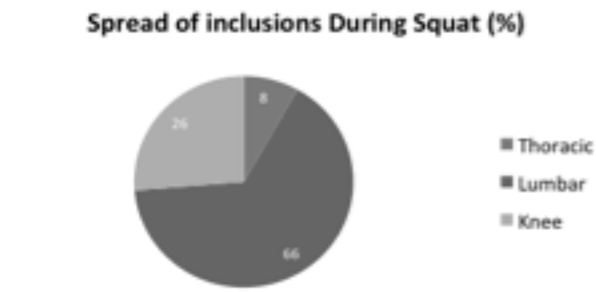

Figure 2. Percentile spread of technical Inclusions during the squat movement.

Despite this, a degree of lumbar flexion under the maximal loading protocol was observed in each participant, regardless of their performance under latter loads. Based on this finding, it appears deadlift form during maximal lifting may be less reliant on each individual's lifting technique, and more reliant on inability to keep their form under heavy loading. Indeed, Brown and Abani (1985) drew similar conclusions when considering the effect of loading on joint moment arms and vertical force production. Furthermore, an important consideration to make is whether some of these inclusions are inherent to maximal lifting, and may be apparent even in elite lifters due to the nature of pushing the body to its limits.

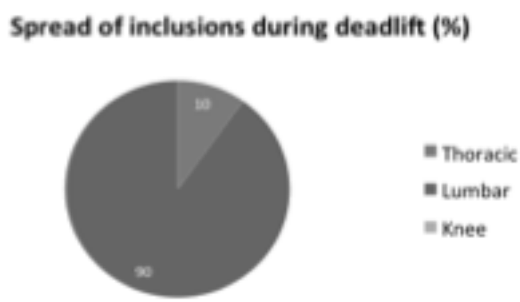

Figure 3. Percentile spread of technical Inclusions during the deadlift movement.

During the squat movement, there was a trend for a large increase in total time under maximal load, likely resultant from an increasing concentric phase. Due to large variability between subjects, there were no statistically significant increases in performance markers for technical inclusions. Although the majority of athletes exhibited excellent technique under all loading protocols, several athletes appeared to be predisposed to a certain technical inclusion, particularly at the lumbar spine, from the outset at lower loading protocols. Most of these inclusions occurred during the concentric phase, with lumbar flexion appearing to appear at end of the eccentric phase, continuing throughout the amortization and into the majority of the concentric phase. The increase in total and relative inclusions, although insignificant, appeared to be resultant of an increased loaded concentric phase. It is likely this illustrates a movement competency issue, rather than an inability to keep form under heavy loading as has been concluded with the deadlift. Anecdotally, lumbar issues appeared at lower loads in athletes with inflexibilities and other movement pattern issues, and remained apparent as the athlete moved into the lowest eccentric position of the squat (Gullett, Tillman, Gutierrez, & Chow, 2009). In comparison to deadlift where at 70% athletes showed perfect form, it appears this finding is congruent with previous literature highlighting that performance in one code does not necessarily reflect the other (Hales et al. 2009).

An interesting outcome of this study is that despite all athletes being academically trained to recognise poor movement form, there were still large incidences of technical inclusions in each lift. It could be easily theorised that novice athletes would have greater chance of eliciting negative lifting form, both in terms of magnitude and time. Interestingly, the highest reading of relative and total inclusions during the deadlift was from the strongest and most experienced lifter - further illustrating the point that deadlift form is dependent on loading percentage, rather than individual technique. The relationship between strength level and inclusions is one that could not be explored with the given dataset, and should be investigated in the future given a larger sample size. Moreover, it should be noted that the inclusions per load was highly varied between subjects, and interpretations of this are discussed in the limitations section of this article.

There are several limitations in the given study that need to be discussed. Firstly, only time of inclusion was measured, not the severity. Due to the way that each movement was coded (from the first instance of damaging form to the last), it is possible for an athlete exhibiting extreme degrees of a particular inclusion to be given the same inclusion rating as one who exhibited small inclusions for the same time frame. Further research should look to include a ranking system classifying the extent of each inclusion. Secondly, athletes coding may have been dependent on their own personal feeling of maximal effort. It is expected that several athletes' perception of maximal was internally defined as how heavy they can push themselves without a high degree of inclusions occurring. Thirdly, athletes were cued to lift as normal, and therefore it is likely that individual lifting styles may have skewed the data. For example, some athletes may have lifted with higher velocity levels (more power) at lower levels, altering time increase data. Further studies should look to normalise this measure by ensuring the athletes lift at maximum-speed and effort. Lastly, in an effort to increase the accuracy of measurement and precision of form monitoring, future studies should look at incorporating two high-speed cameras recording simultaneously in the sagittal and frontal planes.

PRACTICAL APPLICATIONS

Based on the performance by the current sample, it is likely that there is no set level at which inclusions occur in the squat. Inclusions appear to be based more on individual technical tendencies, and therefore athletes should be assessed at lower loading ranges in order to rectify these for higher levels of loading. For the deadlift, it appears that at and above 90% loading inclusions start to appear, particularly at the lumbar spine. A rough guide from this data would be to train at levels less than 90% in the effort of decreasing injury risk, however the best case would be to assess on a athlete-by-athlete basis. Markedly, it is evident from the results that some inclusions at maximal loading may be unavoidable; it may even be interpreted that athletes are strongest with some degree of lumbar and thoracic flexion. As lifting the most weight possible is the key goal for competitive powerlifting, coaches and athletes need to decide whether goal of gaining a higher total is an acceptable trade-off for potentially serious injury resultant from poor movement form under extreme loading.

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