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The Correlation Between Strength Levels Measured Through Dynamic Strength Exercises and the Incidence and Severity of Injury Among Collegiate Athletes

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THE CORRELATION BETWEEN STRENGTH LEVELS MEASURED THROUGH
DYNAMIC STRENGTH EXERCISES AND THE INCIDENCE AND SEVERITY OF
INJURY AMONG COLLEGIATE ATHLETES

BY

ALEX JARDINE

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DEFINITIONS

Power Clean

The power clean is an exercise in which a trainee moves a barbell from the floor to the shoulder. The trainee will receive the bar at the shoulders in a quarter squat position and then stand up.

Squat

The squat is an exercise in which a trainee places a barbell on his or her back while standing and sits down until the crease of the trainee's hip is below the top of the trainee's knee. The trainee then stands back up to the starting position.

Bench Press

The bench press is an exercise in which a trainee is supine on a bench. The trainee takes a barbell out of the bench press stand and holds it over the trainee's chest. The trainee then lowers the barbell until the barbell comes in contact with the trainee's chest. The trainee then raises the barbell back to the starting position.

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ABSTRACT

THE CORRELATION BETWEEN STRENGTH LEVELS MEASURED THROUGH
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ALEX JARDINE

2016

Injury to athletes in sport occurs as a result of extrinsic and intrinsic risk factors. Mounting evidence points toward decreased strength as a predictor of injury in athletes. By comparing strength levels in functional movement patterns to injury, the strength and conditioning professional will be able to design effective training programs to reduce the incidence of injury in sport better. The purpose of this study was to determine the correlation between strength measured through dynamic strength exercises (power clean, the squat, and the bench press) among collegiate athletes and the incidence and severity of injury. We hypothesized that greater incidence and severity of injury to collegiate athletes is correlated to low athlete strength to bodyweight ratios in the power clean, squat, and bench press. Our study included 81 male and 80 female collegiate athletes playing various sports from South Dakota State University. This study utilized strength measurement and injury data collected from the athletic department for two school years. Strength measurements were divided into quartiles and compared to injury data divided into mild, moderate, and severe injury severity categories. An analysis of variance was utilized to determine the correlation of strength with incidence and severity of injury.

We found no correlation between strength measured through dynamic strength exercises and the incidence and severity of injury. However, there were significantly more minor injuries compared to moderate and severe for both males and females. Based on the findings from our study, we are unable to determine the correlation between strength measured through dynamic strength exercises and the incidence and severity of injury among collegiate athlete.

REVIEW OF LITERATURE

This review of literature was completed in order to gain a better understanding of the different risk factors associated with injury in the population of athletes. This review will first define what injury is, then discuss the risk factors, both extrinsic and intrinsic, that have been correlated with injury thus far in the literature. The paper will then finish by summarizing the findings and give recommendations for interventions as well as future studies.

Injury and what it is

Injury has been defined in multiple ways. Some authors have made a distinction between overuse and traumatic injury. Yang et al. (Yang et al., 2012) defined overuse injury as a gradual onset injury caused by repeated micro trauma without a single, identifiable event responsible for the injury. In contrast, acute injury was defined as trauma resulting from a single, identifiable event. Other authors have delineated between severe and moderate injury. Chomiak et al defined severe injury as one resulting in complaints or absence from the sport lasting for more than four weeks, or one resulting in serious damage to the musculoskeletal system such as a fracture or dislocation (Chomiak, Junge, Peterson, & Dvorak, 2000). Others still have defined injury as one resulting in a trip to a medical provider or one resulting in a player leaving a game (Knapik et al., 2001; Lindenfeld, Schmitt, Hendy, Mangine, & Noyes, 1994). However, the most common definition of injury used by authors is time missed from practice or competition (Murphy,

Connolly, & Beynnon, 2003). For example, an injury is not considered an injury if the athlete does not miss subsequent games or practice sessions.

Extrinsic Factors

Injury in sport is associated with many risk factors and can be broken down into extrinsic and intrinsic. Extrinsic risk factors are independent of the injured athlete and typically involve the environment in which the athlete resides as well as the activity with which the athlete is involved. Intrinsic risk factors are dependent on the injured athlete and involve the physical and/or mental condition that predisposes the athlete to injury.

Level of Competition

The present literature contains many studies investigating extrinsic risk factors and injury. One such extrinsic risk factor is the level of competition. An alarming majority of the studies investigating level of competition have reported an increased risk of injury during competition when compared to practice. Seil et al reported a significantly higher incidence of in game injuries (14.3 injuries per 1000 game-hours) when compared to in practice injuries (0.6 injuries per 1000 practice-hours) in team handball players (Seil, Rupp, Tempelhof, & Kohn, 1998). In another population of team handball players, Myklebust and colleagues found a significant difference between incidence of game injuries vs practice injuries with a risk ratio of 29.9(Myklebust, Maehlum, Holm, & Bahr, 1998). Messina et al similarly found a significantly higher risk of injury in games (16.0 injuries per 1000 hours in males, 16.9 injuries per 1000 hours in

females) when compared to practice (2.0 injuries per 1000 hours in males, 1.8 injuries per 1000 hours in females) in high school basketball players (Messina, Farney, & DeLee, 1999). Only one study reported different findings than the previous three research articles. Bahr and Bahr reported no difference in incidence of injury in females during games (3.0 injuries per 1000 hours) when compared to practice (1.6 injuries per 1000 hours) in volleyball players (Bahr & Bahr, 1997). However, the injury rate is higher during competition for both males and females, as well as males alone. One can only speculate as to the cause of the correlation between level of competition and injury. However, the most logical explanation is that athletes will go to extreme lengths to win during competition even at the expense of injury. This same drive would not be present during practice when there is nothing to win or lose.

Playing Surface

Conflicting evidence exists regarding the relation between injury and playing surface. Much evidence exists pointing toward an increased risk of injury on artificial turf when compared to natural grass. Arnason et al found a significantly higher incidence of injury occurring on artificial turf when compared to grass or gravel during both games and practices (Arnason, Gudmundsson, Dahl, & Johannsson, 1996). Similarly, Hershman et al reported a 22% greater injury rate on artificial turf when compared to grass for both knee and ankle injury (Hershman et al., 2012). Ekstrand and colleagues found a greater injury risk playing on artificial turf when compared to grass, however, they reported a significantly greater incidence of ankle sprains on artificial turf when compared to grass (Ekstrand, Timpka, & Hagglund, 2006). In contrast, other studies have found either no

difference in injury risk between the two surfaces (Bjorneboe, Bahr, & Andersen, 2010; Ekstrand, Hagglund, & Fuller, 2011; Fuller, Dick, Corlette, & Schmalz, 2007a, 2007b) or increased injury risk on natural grass when compared to artificial turf (Ekstrand et al., 2006). It is difficult to determine what relationship exists between injury and playing surface due to several factors. First, the studies investigating injury and playing surface tend to use differing definitions of the word injury. Secondly, many of these studies do not report confounding variables such as shoe design, weather conditions during injury, or skill level of the athletes participating. More research is necessary regarding this topic in order to come to a definitive conclusion.

Shoe Type

Limited evidence exists regarding shoe type and incidence of injury among an athletic population. Few authors have correlated shoe type with an increase in incidence of injury. McKay et al. report that basketball players wearing shoes with an air cell in the heel increase the incidence of ankle injury 4.34 times when compared to shoes with no air cell in the heel (McKay, Goldie, Payne, & Oakes, 2001). Lambson and colleagues found greater incidence of ACL injury among high-school football players in cleats with edge designs compared to other designs (Lambson, Barnhill, & Higgins, 1996). Conversely, Barrett and colleagues reported no difference in incidence of ankle injury among intramural basketball players between high top, low top, or high top with an air cell shoes (Barrett et al., 1993). Milgrom et al. reported no difference between lateral ankle sprain among male Israeli military recruits between basketball shoes or standard lightweight infantry boots (Milgrom et al., 1991). Other authors have investigated friction and

torsional forces among different types of shoes. Heidt et al reported greater torsional forces from shoes on field types for which they were not meant than the torsional forces from shoes on field types for which they were meant (Heidt et al., 1996). They concluded that manufacturers should display what field type a certain shoe type is meant for on the box. Due to the lack of investigation on this topic, more research is necessary.

Ankle Injury Prophylaxis

Strong evidence exists suggesting a decreased incidence of injury with the implementation of taping or bracing the ankle among athletes. Specifically, bracing the ankle has been shown to have an established prophylactic effect on ankle injury (Greene & Wight, 1990; McGuine, Brooks, & Hetzel, 2011; Mickel et al., 2006; Pedowitz, Reddy, Parekh, Huffman, & Sennett, 2008; Rovere, Clarke, Yates, & Burley, 1988; Sharpe, Knapik, & Jones, 1997; Sitler et al., 1994). Additionally, taping the ankle has been shown to prevent ankle injuries (Callaghan, 1997; Mickel et al., 2006; Olmsted, Vela, Denegar, & Hertel, 2004; Sharpe et al., 1997; Verhagen, van Mechelen, & de Vente, 2000). A few researchers have reported bracing the ankle to be superior to taping in reducing incidence of injury within an athletic population (Callaghan, 1997; Sharpe et al., 1997; Verhagen et al., 2000). Two other authors found no difference in the reduction of incidence of ankle injury among athletes (Mickel et al., 2006; Olmsted et al., 2004). However, strong evidence exists suggesting that bracing is a more cost effective and less time consuming modality than taping (Callaghan, 1997; Mickel et al., 2006; Olmsted et

al., 2004; Sharpe et al., 1997; Verhagen et al., 2000). Because bracing is just as effective and more cost effective than is taping, bracing should be the provider's preferred modality in preventing ankle injuries among athletes.

Intrinsic Factors

Diet

Conflicting evidence exists regarding diet's relationship to injury. Much research has reported that increased dietary intake of calcium, vitamin D, as well as protein can reduce stress fractures in athletes. Myburgh et al reported that in their population of female athletes, those with stress fractures exhibited lower bone density, lower calcium intake, and menstrual irregularity (Myburgh, Hutchins, Fataar, Hough, & Noakes, 1990). In line with this finding, Nieves and colleagues reported an association between greater consumption of low fat dairy products (containing vitamin D, calcium, and protein) and greater bone mineral density as well as a lower stress fracture rate in female cross country runners (Nieves et al., 2010). In a prospective cohort study by Lappe and colleagues, supplementation with calcium and vitamin D was shown to decrease incidence of stress fractures in Navy Recruits by 21% ($p=.02$) (J. Lappe et al., 2008). Additionally, in an intention to treat analysis, these authors found a 20% lower incidence ($p=.002$) of stress fractures in the treatment vs. the control group. In contrast to these findings, other studies have reported no relation between dietary intake of calcium and stress fractures in populations such as military recruits (Bennell et al., 1996; Cline, Jansen, & Melby, 1998; J. M. Lappe, Stegman, & Recker, 2001). However, studies claiming no relation between dietary intake of calcium and stress fractures provide weak evidence due to their study

design. These studies used questionnaires to determine calcium intake, which, at times asked the subject to recall dietary intake of calcium from as much as 7 years prior. As such, subject recall bias may play a significant role in the fact that these authors found no relationship between dietary intake and stress fractures. The evidence claiming that dietary calcium, vitamin D, and protein can serve in a prophylactic role against stress fractures in athletes is stronger than the evidence to the contrary.

Previous Injury

Many authors have explored the relation between previous injury and subsequent injury. Previous injury in athletes has been established as a strong predictor of future injury (Bahr, Lian, & Bahr, 1997; Judith F. Baumhauer, Alosa, Renström, Trevino, & Beynon, 1995; Chomiak et al., 2000; Hägglund, Waldén, & Ekstrand, 2006; McKay et al., 2001; Messina et al., 1999; Milgrom et al., 1991; J. W. Orchard, 2001; Surve, Schwellnus, Noakes, & Lombard, 1994; Wiesler, Hunter, Martin, Curl, & Hoen, 1996). For example, Hägglund et al reported that athletes who suffered a hamstring injury, groin injury, or knee injury in the previous season were two to three times more likely to suffer a subsequent injury than athletes with no such musculoskeletal damage (Hägglund et al., 2006). Some authors disagree, claiming that no relationship exists between previous and subsequent injury (Barrett et al., 1993; Tropp, Ekstrand, & Gillquist, 1984). For instance, Barrett and colleagues stated that previous history of ankle injuries was not predictive of ankle sprains (Barrett et al., 1993). The discrepancy in the findings throughout the literature could be explained by the differing definitions of the term injury, differing assessment techniques, as well as differing quality of rehabilitation (Murphy et al., 2003).

The evidence showing a relationship between previous and subsequent injury is stronger than the evidence showing no relation. Barrett and colleagues used self-reporting questionnaires to determine previous injury status, which introduces recall bias. In addition to this, there are more studies claiming previous injury to be a predictor of future injury than there are studies claiming the contrary. Moreover, the evidence claiming there to be a positive correlation between previous and future injury is quite a bit more recent than the evidence claiming that no correlation exists. As study designs improve and technology allows for more precise measurements, the findings from more recent studies will have more internal and external validity.

Many reasons have been proposed to explain why previous injury is a strong predictor of future injury. In a review by Murphy et al, previous injury is claimed to influence proprioceptive defects, muscle strength impairment, muscle imbalance, cause persistent ligamentous laxity, diminished muscle flexibility and joint movement, and the presence of localized scar tissue (Murphy et al., 2003). The combination of functional strength impairments, connective tissue damage, and pain may cause an athlete to utilize suboptimal motor patterns that may leave an athlete susceptible to injury. Return to play protocols is another factor contributing to the fact that previous injury is correlated with subsequent injury. Little evidence in the literature exists defining what level to which one must be rehabilitated in order to return to play. This inadequate rehabilitation, which has also been shown to be a risk factor for injury (Chomiak et al., 2000; J. W. Orchard, 2001), facilitates many athletes returning to play before their injury is fully healed.

Physiological and Biological Related Risk Factors

Another intrinsic risk factor for injury that many authors have researched is the sex of the individual. An increased risk for anterior cruciate ligament (ACL) injury in females has been well established (Arendt & Dick, 1995; Chandy & Grana, 1985; Gray et al., 1985; Gwinn, Wilckens, McDevitt, Ross, & Kao, 2000; T. E. Hewett, 2000; Hickey, Fricker, & McDonald, 1997; Myklebust et al., 1998; Powell & Barber-Foss, 2000). Increased Q angle, increased joint laxity during menses, and decreased hamstring to quadriceps strength in females when compared to males are among the proposed reasons for an greater incidence of injury among women (Murphy et al., 2003).

Conflicting evidence exists regarding the relationship between sex and ankle specific injury. Hosea et al reported a 25% greater risk of sustaining a grade I ankle sprain for females when compared to males (Hosea, Carey, & Harrer, 2000). These authors also reported no difference in injury risk of sustaining a grade II, grade III, ankle fractures, or syndesmotic sprains between females and males. In contrast, Lindenfeld and colleagues reported a significantly higher risk of ankle injury in males when compared to females (Lindenfeld et al., 1994). Beynnon et al found no difference in the proportion of injury between females and males but reported that the risk factors for ankle injury are different between sexes (Beynnon, Renstrom, Alosa, Baumhauer, & Vacek, 2001). More research is necessary on the relation between sex and ankle specific injury.

The relationship between sex and all types of injury is unclear. Multiple sources reported females to have over twice the injury rate of males in Army recruits (Bell, Mangione, Hemenway, Amoroso, & Jones, 2000; Knapik et al., 2001). Backous et al reported an increased incidence of injury in females when compared to males in youth soccer (Backous, Friedl, Smith, Parr, & Carpine, 1988). Contrary to those findings,

Messina and colleagues reported high school basketball boys to be 1.14 times as likely to sustain an injury when compared to high school basketball girls (Messina et al., 1999). Stevenson et al also reported a greater injury rate among males when compared to females (Males: 19.0/1000 hours, Females: 13.6/1000 hours, $p < 0.05$) (Stevenson, Hamer, Finch, Elliot, & Kresnow, 2000). Also worth noting is that multiple authors reported no difference in injury rates between females and males (Beachy, Akau, Martinson, & Olderr, 1997; Bennell et al., 1996; Wiesler et al., 1996). The discrepancies in the literature can be explained by the differing injury definitions used, subjects studied, age of the subjects studied, sports studied, and statistical methods utilized between research articles. More research is necessary on the topic of sex and injury in general.

Movement Quality

Movement quality is defined as the ability of a person to move efficiently through functional movement patterns such as the overhead squat. Conflicting research exists on the relationship between movement quality and injury in athletes. The Functional Movement Screen (FMS) is a tool used by healthcare providers that identifies, rates, and ranks movement limitations and asymmetries. Kiesel et al reported that an athlete with a score of 14 or lower on the FMS predicted injury in professional American football players with a specificity of 0.91 and a sensitivity of 0.54 (Kiesel, Plisky, & Voight, 2007). Similarly, O'Connor and colleagues found that among officer candidates, a score of 14 or lower on the FMS predicted serious injury with a specificity of 0.94 and a sensitivity of 0.12 (O'Connor, Deuster, Davis, Pappas, & Knapik, 2011). In contrast, Sorenson reported that a score of 14 or lower on the FMS did not predict injury among

high school basketball athletes (Sorenson, 2009). More research is needed on the topic of movement quality and injury.

The practicality of utilizing a movement screen in a real world setting should be addressed. In situations where resources and the number of practitioners are abundant, a movement screen such as the FMS is easily employed. However, in many settings, there is only one practitioner to perform the screen and this practitioner has many athletes to work with. In such a case, utilizing a movement screen can be extremely time consuming. Additionally, as stated above, there is limited research to support the use of the FMS in clinical settings. Thus, in these settings the barrier for using a screen such as the FMS is high and therefore will likely not be utilized.

Muscle Strength Asymmetry

Limited evidence is present in the literature on the relationship between left-right muscle strength asymmetry in the frontal plane and injury. Knapik et al reported a significantly higher injury rate in collegiate athletes who exhibited a 15% or greater knee or hip extensor imbalance in the frontal plane when compared to athletes without such an imbalance (Knapik, Bauman, Jones, Harris, & Vaughan, 1991). In line with this finding, Nadler et al found that collegiate athletes with lower extremity injury or low back pain exhibited a significant frontal plane asymmetry of maximum hip extension strength when compared to athletes without injury or low back pain (S. F. Nadler, Malanga, DePrince, Stitik, & Feinberg, 2000). Similarly, Nadler and colleagues reported that a significant percent difference between right and left hip extensor strength was predictive of whether an athlete would exhibit low back pain in females (Scott F. Nadler et al., 2001).

Although the evidence is limited, the research that is present in the literature points toward an association between left-right frontal plane muscle imbalance and injury.

Aerobic Fitness

Much research exists regarding the relation between aerobic fitness and injury. Decreased aerobic fitness has been shown to be a predictor of injury in male and female army trainees as well as football players, (Bell et al., 2000; Chomiak et al., 2000; Jones, Bovee, Harris, & Cowan, 1993; Knapik et al., 2001). One author disagrees, Ostenberg et al reported no relation between aerobic fitness and injury in female soccer players (Ostenberg & Roos, 2000). The disagreement in the literature can be explained by the different methods used to define aerobic fitness as well as different populations studied. A few reasons have been proposed for why aerobic fitness is correlated to injury. A lower aerobic fitness level can lead to a reduction in the protective effect of the musculature (Murphy et al., 2003), as well as cause an athlete to lose focus and utilize altered motor patterns to accomplish athletic tasks when fatigued. Although more evidence points to an association between aerobic fitness and injury, the lack of uniformity in the evidence makes comparing studies difficult. More research will be necessary on this subject using uniform standards of what exactly aerobic fitness is as well as uniform populations.

Muscle Strength Imbalance

Much research exists investigating the relationship between muscle imbalance and injury. Muscle imbalance is different than left-right muscle asymmetry in that, left-

right muscle asymmetry refers to differences in strength in the frontal plane. For example, an athlete that has a strong right leg and a weak left leg is said to have a muscle asymmetry. Muscle imbalance refers to the musculature around a joint or group of joints. For example, an athlete that has strong right leg quadriceps strength and weak right leg hamstrings strength is said to have a muscle imbalance.

Strong evidence suggests that a small hamstring to quadriceps strength ratio is a predictor of lower extremity injury. Croisier et al reported athletes demonstrating a hamstring to quadriceps strength ratio of less than 1.4 to be at a significantly higher risk of hamstring injury (Croisier, Ganteaume, Binet, Genty, & Ferret, 2008). Likewise, Yeung et al found athletes with a hamstring to quadriceps strength ratio of less than 0.6 at an angular velocity of 180 degrees/second were 17 times more likely to suffer a hamstring injury (Yeung, Suen, & Yeung, 2009). Knapik and colleagues reported females with a flexor to extensor strength ratio of less than 0.75 at an angular velocity 180 degrees/second to be at a significantly higher risk of lower extremity injury (Knapik et al., 1991). Myer et al found that female athletes that suffered an ACL injury had a significantly smaller hamstring to quadriceps strength ratio when compared to their uninjured male counterparts (Myer et al., 2009). Similarly, Soderman et al reported female athletes that suffered an ACL injury exhibited a smaller hamstring to quadriceps strength ratio when compared to their uninjured counterparts (Soderman, Alfredson, Pietila, & Werner, 2001).

Limited evidence shows other strength imbalances to be related to other types of injury. Baumhauer and colleagues reported an ankle eversion to inversion strength ratio was significantly greater for the injured vs. the uninjured group of athletes with ankle

injuries (Judith F. Baumhauer et al., 1995). Wang et al found a lower shoulder external to internal rotation strength ratio in elite volleyball athletes that experienced either shoulder pain or injury (Wang & Cochrane, 2001). Lastly, Tyler et al reported a smaller hip adduction to abduction strength ratio in injured vs uninjured hockey players (Tyler, Nicholas, Campbell, & McHugh, 2001). Although there is a small amount of evidence showing a relation between other strength imbalances and injury, these research studies must be repeated in order to confirm these findings.

Muscle Strength

Many studies have investigated the relation between muscle strength and injury. Decreased muscle strength in athletes has been established as a strong predictor of lower extremity injury (Askling, Karlsson, & Thorstensson, 2003; Croisier, Forthomme, Namurois, Vanderthommen, & Crielaard, 2002; Fredericson et al., 2000; Timothy E. Hewett, Lindenfeld, Riccobene, & Noyes, 1999; Leetun, Ireland, Willson, Ballantyne, & Davis, 2004; J. Orchard, Marsden, Lord, & Garlick, 1997; Zazulak, Hewett, Reeves, Goldberg, & Cholewicki, 2007). Askling et al reported that a strength training program emphasizing eccentric overloading decreased the occurrence of hamstring strains among elite Swedish soccer players (Askling et al., 2003). Likewise, a few studies have reported a positive correlation between muscle strength and reduced injury risk in athletes when looking at the upper body (Pontillo, Spinelli, & Sennett, 2014; Wang & Cochrane, 2001). For example, Wang and colleagues reported that rotator muscle strength imbalance was correlated with shoulder injury or pain among elite volleyball athletes (Wang & Cochrane, 2001).

The relationship between muscle strength and ankle injury is less clear.

Baumhauer et al reported a decreased incidence of injury in athletes who exhibited a decreased eversion to inversion strength ratio in collegiate soccer, field hockey and lacrosse players (Judith F. Baumhauer et al., 1995). In contrast, Willems et al reported no difference in ankle strength between controls and subjects with previous ankle sprains in physical education students (Willems, Witvrouw, Verstuyft, Vaes, & De Clercq, 2002). In line with this finding, Beynnon et al reported that muscle strength was unrelated to ankle injury in collegiate soccer, field hockey, and lacrosse athletes (Beynnon et al., 2001). The inconsistency in the literature can be explained by differing planes of motion, testing speeds, inherent risks between sports, and sexes used between studies (Murphy et al., 2003). More research on the relationship between muscle strength and ankle injury is warranted.

Weak evidence supports no association between muscle strength and anterior knee pain (Witvrouw, Bellemans, Lysens, Danneels, & Cambier, 2001; Witvrouw, Lysens, Bellemans, Cambier, & Vanderstraeten, 2000). This is due to the fact that Witvrouw et al used poor testing procedure to determine quadriceps and hamstring strength levels. Witvrouw et al used isokinetic dynamometer testing performed with the subject in a non-weight bearing position and therefore cannot duplicate the type of physical activity nor injury mechanism involved in most sporting activities (Murphy et al., 2003). This reduces the internal validity of studies using isokinetic dynamometers. Additionally, isokinetic dynamometers are not readily available to the field of strength and conditioning, so the external validity of this measurement method is weak. There is a missing area in the research that will need to look at the correlation between strength

levels in functional movement patterns such as the squat and injury in athletic populations.

One can only speculate as to the possible reasons for why muscle strength is correlated to injury. Clearly, having sufficient muscle strength would seem desirable in order to control the limbs through running, cutting, and jumping movements. For example, if an athlete does not have adequate abductor strength when cutting, this athlete would be unable to keep his or her knee from caving in toward the midline of the body. Thus, the movement of cutting would cause significant damage to this athlete's musculoskeletal system.

Summary

Many factors exist, both extrinsic and intrinsic, that have been correlated to injury. The extrinsic factor level of competition has been shown to be strong predictor of injury most likely due to an athlete's drive to be successful no matter the cost. More research is necessary on other extrinsic factors of injury such as playing surface.

Many intrinsic factors have been shown to have a strong correlation with injury. Previous injury is an intrinsic predictor that has been shown to have a strong relationship with subsequent injury. Because of this finding, classifying those previously injured as susceptible to injury and taking steps to address weaknesses and prevent future injury would be a good plan of attack. Females have been shown to be at an increased risk for ACL injury. Additionally, athletes with a low hamstring to quadriceps strength ratio have been shown to be at an increased risk for knee as well as other lower extremity

injury. As such, targeting females with a low hamstring to quadriceps strength ratio with an intervention focused on increasing hamstring strength is warranted.

Diminished muscle strength and aerobic fitness are additional intrinsic factors that have been correlated with injury. An intervention program to increase strength and fitness in athletes is a reasonable solution to this problem. However, few studies have been done regarding which exercises will best increase strength and reduce injury risk in athletes. A study looking at the association between exercise type and incidence of injury would address this problem.

INTRODUCTION

Injury to athletes in sport occurs as a result of the high physical demands placed on the individual athlete's body by their sporting activity. Yang and colleagues reported over 1300 injuries sustained by around 600 collegiate athletes in 16 sports over a 4 year period (Yang et al., 2012). Additionally, these authors discovered an overall injury rate of 63.1 per 1000 athlete exposures. The financial costs to rehabilitate these injuries are significant. Knowles et al. reported annual statewide medical costs to be \$9.9 million, annual human capital costs to be \$44.7 million, and annual comprehensive costs to be \$144.6 million among athletes in North Carolina (Knowles et al., 2007). Based on the high prevalence and financial cost of injury among athletes, determining potential relationships between extrinsic and intrinsic risk factors and injury is warranted.

Study Purpose

Numerous predictors of injury to athletes, both extrinsic and intrinsic, have been proposed. Extrinsic factors such as weather, playing surface, and poor training choices have all been shown to predict injury in athletes (Hershman et al., 2012; Lynnette J. Mazur, 1993; Scranton P, 1997). Intrinsic influences such as previous injury, body mass index (BMI), aerobic fitness, and muscular strength levels have also been correlated with subsequent injury (Chomiak et al., 2000; Gregory D. Myer, 2009; Jones et al., 1993; Knapik et al., 2001). The argument could be made that the predictors of injury both extrinsic and intrinsic are multifactorial and inflexible, however, many factors correlated to injury can be influenced. For example, rule changes regarding tackling technique in high school and colleges in the 1980's reduced the occurrence of permanent cervical

quadriplegia from thirty four in 1976 to five in the 1984 season (Joseph S. Torg, 1985). Intrinsic factors have also shown to be accommodating to intervention. Ankle injuries have been shown to decrease in occurrence in response to a proprioception and coordination training program (Tropp, Askling, & Gillquist, 1985). Predictors of injury can and should be affected in such a way that results in positive outcomes regarding injury in sport. Among intrinsic predictors of injury among athletes, strength levels are of particular significance. A low hamstring to quadriceps ratio among female soccer players was shown to be a predictor of anterior cruciate ligament (ACL) injury (Soderman et al., 2001). Ankle strength levels as well as plantar flexion strength to dorsiflexion strength ratio was shown to be different between injured and non-injured ankles (J. F. Baumhauer, Alosa, Renstrom, Trevino, & Beynnon, 1995). Knapik et al. found that left right asymmetries in knee extensor strength was correlated to higher incidence of lower extremity injury (Knapik et al., 1991).

Based on the mounting evidence pointing toward decreased strength as a predictor of injury in athletes, strength and conditioning professionals for years have been attempting to design effective training programs that will help mitigate the risk of injury that athletes accept every time they step on the court or field of play. Up until this point, the research that has investigated the relationship between strength levels and rate of injury has used precise instrumentation to measure outcome variables that reduce confounders and increases internal validity. Isokinetic dynamometers are an example of such a measuring device. What is lacking in the body of evidence is research looking at strength levels with respect to functional exercises that are more specific to an athlete's particular sport. The power clean, the squat, and the bench press are examples of

exercises that mimic more closely the functional movement patterns involved in sport than does the isokinetic dynamometer. The squat, for instance, is an exercise where one is required to support one's own body weight under load in a dynamic movement pattern very similar to a jump. In contrast, the isokinetic dynamometer measures torque at a single joint. As such, the findings in studies using isokinetic dynamometers are not as applicable to athletes in dynamic sporting environments. By comparing strength levels in functional movement patterns to injury, the strength and conditioning professional will be able to design effective training programs to reduce the incidence of injury in sport better.

Specific Aims and Hypothesis

The purpose of this study was to determine the correlation between strength measured through dynamic strength exercises (power clean, the squat, and the bench press) among collegiate athletes and the incidence and severity of injury.

Input variables for both purposes of this study were low, moderate, and high severity injury measured in days missed from practice or games. The other input variable is incidence of injury among the different severity levels. Outcome variables for both purposes of this study were the subject's strength levels measured in kilograms for the power clean, the squat, and the bench press. The population for both purposes of this study included athletes competing for the South Dakota State University (SDSU) Jackrabbits over a two year period.

The hypothesis of this study was that greater incidence and severity of injury to collegiate athletes is correlated to low athlete strength to bodyweight ratios in the power clean, squat, and bench press.

METHODS

This study used strength measurement records from the last two years collected from the Department of Sports Performance at South Dakota State University. Injury rates were determined from injury records collected from the Department of Athletic Training at South Dakota State University. Prior to the collection of the data, approval was obtained by the South Dakota State University Institutional Review Board for the Protection of Human Subjects.

Subjects

This study utilized strength measurement from all individuals who participated in athletics at South Dakota State University during the 2011-2012 and the 2012-2013 school years. Additionally, injury records from that same population were reviewed and the severity of injury was recorded. Athletes with incomplete strength measurement or injury records were excluded. Athletes with missing bench press numbers were not included in the upper extremity injury group. Athletes with missing power clean or squat numbers were not included in the lower extremity injury group. Sports included were men's baseball, (n=9) basketball (n=12), football (n=45), and track and field (n=15). Women's sports included were basketball (n=8), soccer (n=18), softball (n=17), track and field (n=24), and volleyball (n=13). Data were analyzed separately for men and women.

Study Design

Members of the Strength and Conditioning Department at South Dakota State

University (Strength Staff) were responsible for collecting and maintaining strength measurement data. Members of this department were also responsible for supervising collegiate athletes as they attempted to perform the power clean, squat, and bench press. The Strength Staff determined if the lift was completed based on whether competency was achieved in a safe and effective manner. Measurements were taken at different times of year, different times of day, and were collected by different members of the Strength Staff. Although this method introduces confounding variables, this method is used by sports performance departments across the country and therefore will increase the external validity of the findings. Strength measurements of the squat, bench press, and power clean for the 2011-2012 and the 2012-2013 seasons were extracted from the database maintained by the Strength Staff.

Members of the Athletic Training Department at South Dakota State University were responsible for collecting and maintaining injury incidence and severity data. Different members of the Athletic Training staff collected the injury data. Although this method introduces confounding variables, it is typical of athletic training departments across the country and therefore will increase the external validity of the findings. Strength measurement data was then cross-referenced with the injury incidence and severity data.

Statistics and Data Analysis

Strength measurements for the power clean, squat, and bench press were normalized to bodyweight and then divided into quartiles. Quartiles of strength were calculated utilizing the statistical software JMP® 12.1.0 (SAS Institute, Inc.). Injuries

were differentiated into upper and lower extremity injury. Injury severity was classified as minor, moderate, and severe based on research done by Sandelin et al. 1988 (Sandelin, Santavirta, Lattila, Vuolle, & Sarna, 1988). Minor injury was defined as athletes being unable to participate in practices or competition for less than 1 week. Moderate injury was defined as athletes being unable to participate in practices or competition for 1 week to 3 weeks. Severe injury was defined as athletes being unable to participate in practices or competition for more than 3 weeks. An analysis of variance was utilized to determine if there were differences in number of injuries and severity of injury relative to quartile (JMP® 12.1.0, SAS Institute, Inc.).

RESULTS

Tables 1 and 2 provide the quartile range and quartile mean by year and sex for the squat, bench press and power clean exercises. Figures 1 through 12 provide a graphical representation of the quartiles by sex and year with the number of injuries by severity below each figure. The analysis of the data indicates that there were significantly more minor injuries compared to moderate and severe for both males and females in 2012 and 2013. However, there was no difference in the amount of injuries among each quartile within each lift indicating that there is no relationship between strength levels in the power clean, squat, or bench press and incidence of injury.

DISCUSSION

Summary/Results

The purpose of this study was to determine the relationship, if any, between strength levels in the major strength and power exercises (power clean, squat, and bench press) and incidence and severity of injury among collegiate athletes at South Dakota State University. An analysis of variance was used to compare normalized strength levels measured in the above-mentioned exercises to injury severity levels for both upper and lower extremity injury in both male and female athletes. We found there to be significantly more minor injuries when compared to moderate and severe injuries for both males and females for both years. However, there was no difference in the incidence of injury between strength quartiles indicating that there is no relationship between strength levels in dynamic strength exercises (power clean, squat, and bench press) and incidence of injury among student athletes at South Dakota State University.

Muscle strength levels have been shown in much of the research to be an intrinsic risk factor for injury. For example, Soderman et al reported female athletes that suffered an ACL injury exhibited a smaller hamstring to quadriceps strength ratio when compared to their uninjured counterparts (Soderman et al., 2001). Wang et al found an increase incidence of shoulder injury in male volleyball players who exhibited decreased eccentric external rotator cuff strength (Wang & Cochrane, 2001). Additionally, strength training interventions have been shown to decrease the risk of hamstring injury (Askling et al., 2003; Croisier et al., 2002).

Our results are contrary to much of the research on muscle strength's relation to injury. We found no relationship between strength levels in dynamic strength exercises

and incidence of injury. A number of factors may explain the discrepancy between our findings and those in the existing literature.

The first possible factor that may explain the discrepancy between our findings and those in the previous research is the differences in data collection methods. The previous studies have all used some variation of isokinetic dynamometer testing while we used weight lifted in multi-joint exercises in which the contribution from a specific muscle group cannot be identified. Another possible explanation for the discrepancy could be internal training load. A systematic literature review by Drew et al defined internal training load as the product of the rate of perceived exertion (10-point modified Borg) and duration (Drew & Finch, 2016). The authors of the review demonstrate there to be an increased injury risk for athletic populations experiencing sharp increases in internal training loads. In our study we did not have access to internal training load data and therefore could not determine what effect increases in training load had on our incidence of injury.

Lastly, the discrepancy between our findings and that of previous research can be explained by differences in sample sizes. Our study found significantly more minor injuries when compared to moderate and severe injuries among our student athlete population. Worth noting is that in the strongest quartile (quartile 4) for the power clean, squat, and bench press, we found relatively few severe injuries when compared to the weaker quartiles (quartile 1-3). However, this difference was not statistically significant due to a small sample size. Future studies should look at this relation between muscle strength and injury severity with larger sample sizes.

The relation of athlete muscle strength to injury severity is actually a missing area in the current literature. Strength and conditioning professionals accept that the elimination of injury in sport is not realistic. However, the goal is to reduce not only the incidence of injury, but also the severity. For example, if a weak athlete presents with a knee injury and is out for the season and a stronger athlete experiences the same injury mechanism and is only out for a week, then the stronger athlete would have a distinct advantage over the weaker athlete.

Limitations

One limitation of this study was that collection methods for the strength measurements were not precise. Additionally, different judges throughout the years were responsible for recording and maintaining the strength data. The use of different judges that record the squat differently reduced inter-rater reliability and decreased internal validity. However, the use of these methods increased the external validity of this study. This is because these methods are used at numerous strength and conditioning facilities across the country.

Another limitation of this study was using only athletes from SDSU. This limited the external validity of this study, thereby decreasing the applicability of the findings to other universities. However, it is unrealistic to gather data from other universities due to the lack of resources. Delimitations included using strength numbers for only the power clean, the squat, and the bench as outcome variables. This choice was made because the power clean, the squat, and the bench press have been used in training almost universally throughout the 21 varsity sports at SDSU over the last three years. Therefore, we were

able to increase the sample size higher than would have been possible including other exercises.

One strength of this study is the use of dynamic exercises in place of isokinetic dynamometers. Dynamic strength exercises such as the squat mimic more closely than an isokinetic dynamometer the demands imposed on an athlete in a chaotic sporting environment. This increases the internal validity of the findings. Additionally, because dynamic strength exercises are more specific to the athlete's sporting environment, strength and conditioning professionals across the country use these types of exercises to prepare athletes for the rigors of sport. Therefore, these measurements are easily obtained for those who wish to use them.

A weakness to this study is that previous injury to our athletic population was not considered. Previous injury is an established predictor of injury (Bahr et al., 1997; J. F. Baumhauer et al., 1995; Chomiak et al., 2000; Hägglund et al., 2006; McKay et al., 2001; Messina et al., 1999; Milgrom et al., 1991; J. W. Orchard, 2001; Surve et al., 1994; Wiesler et al., 1996). Thus, we are not able to determine the strength of the association between strength and injury because previous injury is a potential confounding variable.

Another weakness to this study is that we did not look at the specific type or mechanism of injury. Strength has been shown to have different correlations to the incidence of injury at different injury sites. For example, conflicting evidence exists regarding muscle strength and ankle injury (J. F. Baumhauer et al., 1995; Willems et al., 2002). However, knee strength imbalance between the knee extensors and flexors has been established as a strong predictor of injury (Croisier et al., 2008; Knapik et al., 1991; Myer et al., 2009; Soderman et al., 2001; Yeung et al., 2009). Additionally, the injury

mechanism may result in different relationships between muscle strength and injury. For instance, muscle strength may be important in preventing non-contact injury but not important in contact injury. Imbalance between knee flexors and extensors has been shown to be a strong predictor of non-contact anterior cruciate ligament injury (Croisier et al., 2008; Knapik et al., 1991; Myer et al., 2009; Soderman et al., 2001; Yeung et al., 2009). However, the resultant contact injury from the force of an opponent's full body mass accelerating through an athlete's knee is most likely not preventable. Future research should attempt to look at the relation between type or mechanism of injury and muscle strength.

Lastly, this study did not have a sufficient sample size. The incidence of injury between strength quartiles was not significant for any dynamic exercise or year among male or female athletes. A larger sample size may have been capable of showing this difference. Additionally, the trend for fewer severe injuries in the strongest strength quartiles may have been a significant difference with a larger sample size. Future research should use a larger sample population.

Summary/Conclusion

Based on the findings from our study, we are unable to determine the correlation between strength measured through dynamic strength exercises and the incidence and severity of injury among collegiate athletes. Unfortunately, there were just too few injuries among our population to make any definitive conclusions. Future research should attempt to do the following: determine the relationship between strength levels

and injury severity, control for confounding variables such as previous injury history, determine the relationship between strength levels and both type and mechanism of injury, and utilize a larger sample size.

TABLES

Table 1: Quartile distribution for Male athletes by year.

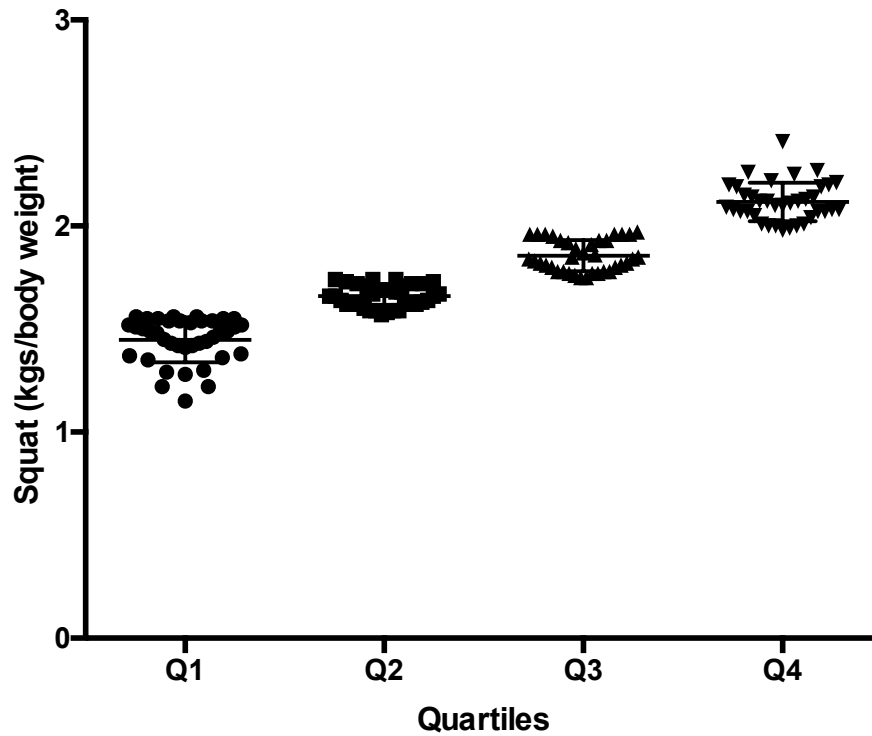
	Q1	Q2	Q3	Q4
2012				
Squat				
Quartile Range, kgs/bodyweight	1.15 – 1.56	1.57 – 1.74	1.75 – 1.97	1.98 – 2.41
Quartile mean \pm SD	1.45 \pm 0.44	1.66 \pm 0.05	1.86 \pm 0.07	2.12 \pm 0.09
Bench Press				
Quartile Range, kgs/bodyweight	0.89 – 1.12	1.13 – 1.26	1.27 – 1.40	1.41 – 1.90
Quartile mean \pm SD	1.04 \pm 0.07	1.20 \pm 0.04	1.34 \pm 0.06	1.60 \pm 0.11
Power Clean				
Quartile Range, kgs/bodyweight	0.82 – 1.0	1.1 – 1.23	1.24 – 1.35	1.36 – 1.65
Quartile mean \pm SD	1.01 \pm 0.08	1.18 \pm 0.03	1.29 \pm 0.03	1.45 \pm 0.08
2013				
Squat				
Quartile Range, kgs/bodyweight	0.79 – 1.57	1.58 – 1.74	1.75 – 1.97	1.98 – 2.50
Quartile mean \pm SD	1.43 \pm 0.17	1.66 \pm 0.05	1.86 \pm 0.07	2.16 \pm 0.13
Bench Press				
Quartile Range, kgs/bodyweight	0.58 – 1.12	1.13 – 1.25	1.26 – 1.38	1.39 – 1.90
Quartile mean \pm SD	1.03 \pm 0.12	1.19 \pm 0.03	1.32 \pm 0.03	1.53 \pm 0.10
Power Clean				
Quartile Range, kgs/bodyweight	0.82 – 1.14	1.15 – 1.26	1.27 – 1.38	1.39 – 1.61
Quartile mean \pm SD	1.03 \pm 0.08	1.20 \pm 0.03	1.32 \pm 0.03	1.47 \pm 0.06

Table 2: Quartile distribution for Female athletes by year.

	Q1	Q2	Q3	Q4
2012				
Squat				
Quartile Range, kgs/bodyweight	0.69 – 1.15	1.16 – 1.28	1.29 – 1.41	1.42 – 1.65
Quartile mean \pm SD	1.01 \pm 0.13	1.22 \pm 0.03	1.36 \pm 0.04	1.52 \pm 0.07
Bench Press				
Quartile Range, kgs/bodyweight	0.48 – 0.68	0.69 – 0.72	0.73 – 0.80	0.81 – 1.05
Quartile mean \pm SD	0.62 \pm 0.05	0.71 \pm 0.01	0.77 \pm 0.02	0.88 \pm 0.07
Power Clean				
Quartile Range, kgs/bodyweight	0.64 – 0.80	0.81 – 0.88	0.89 -0.96	0.97 – 1.29
Quartile mean \pm SD	0.75 \pm 0.05	0.87 \pm 0.03	0.94 \pm 0.02	1.05 \pm 0.09
2013				
Squat				
Quartile Range, kgs/bodyweight	0.82 – 1.07	1.08 – 1.26	1.27 – 1.39	1.40 – 1.78
Quartile mean \pm SD	0.96 \pm 0.7	1.16 \pm 0.06	1.32 \pm 0.04	1.53 \pm 0.09
Bench Press				
Quartile Range, kgs/bodyweight	0.5 – 0.65	0.66 – 0.72	0.73 – 0.79	0.80 -1.30
Quartile mean \pm SD	0.60 \pm 0.05	0.69 \pm 0.02	0.76 \pm 0.02	0.89 \pm 0.12
Power Clean				
Quartile Range, kgs/bodyweight	0.58 – 0.77	0.78 – 0.87	0.88 – 0.99	1.00 – 1.57
Quartile mean \pm SD	0.71 \pm 0.06	0.82 \pm 0.03	0.94 \pm 0.04	1.09 \pm 0.12

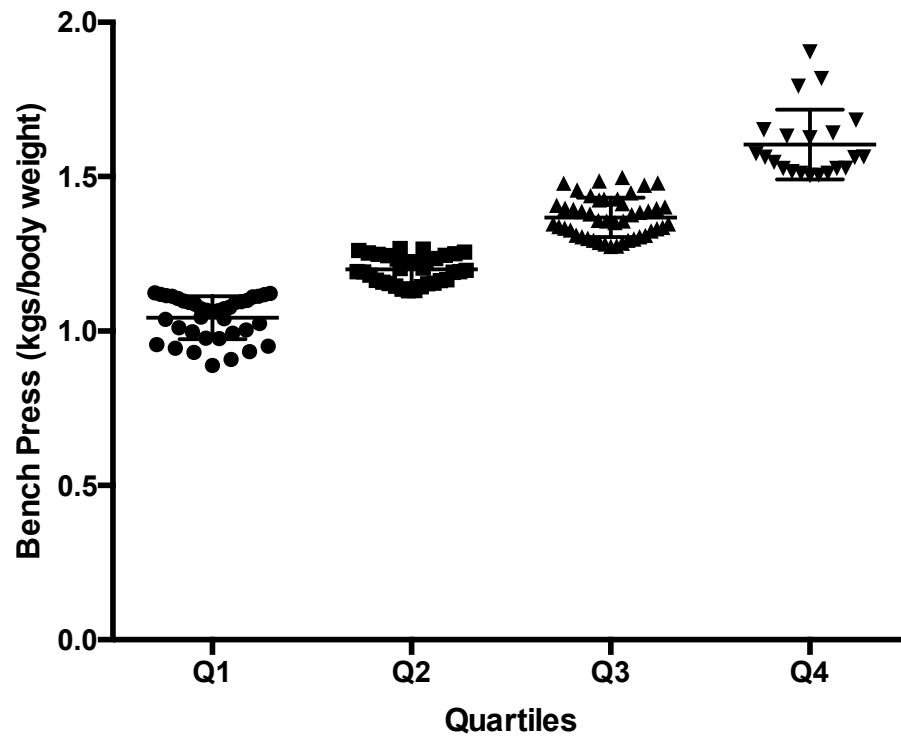
FIGURES

Figure 1: Male Athletes Squat 2012
 Quartiles of Strength in the squat exercise relative to body weight for male athletes in 2012



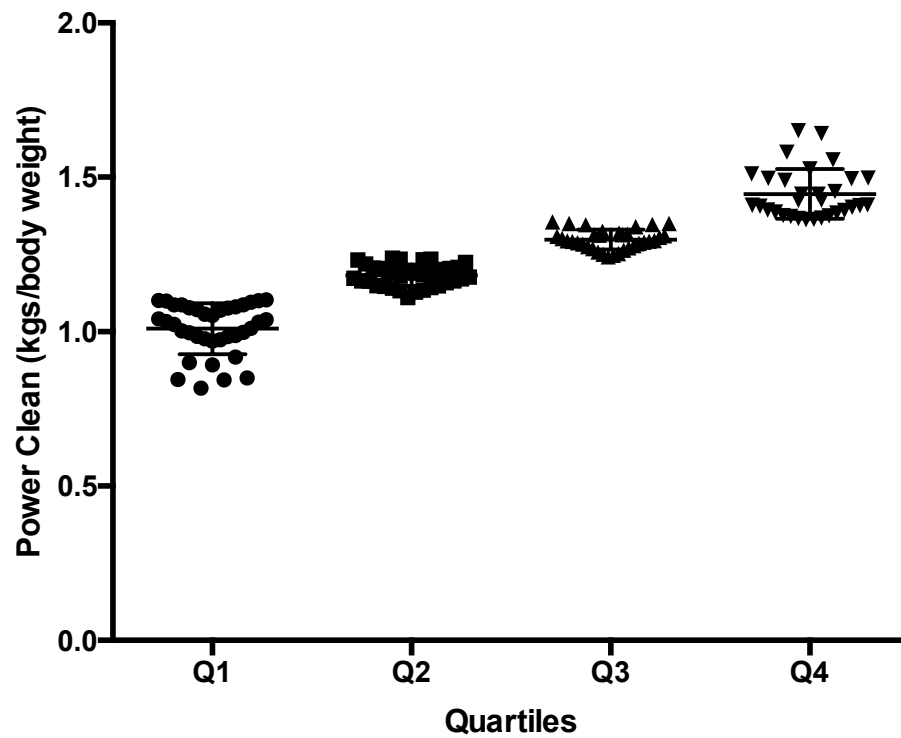
Severity	Q1	Q2	Q3	Q4	Total
Minor	8	9	3	7	27
Moderate	2	0	1	0	3
Severe	2	0	0	0	2
Total	12	9	4	7	

Figure 2: Male Athletes Bench Press 2012
 Quartiles of Strength in the bench press exercise relative to body weight for male athletes in 2012



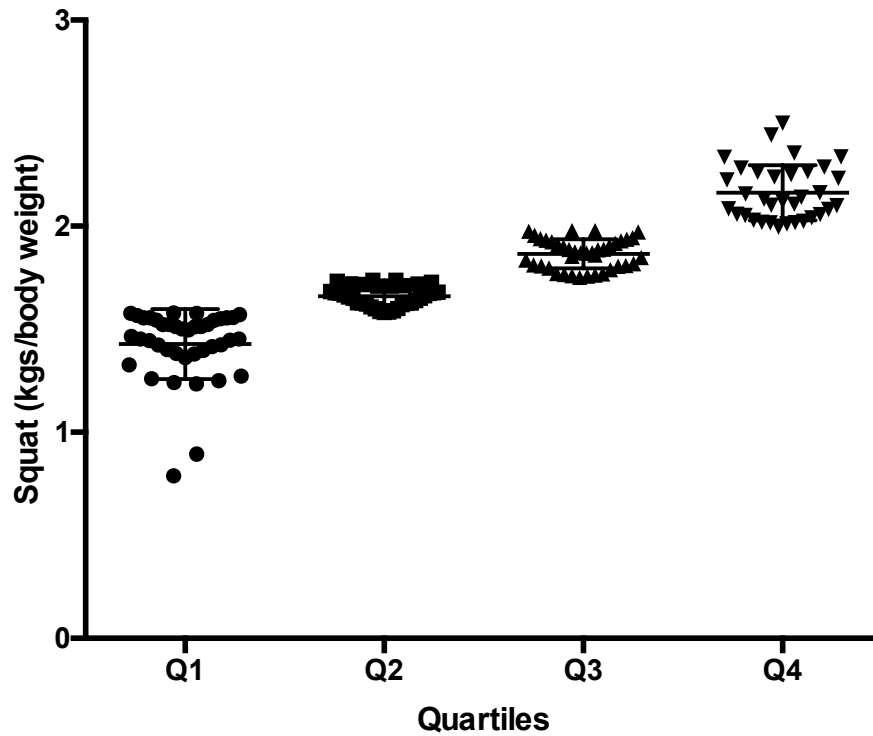
Severity	Q1	Q2	Q3	Q4	Total
Minor	2	1	3	2	8
Moderate	0	0	1	0	1
Severe	0	0	0	0	0
Total	2	1	4	2	

Figure 3: Male Athletes Power Clean 2012
 Quartiles of Strength in the power clean exercise relative to body weight for male athletes in 2012



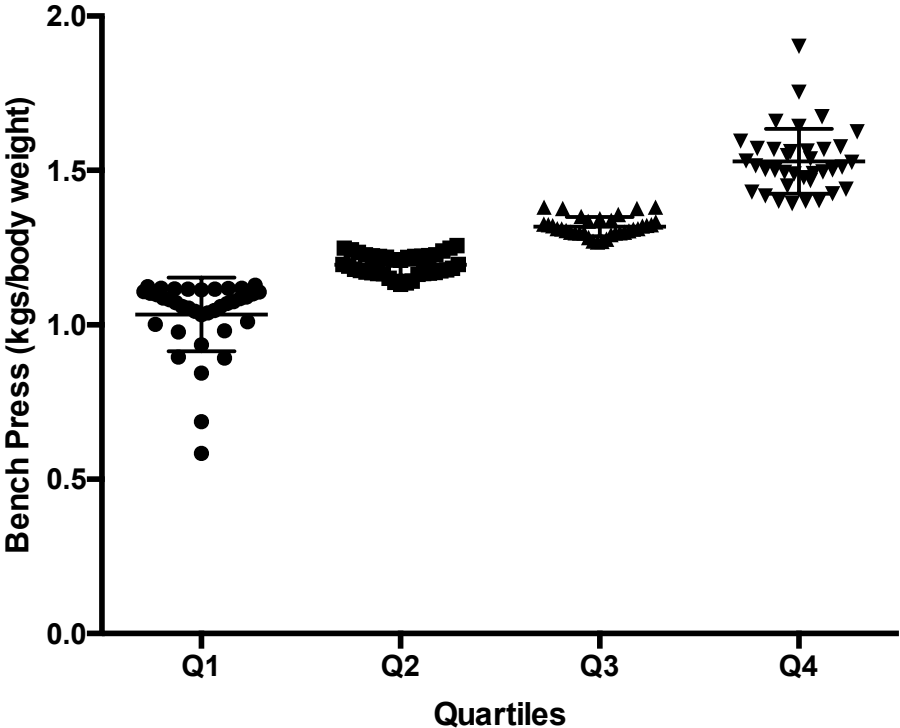
Severity	Q1	Q2	Q3	Q4	Total
Minor	5	7	6	6	24
Moderate	0	3	1	0	4
Severe	2	0	0	0	2
Total	7	10	7	6	

Figure 4: Male Athletes Squat 2013
 Quartiles of Strength in the squat exercise relative to body weight for male athletes in 2013



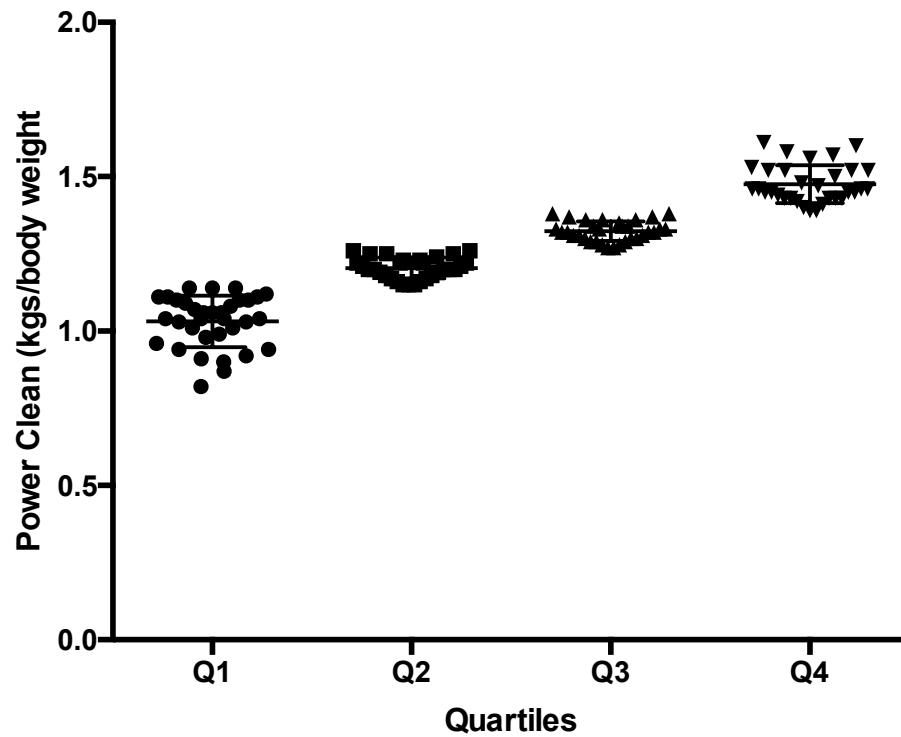
Severity	Q1	Q2	Q3	Q4	Total
Minor	5	6	12	6	29
Moderate	2	0	2	3	7
Severe	3	0	2	0	5
Total	10	6	16	9	

Figure 5: Male Athletes Bench Press 2013
 Quartiles of Strength in the bench press exercise relative to body weight for male athletes in 2013



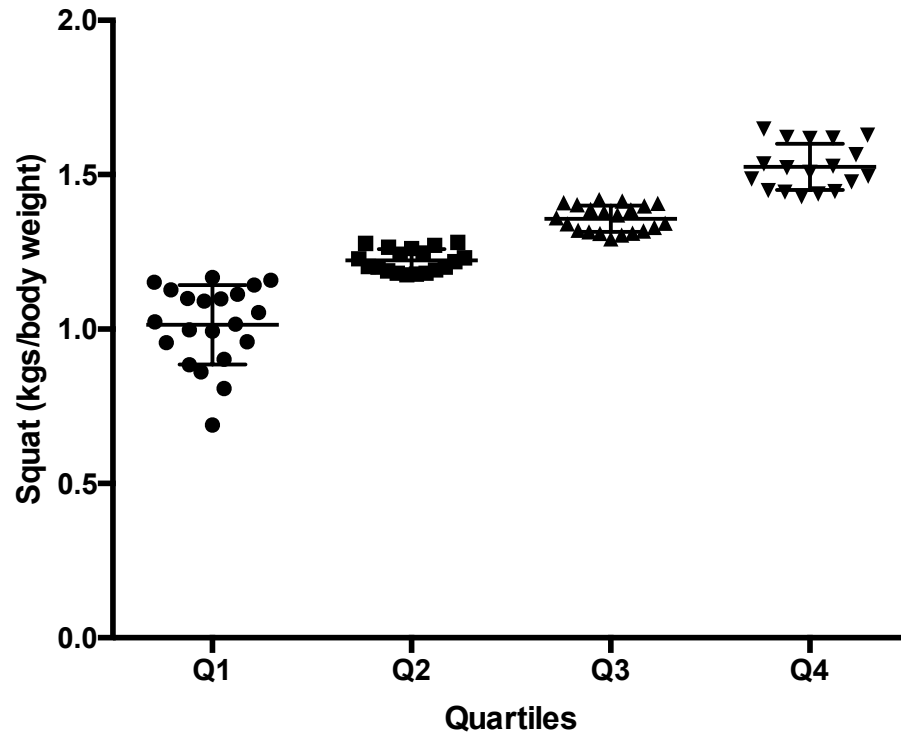
Severity	Q1	Q2	Q3	Q4	Total
Minor	4	1	3	4	12
Moderate	0	0	0	0	0
Severe	1	0	0	0	1
Total	5	1	3	4	

Figure 6: Male Athletes Power Clean 2013
 Quartiles of Strength in the power clean exercise relative to body weight for male athletes in 2013



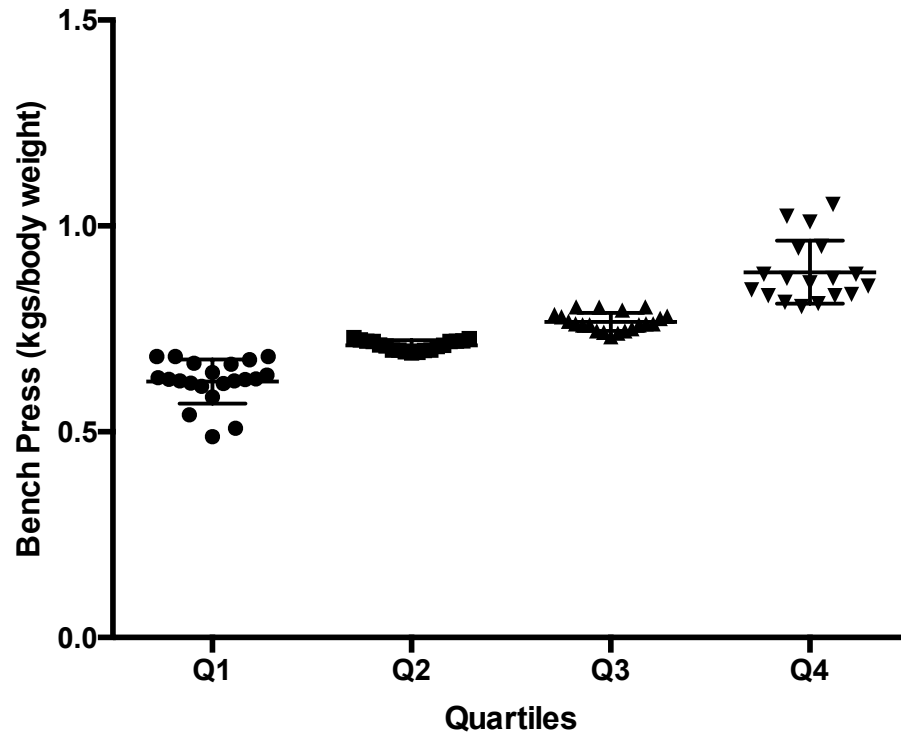
Severity	Q1	Q2	Q3	Q4	Total
Minor	6	6	10	7	29
Moderate	0	1	2	3	6
Severe	0	1	1	3	5
Total	6	8	13	13	

Figure 7: Female Athletes Squat 2012
 Quartiles of Strength in the squat exercise relative to body weight for female athletes in 2012



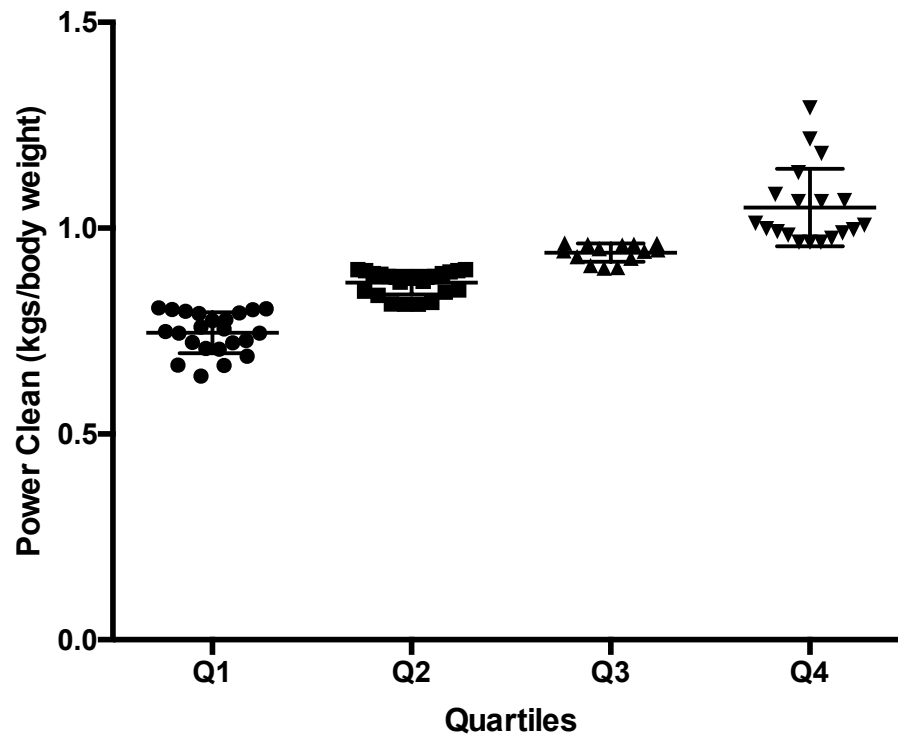
Severity	Q1	Q2	Q3	Q4	Total
Minor	9	7	6	10	32
Moderate	1	0	1	1	3
Severe	0	2	2	0	4
Total	10	9	9	11	

Figure 8: Female Athletes 2012 Bench Press
 Quartiles of Strength in the bench press exercise relative to body weight for female athletes in 2012



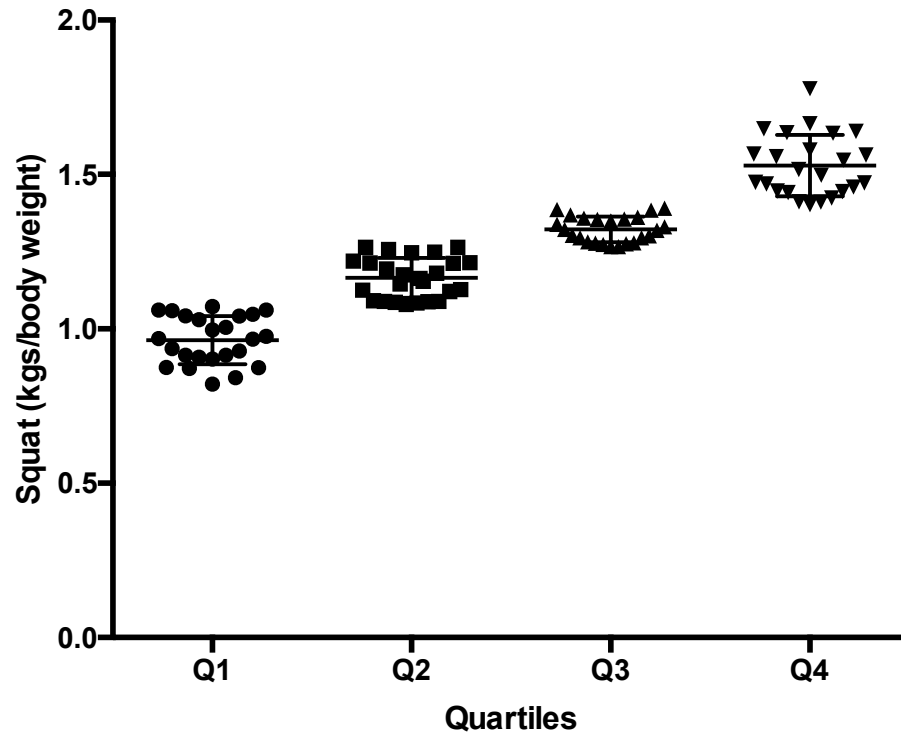
Severity	Q1	Q2	Q3	Q4	Total
Minor	1	0	2	4	7
Moderate	0	0	0	0	0
Severe	0	0	0	0	0
Total	1	0	2	4	

Figure 9: Female Athletes Power Clean 2012
 Quartiles of Strength in the power clean exercise relative to body weight for female athletes in 2012



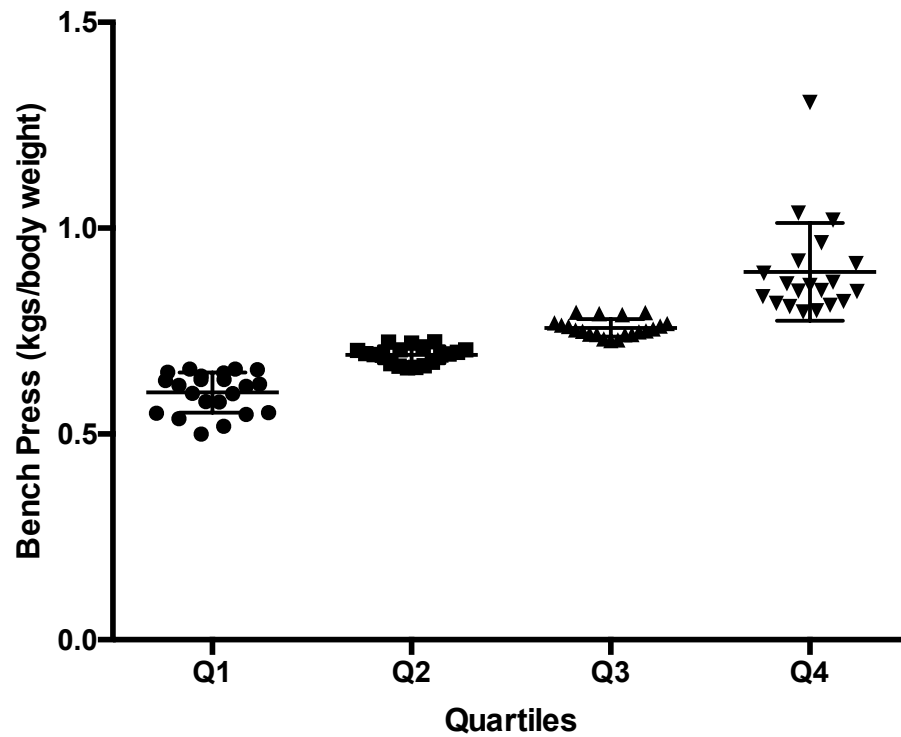
Severity	Q1	Q2	Q3	Q4	Total
Minor	6	7	11	8	32
Moderate	0	1	1	1	3
Severe	1	3	0	0	4
Total	7	11	12	9	

Figure 10: Female Athletes Squat 2013
 Quartiles of Strength in the squat exercise relative to body weight for female athletes in 2013



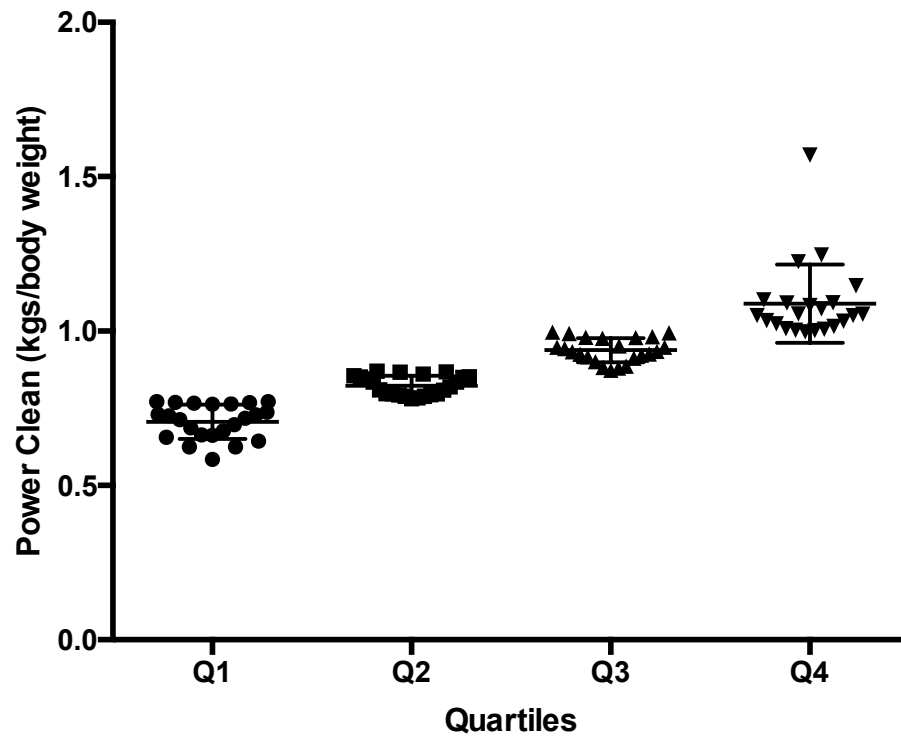
Severity	Q1	Q2	Q3	Q4	Total
Minor	6	4	11	4	25
Moderate	2	0	0	0	2
Severe	0	1	1	1	3
Total	8	5	12	5	

Figure 11: Female Athletes Bench Press 2013
 Quartiles of Strength in the bench press exercise relative to body weight for female athletes in 2013



Severity	Q1	Q2	Q3	Q4	Total
Minor	1	1	3	3	8
Moderate	0	0	0	0	0
Severe	0	0	0	0	0
Total	1	1	3	3	

Figure 12: Female Athletes Power Clean 2013
 Quartiles of Strength in the power clean exercise relative to body weight for female athletes in 2013



Severity	Q1	Q2	Q3	Q4	Total
Minor	7	6	5	6	24
Moderate	1	1	0	0	2
Severe	1	1	0	1	3
Total	9	8	5	7	

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