The relationship between strength and flexibility in powerlifters

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Abstract

Powerlifting is a strength sport comprised of the squat, bench press, and deadlift. To win, powerlifters must accumulate the greatest total, which is the sum of their heaviest successful attempts in the competition lifts. The addition of chronic stretching to powerlifting training may be beneficial for several reasons. Firstly, the squat and bench press are slow stretch-shortening cycle (SSC) movements, which may benefit from a more compliant musculotendinous unit. Secondly, male powerlifters have less range of motion (ROM) on average than sedentary men about the shoulder, hip, and knee. Finally, the areas with less ROM correspond with common areas of injury in powerlifters. While stretching may be beneficial to improve SSC performance and increase ROM, the stretching practices of powerlifters are unknown, and it is unclear if there is an optimal ROM for powerlifting. Therefore, the aim of this thesis was to investigate the relationship between strength and flexibility in powerlifters. Several investigations were undertaken to examine this relationship. Firstly, a survey was implemented with the purpose of identifying the prevalence and characteristics of stretching practices among powerlifters. Over 300 powerlifters from around the world participated and the main findings from this study were that irrespective of sex or competitive level approximately 50% of powerlifters reported participating in regular stretching. Of those who reported stretching, 78% stretched before training and 84% engaged in static stretching, while only 44% stretched after training. Following this, two cross-sectional studies were employed to determine active single-joint ROM in female and male powerlifters, respectively, compared with recreationally strength-trained controls, and to determine if single-joint ROM could be used to predict strength levels in powerlifters. Interestingly, female powerlifters did not have less ROM than recreationally trained women, and ROM was not a predictor for strength in female powerlifters. Whereas male powerlifters had less ROM in several movements about the shoulder (extension and horizontal abduction) and hip (flexion, extension, and adduction) than recreationally strength-trained men, and several movements (shoulder extension and horizontal abduction, hip flexion and extension) were useful to predict strength. The last series of studies were implemented to investigate the effects of chronic post-training stretching on powerlifting performance, to examine mechanisms that might contribute to changes in performance, and to observe ROM responses to strength training in the absence of stretching. The main finding of the first case study

was that ROM did not increase following eight weeks of stretching and it was concluded that stretching programmes like the one implemented may not be sufficient to improve ROM in more flexible strength-trained individuals. Two more case studies were undertaken and included strength-trained men with ROM similar to male powerlifters. Both stretching and strength-training increased ROM; however, stretching was more effective than resistance training. Strength improved in the squat and bench press for both participants irrespective of the area targeted by the stretching intervention. Additionally, there were no clear patterns connecting potential mechanisms to strength or ROM changes. Further research is needed to investigate the effects of chronic post-training stretching on powerlifting performance.

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Attestation of authorship

"I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning."

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Chapter 1 Introduction

Background and rationale

The goal of powerlifting is to lift the heaviest load for a single repetition in the squat, bench press, and deadlift. The heaviest successful attempt for each lift comprises the total, and the lifter with the heaviest total in each weight class wins. To increase maximal strength, powerlifters typically train the competition lifts with multiple sets at high intensities of 1–5 repetition maximum (RM) (144). This type of training puts considerable stress on the body and may increase injury risk (35,58). Limited range of motion (ROM) may also increase injury risk in athletic populations (87). Notably, in powerlifters the most commonly injured areas are the shoulder, hip, and knee (1,84) which correspond with joints where male powerlifters have less ROM than age-matched sedentary men (34,57). The specific movements where ROM is less in male powerlifters are those that lengthen muscles that are essential to the competition lifts. Shoulder flexion (57) and extension (34,57) lengthen the triceps brachii, and anterior deltoid and pectoralis major muscles, respectively, which are prime movers of the bench press (150). Hip flexion lengthens the gluteus maximus and knee flexion (34) lengthens the quadriceps, which are prime movers of the squat and deadlift (28,43). Shoulder (34,57) and hip rotation (34) lengthen the rotator cuff and deep hip rotators which stabilise the shoulder and hip, respectively. These connections may suggest that the reduced ROM results from the repetitive nature of powerlifting training. Interestingly, the extent of these differences is greater in stronger powerlifters (57). Thus, it is plausible that heavy training loads, specific/repetitive training, and/or strength adaptations contribute to lower ROM and injury risk in powerlifters.

Two of the competition lifts, the squat and bench press, begin with an eccentric contraction and transition quickly to a concentric contraction and thus may benefit from the stretch shortening cycle (SSC). The SSC enhances concentric force production following an eccentric contraction (127,162). Potential mechanisms of this enhancement include storage and use of elastic energy, increased reflex activity (22,23), cross-bridge kinetics, and residual force enhancement (55). Slow SSC movements may benefit from a more compliant musculotendinous unit, as it may more effectively store elastic energy (166,167). Thus, the involvement of the SSC in the squat and bench press presents the unique possibility to improve performance (85,166) and reduce injury risk (17,170) through other training methods, such as stretching.

While the stretching practices of powerlifters specifically are unknown, the use (9,77,118) and perceived value (9,20,76) of stretching is widespread among athletes. Stretching increases ROM and may improve powerlifting performance directly by augmenting strength (126) or indirectly through injury reduction (87), increased hypertrophy (45), or an enhanced SSC effect (85,166). Chronic stretching without resistance training has increased 1RM strength in sedentary to recreationally active individuals (85,126), and when combined with resistance training, chronic stretching has improved 1RM bench press in powerlifters (166). Similarly, stretching alone (116) and combined with resistance training (45) resulted in a significant increase in muscle thickness in sedentary men and minimally active individuals, respectively. The mechanisms underpinning the effects of stretching on performance are not yet established; however, decreased musculotendinous unit stiffness may be a possible mechanism for both SSC enhancement (166,167) and injury reduction (17,18,170). Taken together, these observations indicate that a stretching intervention has the potential to improve ROM, decrease injury risk, and ultimately improve squat, bench press, and deadlift performance in powerlifters. Though injury risk is difficult to quantify, less time away from training due to injury would likely improve powerlifting performance, a quantifiable outcome that is a focus of the thesis. Currently there is little research on the role of stretching and flexibility in powerlifters, therefore more research is needed to determine the stretching practices, the relationship between flexibility and strength, and the effects of chronic stretching in powerlifters.

Purpose of the research

The overarching aim of this thesis was to determine "what is the relationship between strength, flexibility and stiffness in powerlifters?" The specific research questions were:

1. What are the current stretching practices of powerlifters?
2. a) What are the current levels of flexibility and stiffness in powerlifters?
   b) Is there a relationship between strength, flexibility, and stiffness measures in these athletes?

3. a) Will the addition of stretching to a strength training programme affect strength performance?
   b) What is the mechanism of any stretching related changes in powerlifters?

Significance of the thesis

Strength is an important capacity across many athletic populations (156). In team sports such as rugby league, maximal strength is indicative of the level of play (10,11) and in individual sports such as powerlifting or Olympic weightlifting, athletes succeed based on their ability to lift more weight than their competitors. Strength is associated with decreased injury rates (8,100,156) which play an important role in athlete mental health and performance (37). Due to the importance of strength for athletes, it would be advantageous to find the most efficient method to induce strength gains.

Strength development is underpinned by neural and morphological factors typically acquired through resistance training. Neurological adaptations improve force production via motor unit recruitment, voluntary activation, and intermuscular coordination (50,139). As such, task-specificity is necessary. However, lifting heavy weights can produce large compressive and sheer forces within the body (35) and may increase injury risk (41). In contrast, morphological adaptations such as hypertrophy and decreased tissue stiffness may occur due to chronic stretching (45,85,116,166), which places relatively lower loads on the body. The addition of stretching to resistance training programmes may augment strength development through morphological adaptations, or by decreasing injury risk. However, little is known about the current flexibility practices of strength athletes. Additionally, while stretching may be beneficial for strength development (45,85,116,166), depending on the timing and duration stretching also has the potential to impair strength performance (16,79,148). Insight into the prevalence, type (e.g., static, dynamic, etc.), timing (e.g., before or after training, etc.), and duration of stretches utilised by strength athletes will allow for constructive and specific recommendations. Finally, given the limited research into the effects of chronic stretching combined with resistance training on strength development, further research is required to assess the effectiveness of this strategy among strength athletes.

Structure of the thesis

This thesis is presented in the pathway two format whereby each chapter following the introduction and preceding the conclusion is presented in the format of a journal article. Further, it is organised into three primary sections (Figure 1-1). The first section introduces the thesis (Chapter 1) and reviews the relevant literature in the areas of powerlifting, stretching, and stiffness (Chapter 2). The second section describes the use of stretching in international powerlifting federation (IPF) unequipped powerlifters (Chapter 3) and establishes current flexibility levels in female (Chapter 4) and male (Chapter 5) powerlifters. It also describes the technical difficulties with measuring stiffness in powerlifters (Chapter 6). The third section investigates the effects of flexibility training on an international-level powerlifter (Chapter 7) and in well-trained men (Chapter 8) as well as a general discussion of the thesis, limitations, practical applications, and recommendations for future research (Chapter 9). Chapters 3, 4, and 5 have been published in the *Journal of Strength and Conditioning Research*. As such, these chapters are presented in the format of the given journal.

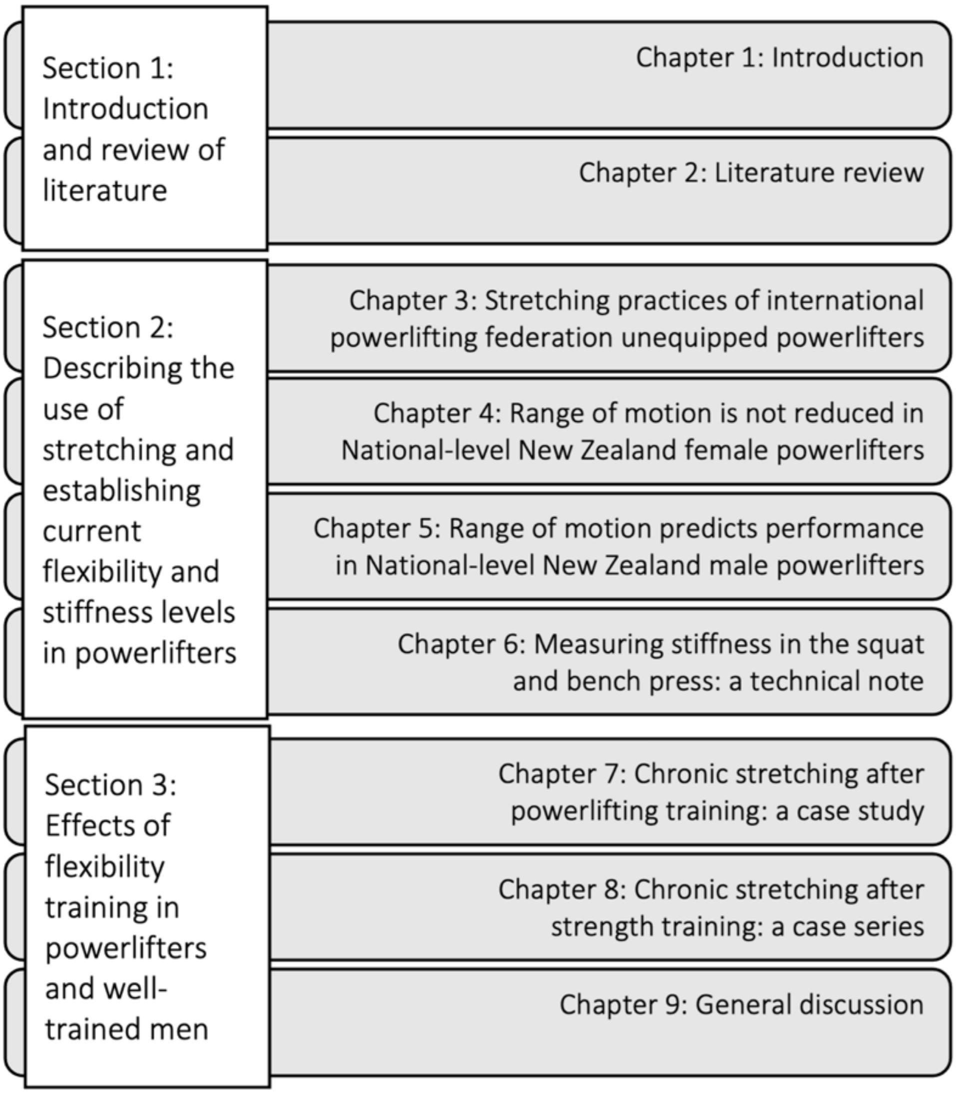

Figure 1-1 Thesis structure

Chapter 2 Literature review

Introduction

Powerlifting is a weight-class based strength sport. To win, powerlifters must accumulate the greatest total, which is the sum of their heaviest successful attempts in the squat, bench press, and deadlift. Both the bench press and squat utilise the stretch-shortening cycle (SSC), whereas the deadlift is a concentric only movement. SSC movements are characterised by an active muscle being lengthened (eccentric contraction) and then shortened (concentric contraction). The SSC allows for greater concentric work to be produced following an eccentric contraction compared to the work produced by a concentric contraction alone (32). The exact mechanisms underpinning the increased force production as a result of the SSC are not clearly elucidated but are theorised to be storage and use of elastic energy (22,23,56), stretch-induced residual force enhancement (56), and increased reflex activity (22,23).

Participation in powerlifting may result in sport-specific morphological adaptations; for example, male powerlifters have less ROM on average than sedentary men in movements about the shoulder (34,57), hip and knee (34). A certain amount of ROM about these joints in necessary for powerlifters to achieve regulation depth in the squat and bench press. However, purposefully limiting squat or bench press distance (independent of flexibility) is a strategy sometimes used to reduce work (work = force x displacement) in an effort to lift heavier loads, which may result in longitudinal loss of ROM. It is unclear if there is an optimal ROM, and if so, what it may be for powerlifters because the relationship between strength and flexibility in this population has not been investigated. Therefore, this review will explore the evidence on characteristics of successful powerlifters, and flexibility as it relates to powerlifting performance.

Competition lifts

Overview

Competitors are given three attempts each of the squat, bench press, and deadlift and must successfully complete at least one attempt of each lift to remain in the competition. Additionally, a ‘best overall lifter’ is determined via a relative strength index, such as a Wilks score, which is a validated method that allows comparison across weight classes (161). The Wilks score is determined using two tables of coefficients (one for men and one for women), body weight is used to find the appropriate coefficient and that coefficient is multiplied by the total to determine the Wilks score. Three referees decide lift success by majority vote, based on predetermined technical standards (72). These standards include squat depth (hip crease must dip below the top of the knee joint at the bottom of the lift), bench press depth (barbell must touch the chest), and bench press setup (head, shoulders, and buttocks must remain in contact with the bench for the duration of the lift) (72). Competitors are divided into groups by equipment (either allowing or not allowing supportive compression garments), age, and sex.

Back squat

The back squat requires coordinated actions and sufficient ROM of the hip, knee, and ankle that vary based on factors such as bar placement (high- or low-bar), stance, and depth. In competition a successful squat must achieve the minimum regulation depth, and to do so lifters are allowed to choose a bar placement and stance width. These choices may lead to variations in biomechanical characteristics of the lift. For example, the high-bar squat involves relatively greater knee flexion (61,121), ankle dorsiflexion (121), and a deeper bottom position (61,121) compared to the low-bar squat which involves relatively greater hip flexion (61), although these differences are more pronounced in recreationally trained lifters than competitive powerlifters and Olympic weightlifters (60). Additionally, a moderate to wide stance results in more hip flexion and less ankle dorsiflexion than a narrow stance (42,98). Interestingly, maximum squat depth has been associated with ankle dorsiflexion ROM in the lunge test ($r = 0.69$, $p = 0.001$) (62), so ankle flexibility may play a role in the stance an athlete chooses. When compared directly, the low-bar position has allowed for greater loads to be lifted than the high-bar position ($g = 0.13\text{-}0.39$, $p \leq 0.01$) (94,98). This is thought to be due to the greater emphasis on hip musculature than knee musculature in low- versus high-bar squats, respectively (60,98). As such, the low-bar squat may be preferable for powerlifters on average, although individual differences likely come into play as well.

Bench press

The bench press involves coordinated actions at the shoulder and elbow. In competition lifters can select their grip width, but it must not exceed 81 cm between index fingers. Lifters can arch their back, to reduce the vertical distance the bar must travel, as long as their head, shoulders, and buttocks remain on the bench (72). A wider grip decreases vertical displacement of the bar and results in more shoulder abduction, less shoulder extension, and less elbow flexion compared to a narrow grip (97). The wider grip may put more emphasis on the shoulder horizontal adductors, whereas a narrow grip may put more emphasis on the elbow extensors and shoulder flexors (111). When compared directly, a wide grip (81 cm) has allowed greater load to be lifted than a moderate or narrow grip (ES = 0.42–0.80, $p \leq 0.001$) (97,140). A moderate to wide grip has been suggested when the goal is to lift the most weight (63,97,140,141).

Deadlift

Similar to the squat, the deadlift requires coordinated actions at the hip, knee, and ankle. However, the deadlift begins with the concentric portion and finishes with the lifter standing erect; thus, unlike the squat there are no "depth" requirements for competition. To lift the barbell from the floor, powerlifters self-select one of two deadlift styles based on their preference and available hip ROM. The sumo deadlift requires relatively more ROM, specifically hip abduction and external rotation, than the conventional deadlift. This allows the sumo lifter to start the lift with a more upright torso, more horizontal thigh, and more vertical shin (43,113). Conversely, the conventional lifter starts with a relatively horizontal torso and shin, so the hip, knee, and ankle must pass through a larger ROM throughout the lift (43). Less mechanical work and a lower predicted energy expenditure (due to a lower centre of mass and reduced vertical bar displacement) (43), as well as less load shear forces at the L4/L5 (35) have been observed during the sumo compared to conventional deadlift. Both deadlift styles recruit the hip extensors similarly; however, based on 3D analysis of joint moments and electromyography, the sumo deadlift produces greater activation of the ankle dorsiflexors and knee extensors, whereas the conventional deadlift may more effectively recruit the ankle plantar flexors (43,44).

Training characteristics

The principle of specificity is easily applied to powerlifting training. There are no uncontrolled components in powerlifting competitions, it consists of three barbell lifts that can be replicated and progressively overloaded in training. Therefore, powerlifters can train with a very high level of specificity, and according to current research they generally take advantage of this option. Powerlifters typically squat 1-3 times, bench press 1-3 times, and deadlift 1-2 times per week (57) with bench press and bench press variations accounting for most upper body exercises (74.8%) and the back squat and deadlift accounting for most lower-body exercises (79.7%) (57). Powerlifters often train using multiple low-repetition sets (≤ 5) with heavy loads (1-5RM) and longer rest periods (3 minutes). This strategy is effective when training for maximal strength as well as hypertrophy when sufficient sets are performed (144). While strength is the primary goal for powerlifting, hypertrophy is also important as powerlifting performance is significantly correlated with muscle thickness ($r = 0.63$-0.91; $p \leq 0.01$) (26).

Very little is known about the flexibility training practices of powerlifters. A small sample ($n = 15$) of male powerlifters reported stretching 1.87 ± 0.54 days per week (57), but no additional details such as timing, type, or duration of stretching were given. Further, there is no information available for other individual strength sports such as strongman and Olympic weightlifting. There is some insight into stretching practices of strength-based team sport athletes, although it is minimal. In a recent survey of 83 rugby league players, 86% reported static stretching during their warm-up and more than 50% of those stretched for more than 15 minutes (118). In 2009 authors reported 91% of American football coaches ($n = 23$) had athletes stretch during the warm-up, with the majority (60.9%) using a combination of static and dynamic stretching. Fewer coaches (69.6%) had athletes stretch after training (77). Again, the duration of stretches was not reported. More information is needed on the stretching practices of powerlifters, as there is currently very little for any strength sport.

Physical characteristics

Competitive male powerlifters tend to be classified as endo-mesomorphs (82,83), demonstrating large girths and bone breadths (82), with large proportions of muscle mass (26,82). They are typically average to below average height (82). When categorising male powerlifters by competition placement (105) or by relative strength (Wilks > 410 versus Wilks < 370) (83), stronger lifters have significantly more muscle mass than weaker lifters. Similarly, muscle thickness (26), lean body mass (dual-energy x-ray absorptiometry (DEXA)) (48), and lean body weight (bio-impedance scale) (47) are all significantly correlated ($r = 0.63$-0.93) with powerlifting performance. Thus, hypertrophy is the single consistent measure that is positively associated with powerlifting performance. Other anthropometric measures such as Brugsch Index (chest girth/height) (47,83), crural index (shank to thigh ratio) (105), and chest girth (47) have been associated with male powerlifting performance, but less consistently. When comparing stronger to weaker powerlifters (Wilks score greater or less than 370), upper arm girth (flexed and relaxed) is greater among stronger lifters of both sexes (49). Only one study investigated the relationship between body composition and maximal strength of competitive female powerlifters ($n = 6$). In this study lean body mass (DEXA) was significantly positively correlated with absolute ($r = 0.83$-0.86, $p < 0.05$) but not relative strength ($r = 0.01$-0.31, $p > 0.05$) (48).

Powerlifting does not have high flexibility demands when compared to other strength sports such as Olympic weightlifting (24). In fact, male powerlifters have less ROM in several movements about the shoulder, hip, and knee than sedentary age-matched controls ($g = 0.66$-2.66, $p < 0.05$) (34,57). Chang et al. (34) measured active shoulder flexion, extension, internal and external rotation and found that powerlifters ($n = 10$) had significantly less ROM than the controls in all movements. Gadomski et al. (57) measured all passive movements at the shoulder and found that powerlifters ($n = 15$) had significantly less extension and internal and external rotation than controls with no significant differences in flexion or horizontal adduction and abduction. Interestingly, when powerlifters were divided into groups based on relative strength, the ROM discrepancies compared to the sedentary control group were only evident in stronger lifters (> 400 Wilks) and were the most pronounced in the elite lifters (> 500 Wilks). ROM differences in the lower body were less consistent, Chang et al. (34) measured active hip flexion and internal and external rotation and found powerlifters had significantly less ROM in each of these movements. Conversely, Gadomski et al. (57) found no significant differences between groups in passive hip flexion, extension, adduction, or abduction, but did not measure rotation. However, both Chang et al. (34)

and Gadomski et al. (57) showed that powerlifters had greater hamstring flexibility than controls. Notably, both studies included only male participants, therefore the findings may not be generalisable to female powerlifters.

Injury occurrence

Powerlifting has low to moderate rates of injury (1–4.4 injuries per 1000 hours of training) similar to other strength-based sports such as weightlifting (2.4–3.3 injuries/1000 hours of training) (1). Specificity of powerlifting training (heavy singles, high loads, competition lift focus) may be necessary for high performance in the sport due to the relatively narrow biomechanics of competitions, but may also contribute to injury risk. In a recent survey, 90 powerlifters who were currently injured or had previously been injured were asked what they thought was the cause of their injury. High training volume/intensity was the most common response (23.3%, 21/90), followed by poor technique (5.6%, 5/90), and poor mobility (5.6%, 5/90) (155). While these responses are subjective, they are supported as possible causes in the literature (58,87,149). Many repetitions at high loads (58), limited ROM (87), and lifting technique (149) have been identified as musculoskeletal injury risk factors. Moreover, areas where powerlifters have limited ROM correspond with common areas of injury in powerlifters: the shoulder (1,84,155), lumbopelvic area (1,84,155), hip (155), and knee (1,84). These restrictions occur in the prime movers of the squat, bench press and deadlift (anterior deltoid, pectoralis major, gluteus maximus, and the quadriceps), suggesting that they may result from the repetitive nature of powerlifting training. While previous research has not shown stretching to be effective in preventing injuries (16,100), these reviews have grouped all types of activity and sports together, and thus should be interpreted with caution. Witvrouw, et al. (170) and Behm and Chaouachi (17) suggested that stretching may reduce injury risk in sports involving maximal SSC movements and prolonged contractions because stretching can increase the compliance of the musculotendinous unit, and subsequently increase the capacity of the tendon to absorb energy. Furthermore, based on retrospective injury epidemiology, improving flexibility of the shoulder, lower back, elbow, and knee has been recommended to minimise injury risk in powerlifters (84). More research is needed to clarify the main injury risk factors and management options associated with powerlifting. However, based on these findings, it is plausible that a targeted stretching programme could increase ROM and possibly decrease injury risk. As no investigations have looked at the effects of stretching on injury risk management in powerlifting specifically, research is required in this area.

Flexibility

Overview

Flexibility describes the movement capacity of a joint or series of joints. Flexibility is a prominent component of many sports that can directly (e.g., powerlifting, where a certain level is required to successfully complete competition lifts) or indirectly (e.g., powerlifting, where increased flexibility might allow a lifter to reduce the distance the bar has to travel to complete a lift) affect performance. ROM is used to quantify flexibility; it can be measured actively, when the subject moves the body part without assistance, which is also referred to as mobility. ROM can also be measured passively, when an external force moves the body part while the subject remains relaxed. Goniometry is used to measure ROM about individual joints and gives relatively specific information. For example, the degree of knee flexion available largely reflects the flexibility of the knee extensors, although, the structures surrounding and making up the joint (e.g., joint capsules, ligaments, etc.) contribute as well (12). Since joints are crossed by several muscles or muscle groups and many muscles are biarticular, the ROM measured cannot be attributed to individual muscles. Some flexibility tests can be used to assess specific muscle lengths, for example the 'Thomas test' and 'rectus femoris test', which evaluate hip flexor and iliotibial band and rectus femoris "tightness", respectively (108). These are commonly used for clinical assessment; however, there is little evidence regarding the validity of muscle length tests. Other tests are used to assess flexibility across multiple joints, like the 'sit and reach' test which is used as a measure of lower back and hamstring flexibility. While convenient for field testing, the combination of movements involved may reduce validity. For example, a meta-analysis assessed the validity of the sit and reach test for estimating hamstring and lower back flexibility in healthy individuals, and it was only moderately accurate for describing isolated hamstring flexibility (corrected correlation mean ($r_{p)}$ = 0.46-0.67) and less accurate for the lower back (r_p = 0.16-0.35) (112). Passive torque or resistance to stretch are also measures of flexibility, they can be determined across different joint angles and the torque-angle curve can then be used to calculate stiffness (107). While colloquially flexibility and stiffness are sometimes used interchangeably, they are different but related measures (stiffness will be discussed in depth in a subsequent section). Active ROM is correlated with both active ($r = -0.369$-0.544, $p < 0.05$) (19,168) and passive stiffness ($r = -0.552$, $p = 0.001$) (19) such that higher levels of stiffness are associated with less ROM. Similarly, passive ROM has been associated with passive muscle stiffness and tolerance to stretch in healthy young adults (115). Interestingly, there appear to be sex-differences, as Miyamoto et al. (115) found that passive muscle stiffness and tolerance to muscle stretch were both associated with ROM in men, whereas only tolerance to muscle stretch was associated with ROM in women. While the exact factors underpinning ROM have yet to be fully established, it serves as a useful performance outcome (quantification of flexibility).

Stretching

Stretching via various methods can improve ROM; methods of stretching include static, dynamic, and peripheral neuromuscular facilitation (PNF) (106). Static stretching involves holding still in a position. It can be performed as constant angle stretching where the joint angle does not change for the duration of the stretch, and/or constant torque stretching where a constant level of torque is applied. Constant torque stretching does result in some movement at the joint and is not completely static, but still falls within the static stretching category (68). Dynamic stretching involves moving joints through their full ROM rather than holding in one place. PNF stretching involves contraction of the agonist and/or antagonist muscles. While it is generally agreed that all methods of stretching effectively increase ROM, there is less consensus around the mechanisms underpinning ROM improvements. Acute bouts of constant angle (90,92,123), constant torque (90,130), and PNF (80,92) stretching decrease muscle and musculotendinous stiffness, and passive torque (tolerance to stretch). PNF stretching can decrease tendon stiffness (80); whereas both constant angle (78,90,119) and constant torque (90) stretching seem to have no significant effect on tendon stiffness. Interestingly, the mechanisms may not be the same for acute and chronic ROM changes. A recent study assessed ROM, passive stiffness, and passive torque acutely after each session and after four weeks of stretching (54). Twenty-three healthy men completed 60 seconds of stretching for the plantar flexors, at either 100% (maximal pain free range; n = 12) or 120% intensity (n = 11). Significant improvements were found in all measures acutely, with greater improvements in the higher intensity group. However, only ROM and passive torque were improved when tested after the four weeks, and with no significant difference based on intensity (54). The authors postulated that four weeks may not have been sufficient to change passive stiffness, and that the lack of change in passive stiffness may explain the lack of a difference in ROM change between groups (54). However, this study as well as several others (for review see (52)) indicate that an increase in ROM is not necessarily accompanied by a structural change. That being said, chronic static stretching can decrease muscle (104,125,172), and musculotendinous (95,104) stiffness. The discrepancies in results are likely due in part to the variety of stiffness measures investigated (active, passive, muscle, tendon, musculotendinous) as well as the different durations and methodologies used for both stiffness measurements and stretching interventions.

Stiffness

Stiffness describes the capacity for structures to withstand change when forces are applied (Stiffness = Δ Force/ Δ Length of a given structure). Both contractile and noncontractile elements contribute to stiffness within the human body (99), and stiffness can be measured while muscles are contracting (active stiffness) or relaxed (passive stiffness). Measurements or estimations of stiffness can be made in individual structures (such as tendons, muscles, and muscle fibres) or more globally in single or multiple joints. Moreover, stiffness can refer to longitudinal or transverse force-elongation relationships in muscles and tendons (4). Historically, stiffness measurements required direct assessments of length and force (e.g., on cadavers). However, recent developments in ultrasonography enabled dynamic measurements of muscles and tendons in vivo, which when combined with measures of force can be used to determine passive stiffness (125) and active stiffness during isometric (74) and isotonic (96) contractions. To ensure clear images are captured, the ultrasound probe must be carefully fixed onto the tissue's surface, which requires unimpeded access to the structures of interest. Additionally, forces are typically estimated from joint moments, thus one must measure joint angles and moment arms or rely on normative data to calculate the forces on individual structures (145). These methodological considerations are likely the reason most research in this area focuses on passive stiffness, uniarticular muscles, and/or single joint movements.

Investigating the stiffness of individual tissue components is important for understanding how each contributes to human movement; however, in practice these structures work together. Additionally, how these structures interact is likely movement, intensity, and muscle specific (73). Therefore, when investigating the role of stiffness in performance, the task should be as sport specific as possible (167). Both excessive and limited stiffness are associated with injury risk (25,30), but optimal stiffness for both athletic performance and injury risk have yet to be defined and seems to be task specific (25,167). Wilson et al. (166) were the only researchers to examine how stretching affects stiffness and performance in experienced powerlifters. They implemented an eight-week stretching intervention that targeted the pectoralis and deltoid muscles. Four stretches were performed twice per week for eight weeks. The stretches consisted of one unloaded static stretch, two loaded static stretches, and one dynamic stretch. The free-oscillation technique was used to measure musculoarticular stiffness, such that participants lowered a barbell until it was approximately three centimetres above their chest, a perturbation was applied with a downward push of the researcher's hand, and the resulting oscillations were measured by force plate. Following the intervention, the experimental group had significantly more horizontal abduction (increased 13.1%) and significantly decreased stiffness at 70% of 1RM (7.2%). The experimental group also had significantly greater 1RMs in the touch and go bench press, and a nonsignificant (4.5%; $p = 0.10$) increase in concentric only bench press. The control group did not have any significant changes in any measure. The authors speculated that the decrease in stiffness improved the capacity for elastic energy storage, resulting in improved performance. No studies have replicated this procedure, possibly because it was recently demonstrated that the impulse applied during the perturbation affects stiffness and should be standardised (46), making the free-oscillation technique impractical for use with barbell exercises. An alternative method to estimate active musculoarticular stiffness in the bench press has been proposed by Hernández-Davó et al. (69). This method uses the vertical stiffness equation: stiffness $(k) = F / d$ where $F = m \times a$. Vertical stiffness is typically applied to running or hopping, with peak force measured on a force plate, and change in displacement of centre of mass calculated by double integration of the vertical acceleration. Hernández-Davó et al. (69) instead used a linear velocity transducer to calculate force, and displacement during the final 50 ms of the eccentric phase of a bench press. The authors suggest that during the last 50 ms of the eccentric phase the musculoarticular complex undergoes minimal length change, and the stiffness of the complex will theoretically influence the velocity of the barbell (69). This method is feasible to setup for barbell lifts, allows for appropriate movement and intensity, and thus, may serve as a practical performance measure of stiffness.

Possible effects of stretching on powerlifting performance

Acute stretching

Stretching may be necessary to improve ROM for some sports and/or for individuals who do not otherwise have sufficient ROM to perform movements in their sport. For example, some powerlifters may need to increase ROM with stretching to achieve the required squat depth. However, due to the possible acute performance decrements associated with static stretching there are several factors that need to be considered. The type of performance, timing of stretching, duration of stretching, circumstances (e.g., during a warmup), and individual flexibility all play a role in determining stretching best practice. A great deal of research has looked at the acute effects of stretching on performance and it is currently recommended that caution be used when implementing static stretching prior to strength-tasks (16,79,148), particularly before competition and in high performance athletes (33). This is because long duration (> 60 seconds per muscle group) static stretching has repeatedly been observed to reduce neural drive to the muscle resulting in a reduction in maximal force production (for review (160)). Additionally, while the effects of short duration (< 60 seconds per muscle group) static stretching on strength and power tasks are trivial, they are still prevalent (16,79). Although the stretching practices of powerlifters are unknown, static stretching prior to training is still common in other strength athletes (77,118).

Some research suggests that short duration stretching when included in a full warmup does not significantly impair strength-tasks (110,136). Several studies have been conducted in this area; however, there is not always an improvement in ROM after the stretching protocol (20) and many studies do not measure ROM (154,159,173). It is also important to note that of the studies that measured ROM, very few have measured strength. Reid et al. (136) included voluntary isometric contractions to determine peak knee extensor force and countermovement jump (CMJ) height, while Mascarin et al. (110) measured medicine ball throw maximum distance. Total stretching times of 30 seconds and 60 seconds (136), and 90 seconds (110) did not significantly impair performance; however, a warm-up without stretching resulted in the best performance outcomes. These results combined with evidence that static stretching may decrease the incidence of musculotendinous injuries (17,170), and evidence that some athletes feel more prepared after stretching (20) suggest that if short duration static stretching is performed prior to activity, it should be included early on in a full warm up to mitigate stretch-induced force loss. More research looking at the effects of stretching as a part of a warm-up on maximal strength are needed to determine if this recommendation would be beneficial for powerlifters. If acute improvement in ROM is not needed prior to lifting, it may be preferable to stretch after or independent of training and competition.

Chronic stretching

Stretch-shortening cycle

Several studies investigated the effects of chronic stretching on SSC movements with the focus on jumps or bench press as performance measures (71,85,102,166). While no studies investigated the squat specifically, CMJs have a similar kinematic profile, and performance between the two movements is strongly related ($r = 0.690$-0.836) (129). Results of these chronic stretching studies are predominately positive, as Kokkonen et al. (85), Lévénez et al. (102), and Wilson et al. (166) found that chronic stretching (ranging 5 to 10 weeks) improved vertical jump (6.7%), drop jump (9.1%), and bench press performance (5.4%), respectively. Stretching interventions in these studies were diverse indicating there is not a single effective stretching strategy. Kokkonen et al. (85) had participants ($n = 19$; 11 female) perform a series of 15 stretches targeting all major lower body muscle groups three times per week. Whereas Wilson et al. (166) had participants ($n = 9$; male) perform a series of four stretches targeting the prime movers of the bench press twice per week. Lévénez et al. (102) had participants ($n = 8$; 4 female) perform a single stretch targeting the plantar flexors three times per day seven days per week. Hunter and Marshall (71) observed partially positive results from stretching male team sport athletes four times per week, demonstrated by a significant improvement in CMJ performance but not drop jump performance compared to a control group (n = 14). The stretching programme targeted the major lower body muscle groups, and the stretching duration progressively increased over the course of the study. Interestingly, stretching combined with power training resulted in the largest improvement in CMJ (n = 14; g_{av} = 0.83), followed by power training alone (n = 11; g_{av} = 0.52), and stretching alone (n = 11; g_{av} = 0.22). Chronic stretching did not affect SSC performance in two studies. Yuktasir and Kaya (174) had participants (n = 28; male) stretch the knee flexors and plantar flexors simultaneously four times per week via static stretching in one group (n = 10) and PNF stretching in another (n = 9), and measured ROM and drop jump height. Both groups increased ROM, but neither stretching intervention affected drop jump height. This may be because the knee flexors are important for knee stability during jumping (169), but the knee extensors and plantar flexors are the primary muscle groups contributing to force production during jumping. Although Yuktasir and Kaya's participants did stretch their plantar flexors, they did not measure or report ankle ROM; so, it is possible that the plantar flexors were not adequately stretched. Similarly, Bazett-Jones et al. (15) had participants (n = 21; female) stretch their knee flexors four times per week and measured vertical jump and found no significant difference in ROM or vertical jump after 6 weeks of training. Of the studies mentioned above, only Wilson et al. (166) specifically included resistance-trained participants (powerlifters) and implemented upper body stretching. Based on these findings, there is evidence that chronic stretching of the primary muscle groups involved in the squat and bench press could prove beneficial for increasing squat and bench press performance; however, more research including resistance-trained participants is needed.

Strength

A number of studies investigated the effects of chronic stretching on non-SSC strength (concentric only, or multiple repetition performance) with mixed results. Kokkonen et al. (85) and Nelson et al. (126) found chronic static stretching of the agonist muscles for 10 weeks significantly improved 1RM performance in knee flexion (15.3%) and extension (32.4%), and standing plantar flexion (29%), respectively. Several other studies found partially positive results; Li et al. (103) combined static, dynamic, and PNF stretching of the hamstrings and found increased concentric knee flexion strength in female but not male participants after 8 weeks. Li and colleagues (103) hypothesized that strength significantly improved in women and not men because men had higher initial strength (142 ± 40.9 Nm versus 77.9 ± 22.4 Nm; d = 1.94) (103); however, no other studies investigated sex or initial strength differences in response to stretching. Mizuno et al. (116) compared chronic static stretching of the plantar flexors with and without electrical stimulation to a control group. They reported no significant group interaction, but significant 1RM improvement in only the stretching and stretching with electrical stimulation groups (static stretch with stimulation 22.4 ± 27.6%, p = 0.021; static stretch 20.2 ± 28.7%, p = 0.033; control 6.4 ± 18.3%, p = 0.575). Leite et al. (101) investigated the effects of dynamic stretching and resistance training, alone and combined, on women (n = 7/group) with at least three years of resistance training and stretching experience. This was the only study that included strength- and flexibility-trained participants, and they found a significant improvement in leg press 10RM for all groups, and a significant improvement in bench press 10RM for all but the stretching only group. While the results were positive, the strength improvements were greatest in the resistance training only group (Hedge's within group effect size (g_{av}) for flexibility group = 0.06 (bench press); 0.39 (leg press); combined group = 0.80 (bench press); 1.25 (leg press); resistance training group= 1.17 (bench press) 2.65 (leg press)). This may be because the stretching intervention was comprehensive and of similar length to the resistance training intervention (stretching: 60 min total, upper limb, lower limb, and trunk stretches. 3 sets of 30 repetitions versus strength: 8 exercises, 3 sets of 6-15 repetitions), thus the participants who did both interventions would likely have accumulated more fatigue. Similar to the study by Leite and colleagues (101), Simao et al. (147) investigated stretching and resistance training, alone and combined, but with a combination of upper and lower body static stretches in sedentary women. After 16 weeks, there was a significant improvement in leg press and bench press 10RM in the resistance training and combined groups. While there were no significant strength improvements for the stretching group, there was an increase in bench press 10RM (d_{av} = 0.50). While the effects of chronic stretching on strength appear positive, particularly in untrained females, more research is needed to determine if these effects would be similar in strength-athletes.

Hypertrophy

Some strength and conditioning researchers propose that the muscle tension produced from stretching might induce hypertrophy, which has been previously observed in animal models (6,163). However, there is limited research investigating the effects of chronic stretching on muscle hypertrophy in humans, and results in this area are conflicting. A recent review by Nunes et al. (128) concluded that based on the current evidence, low intensity stretching is insufficient, but loaded stretching or stretching between active muscle contractions may elicit muscle hypertrophy. This review included 10 studies from 2012-2019. Since then, several more studies have been published, but the results are equivocal. Notably, where training status was reported participants ranged from sedentary to recreationally active, with no mention of resistance training experience. Both Evangelista et al. (45) and Nakamura et al. (124) implemented inter-set static stretching of the agonist muscle(s) in untrained males; however, only Evangelista found a significant increase in muscle thickness in the stretching group (n = 12), and only in one of the four muscles measured (vastus lateralis: 7.07% change control, 17.22% change inter-set stretching). Three other research groups investigated chronic stretching without resistance training lasting 5-12 weeks with stretches totalling two to 30 minutes per session, but there were no significant differences in muscle thickness measures between stretching and control groups in any of these studies (104,134,171). Importantly, none of these studies used an external load while stretching. These results agree with the above-mentioned review that low intensity stretching alone is not sufficient to elicit hypertrophy; however more research combining stretching with resistance training is needed.

Conclusion

Male powerlifters have less ROM than sedentary men in some movements about the shoulder (34,57) and hip (34). These ROM differences are more pronounced in more competitive lifters (57) and correspond with common areas of injury in powerlifting (1,84,155). Stretching is an effective tool to increase ROM and could plausibly reduce injury risk in sports with maximal SSC movements (17,170). Moreover, stretching can enhance force production in SSC movements (166), improve strength (85,126) and could possibly induce hypertrophy (45), all of which have the potential to improve powerlifting performance. However, very little research has investigated the effects of stretching in powerlifters. Further research is needed to investigate ROM adaptations in female powerlifters, and to determine the effects of chronic stretching on powerlifting performance.

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Prelude

The review of literature (Chapter 2) identified potential benefits of stretching for powerlifters as well as the importance of timing and duration of stretches. It also revealed how little is currently known about the stretching practices of powerlifters. Therefore, the first priority was to determine if powerlifters engage in regular stretching, and if so, the specific types, timing, and durations used.

Chapter 3 Stretching practices of International Powerlifting Federation unequipped powerlifters

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Introduction

Powerlifting is a strength sport comprised of the squat, bench press, and deadlift. Competitors are given 3 attempts to lift the heaviest weight in each of these lifts and win by accumulating the greatest total -the sum of their best successful squat, bench press, and deadlift attempts. Due to the nature of the competition, training for powerlifting consists primarily of the 3 competition lifts, and close variations of them (e.g., pause squat, close grip bench, deadlift variations etc.). Participation in powerlifting continues to rise and more research has been undertaken and is available (48,133,177). Previous surveys have explored training practices (146,158) and tapering practices (65,135) of powerlifters. These have provided insights into the strength training and recovery strategies employed but give little insight into flexibility training. Approximately half of powerlifters reported employing stretching or mobility work during their taper (65,135), but no additional information regarding frequency, duration, or timing was reported.

The relatively narrow biomechanics of powerlifting and resulting specificity of training is necessary for high performance in the sport; however, it may also contribute to decreased ROM and injury risk (58). Powerlifters have been shown to have distinct ROM deficits such as decreased passive (57) and active (34) ROM about the shoulder joint, and decreased active hip and knee flexion ROM (34). These restrictions occur in the prime movers of both the bench press and the squat (anterior deltoid, pectoralis major, gluteus maximus, and the quadriceps), suggesting that these limitations may result from the repetitive nature of powerlifting training. Furthermore, the ROM restrictions correspond with common areas of injury in strength sports: the shoulder (1,84,155), lumbopelvic area (1,84,155), hip (155), and knee (1,84). While previous research has not shown stretching to be effective in preventing injuries (16,100), these reviews have grouped all types of activity and sports together, thus should be interpreted with caution. Witvrouw et al. (170) suggested that stretching may reduce injury risk in sports involving maximal stretch shortening cycle (SSC) movements because it can increase the compliance of the musculotendinous unit and subsequently increase the capacity of the tendon to absorb energy.

Stretching has consistently been shown to increase ROM acutely (16) and chronically (71,85,102,166). Furthermore, chronic stretching has been shown to improve performance in SSC movements (71,85,102,166) and thus could plausibly improve squat and bench press performance (but likely not the deadlift, as it is not preceded by an eccentric muscle action); however, static stretching immediately before strength activities has been shown to decrease performance (17,79). A dose-response effect is seen with pre-strength task stretching where longer durations (≥ 60 sec) elicit greater reductions in performance (16,79). Therefore, the timing and duration of stretching practices is important when trying to optimise strength performance.

Currently little is known regarding the stretching practices of powerlifters. Therefore, the purpose of this study was to determine how prevalent stretching is amongst powerlifters and investigate the ways stretching is performed and utilised.

Methods

Experimental approach to the problem

An anonymous online survey was implemented with the purpose of identifying the prevalence and characteristics of stretching practices among unequipped powerlifters. Unequipped powerlifters (competing without the use of specially designed assistive garments; bench press shirts, squat suits, etc.) were recruited through social media (Facebook, Twitter, and Instagram) via a recruitment poster, which included the link needed to access the survey. The survey was available from May until August 2019. Based on the ROM deficits seen in powerlifters (34,57) the research hypothesis was that most powerlifters would not regularly engage in stretching.

Subjects

Four hundred twenty powerlifters accessed an online survey via Qualtrics. Once partial responses were removed 319 responses remained and were analysed. Powerlifters from 51 countries participated in this online survey. Participant inclusion criteria were powerlifters who were at least 16 years old, were currently training for powerlifting, and had competed in at least 1 unequipped IPF sanctioned powerlifting competition. A survey was considered completed and included for analysis when participants completed at least 97% of questions.

An information sheet describing the objectives and purpose of the study as well as risks and benefits was included as the first page of the online survey. Due to the anonymous nature of the survey participants were advised on the information sheet that by submitting the survey they were consenting to participate. Participants were able to exit the survey at any time. The research was approved by Auckland University of Technology Ethics Committee on 5 August 2019, AUTEC Reference number 19/150.

Procedures

Powerlifters completed a self-reported survey consisting of 37 questions. The survey consisted of 4 main sections; (1) demographics and background information; (2) training practices; (3) injury status and history; and (4) stretching practices. Background information included questions on age-class, sex, weight-class, resistance training experience, powerlifting training experience, and highest level of competition (having competed at a regional/club, national, or international competition). The training practices section included questions on the number of training sessions per week for each of the 3 main lifts and variations, current best lifts, best Wilks score, and coaching. Wilks score was used as it is a method by which strength can be compared across athletes of different sexes and weight classes (161). The injury section included questions on injury status (are you currently injured) and the timing of any injuries that occurred during the individual's powerlifting career (during competition and/or training). The stretching practices section included questions on the types and timing of stretching (static and/or dynamic stretching and/or foam rolling; before and/or after and/or independent of resistance training). In addition, there were questions about stretching volume (sets and repetitions) and duration.

Statistical analyses

Mean and SDs as well as medians and interquartile ranges (IQR) were calculated for the resistance training experience, training practices, and stretching volume. Frequencies of responses were calculated for demographics and stretching practices. Categorical and ordinal data were reported as both absolute numbers and percentage of responses.

Non-parametric tests were used as data did not follow normal distribution. Specifically, Mann-Whitney U tests were used to determine whether any statistical differences were present in the background information, training practices, and stretching practices of powerlifters as a function of sex. Kruskal-Wallis tests with pairwise comparisons were used to determine whether any statistical differences were present in the background information, training practices, and stretching practices of powerlifters in each competitive standard (i.e., club/regional, National, and International). Chi-square tests were used to determine associations between sub-groups for categorical data. Significance was accepted at the $p \leq 0.05$ level. All statistical analyses were performed using SPSS 25.0 for Windows (SPSS Inc., Chicago, IL, USA).

Results

Training experience and characteristics

Training experience and characteristics are presented in Table 3-1. The powerlifters had 7.69 ± 6.05; 6.00, 6.00 (mean ± SD; median, IQR) years of general resistance training experience, 4.41 ± 4.45; 3.00, 3.00 years of strength specific training, and 3.00 ± 3.67; 2.00, 2.00 years competing in powerlifting. Sub-group analyses revealed that men had significantly greater general resistance training experience (years) (7.80 ± 5.77; 6.00, 6.00 vs 7.38 ± 6.88; 4.00, 6.00; $p = 0.015$). International level lifters had significantly more strength specific training than club/regional level lifters ($p = 0.02$), and time competing (years) increased significantly as the level of competition increased (Regional to National $p = 0.005$, National to International $p = 0.02$, Regional to International $p < 0.001$), Wilks score also increased significantly as the level of competition increased (Regional to National $p < 0.001$, National to International $p = 0.002$, Regional to International $p < 0.001$) but did not significantly differ between sexes. The powerlifters trained the squat 1.94 ± 0.75; 2.00, 1.00 times per week, bench press 2.35 ± 0.96; 2.00, 1.00 times per week and deadlift 1.41 ± 0.64; 1.00, 1.00 with no significant differences occurring between sexes. When comparing across level of competition, club/regional lifters performed squat variations (front squat, pause squat etc.) significantly more than international lifters (1.62 ± 0.94; 2.00, 1.00 vs 1.30 ± 1.08; 1.00, 1.00; $p = 0.043$), and trained the bench press significantly less frequently than international lifters (2.25 ± 0.94; 2.00, 1.00 vs 2.66 ± 0.94; 3.00, 1.00; $p = 0.042$).

Coaching and injury status

Coaching and injury status of powerlifters are presented in Table 3-2. Approximately half of the athletes (49.2%) were coached. Sub-group analysis revealed a significant association between sex and coaching status (X^2 (1) = 32.935, $p < 0.001$) with 77.2% of females having a coach and 40% of males having a coach. There was also a significant association between competitive standard and coaching status (X^2 (2) = 15.003, $p < 0.001$) with 78.4% of international level lifters having a coach and 43.5% and 48.4% of club/regional and National level lifters, respectively, having a coach. Twenty-one percent of lifters were currently injured. Sub-group analysis revealed significant associations between sex and injury status (X^2 (1) = 5.564, $p = 0.025$) and competitive standard and injury status (X^2 (2) = 8.112, $p = 0.016$). More females than males were injured (30.4% vs 17.9%) and more National and International than club/regional level lifters were injured (29.7% and 28.4% vs 15.5%). Of people who had been injured at some point during their time as a powerlifter, 67.4% of those were injured during training, whereas only 11.3% had been injured during a competition. Sub-group analysis revealed a significant association between competitive standard and injury incidence during a competition. Injury incidence increased as level of competition increased with 8.6% of club/regional level lifters, 11.6% of National level lifters, and 24.3% of international level lifters reporting in-competition injuries

Table 3-1 Training experience and characteristics (mean ± SD; median, IQR)

	Sex			Competitive Standard		
	All (n = 319)	Male (n = 240)	Female (n = 79)	Club/Regional (n = 186)	National (n = 95)	International (n = 37)
Experience (years)						
General RT	7.69 ± 6.05; 6.00, 6.00	7.80 ± 5.77; 6.00, 6.00 ~	7.38 ± 6.88; 4.00, 6.00 ~	7.08 ± 5.01; 6.00, 5.00	7.78 ± 5.01; 6.00, 5.00	10.50 ± 9.46; 7.00, 11.50
PL training	4.41 ± 4.45; 3.00, 3.00	4.34 ± 4.01; 3.00, 3.00	4.61 ± 5.60; 3.00, 3.00	3.97 ± 3.86; 3.00, 3.00 $	4.56 ± 4.75; 3.00, 3.00	6.27 ± 5.90; 4.00, 6.00 $
Competing	3.00 ± 3.67; 2.00, 2.00	3.01 ± 3.90; 2.00, 2.00	2.95 ± 2.90; 2.00, 3.00	2.30 ± 1.88; 1.50, 2.00 #*	3.32 ± 3.78; 2.00, 2.50 #^	5.67 ± 7.27; 3.00, 4.50 *^
Training (sessions/week)						
Squat	1.94 ± 0.75; 2.00, 1.00	1.92 ± 0.75; 2.00, 1.00	1.99 ± 0.76; 2.00, 1.00	1.88 ± 0.75; 2.00, 1.00	1.96 ± 0.72; 2.00, 1.00	2.12 ± 0.81; 2.00, 0.80
Squat variations	1.55 ± 0.96; 1.00, 1.00	1.57 ± 0.98; 1.00, 1.00	1.48 ± 0.89; 1.00, 1.00	1.62 ± 0.94; 2.00, 1.00 $	1.51 ± 0.95; 1.00, 1.00	1.30 ± 1.08; 1.00, 1.00 $
Bench	2.35 ± 0.96; 2.00, 1.00	2.38 ± 0.97; 2.00, 1.00	2.25 ± 0.92; 2.00, 1.00	2.25 ± 0.94; 2.00, 1.00 $	2.42 ± 0.97; 2.00, 1.00	2.66 ± 0.94; 3.00, 1.00 $
Bench variations	2.09 ± 1.08; 2.00, 2.00	2.09 ± 1.13; 2.00, 2.00	2.08 ± 0.91; 2.00, 2.00	2.18 ± 1.12; 2.00, 1.10	1.93 ± 1.03; 2.00, 2.00	2.01 ± 0.96; 2.00, 2.00
Deadlift	1.41 ± 0.64; 1.00, 1.00	1.42 ± 0.65; 1.00, 1.00	1.37 ± 0.60; 1.00, 1.00	1.36 ± 0.64; 1.00, 1.00	1.48 ± 0.63; 1.00, 1.00	1.49 ± 0.69; 1.00, 1.00
Deadlift variations	1.22 ± 0.79; 1.00, 1.00	1.21 ± 0.80; 1.00, 1.00	1.24 ± 0.75; 1.00, 1.00	1.29 ± 0.79; 1.00, 1.00	1.12 ± 0.81; 1.00, 0.00	1.11 ± 0.67; 1.00, 0.00
Competitive standard						
Wilks score	366.39 ± 52.20; 365.00, 60.00	368.71 ± 50.41; 370.00, 62.18	358.98 ± 57.27; 356.00, 68.50	351.11 ± 43.06; 350.0, 60.57 #*	376.24 ± 48.03; 382.0, 51.40 #!	416.29 ± 67.00; 425.0, 66.85 *!

Significant differences marked as: ~ p < 0.05; * p < 0.01; $ p < 0.05 regional-national; # p < 0.01 national-international; ^ p < 0.05; ! p < 0.01

Table 3-2 Coaching and injury status

		Sex		Competitive Standard		
	All	Male	Female	Club/Regional	National	International
Coaching						
Coached	157 (49.2)	96 (40)	61 (77.2)	81 (43.5)	46 (48.4)	29 (78.4)
Self-coached	162 (50.8)	144 (60)	18 (22.8)	105 (56.5)	49 (51.6)	8 (21.6)
		X^2 (1) = 32.935, p < .001			X^2 (2) = 15.003, p < .001	
Injury Status						
Injured	67 (21)	43 (17.9)	24 (30.4)	29 (15.6)	27 (28.4)	11 (29.7)
Not injured	252 (79)	197 (82.1)	55 (69.6)	157 (84.4)	68 (71.6)	26 (70.3)
		X^2 (1) = 5.564, p < .05			X^2 (2) = 8.112, p < .05	
Injury history						
Training	215 (67.4)	163 (67.9)	52 (65.8)	118 (63.4)	70 (73.7)	26 (70.3)
Competition	36 (11.3)	23 (9.6)	13 (16.5)	16 (8.6)*	11 (11.6)*	9 (24.3)*
No injuries	68 (21.3)	51 (21.3)	17 (21.5)	46 (24.7)	14 (14.7)	8 (21.6)
					*X^2 (2) = 7.608, p < .05	

(Percentage in brackets)

Stretching characteristics

General stretching characteristics of powerlifters are presented in Table 3-3. Approximately half of the athletes (52.4%) reported stretching regularly. Most (66.9%) programmed the stretching into their own training, while 10.2% had stretching programmed by their coach. Of those who stretched, 90.4% performed static stretching and 84.4% performed dynamic stretching. Stretching was most commonly performed before resistance training (77.8%), but also often performed after resistance training (43.7%) and independent of resistance training (53.9%). Sub-group analysis revealed an association between sex and stretch time, females were more likely to stretch after resistance training than males (66% vs 35%; $p < 0.001$).

Specific stretching characteristics of powerlifters are presented in Table 3-4. The powerlifters had 5.79 ± 7.56; 3.00, 5.00 years of flexibility training. The average stretching frequency was 4.26 ± 1.76; 4.00, 2.00 days per week and stretching sessions lasted 16.91 ± 14.12; 15.00, 10.00 minutes. When static stretching was included in the sessions 6.56 ± 3.33; 6.00, 4.00 stretches were completed for 5.50 ± 4.75; 3.00, 8.00 repetitions, and held for 33.51 ± 31.56; 25.00, 25.00 seconds. Women had significantly more years of flexibility training than men ($p = 0.028$), and international level lifters had significantly more years of flexibility training than club/regional level lifters ($p = 0.008$) and National level lifters ($p = 0.002$).

A Kruskal-Wallis test revealed no significant differences in stretching characteristics (frequency, duration, etc.) based on the timing of stretching (before, after, or independent of resistance training). However, a Mann-Whitney U test revealed that powerlifters who static stretch before resistance training do significantly more repetitions ($p = 0.01$) and hold for significantly less time ($p = 0.001$) than those who static stretch after and/or independent of resistance training (Table 3-5).

Table 3-3 General stretching characteristics

		Sex		Competitive Standard		
	All	Male	Female	Club/Regional	National	International
Stretching						
Yes	167 (52.4)	120 (50)	47 (59.5)	92 (49.5)	55 (57.9)	20 (54.1)
No	153 (47.6)	120 (50)	32 (40.5)	94 (50.5)	40 (42.1)	17 (45.9)
Programmed						
Self	111 (66.9)	81 (67.5)	30 (63.8)	59 (64.1)	38 (69.1)	14 (70)
Coach	17 (10.2)	10 (8.3)	7 (14.9)	8 (8.7)	5 (9.1)	4 (20)
Not	38 (22.9)	29 (24.2)	9 (19.1)	24 (26.1)	12 (21.8)	2 (10)
Type						
Static	141 (84.4)	100 (83.3)	41 (87.2)	79 (85.9)	46 (83.6)	16 (80)
Dynamic	151 (90.4)	107 (89.2)	44 (93.6)	85 (92.4)	49 (89.1)	17 (85)
Foam roll	115 (68.9)	79 (65.8)*	36 (76.6)*	62 (67.4)	40 (72.7)	13 (65)
		***** X^2 (1) = 4.127, $p < .05$				
Timing						
Before RT	130 (77.8)	94 (78.3)	36 (76.6)	73 (79.3)	41 (74.5)	16 (80)
After RT	73 (43.7)	42 (35)*	31 (66)*	41 (44.6)	24 (43.6)	8 (40)
Independent	90 (53.9)	66 (55)	24 (51.1)	50 (54.3)	32 (58.2)	8 (40)
		* X^2 (1) = 15.919, $p < .001$				

(Percentage of those who stretch in brackets)

Table 3-4 Specific stretching characteristics (mean ± SD; median, IQR)

		Sex		Competitive Standard		
	All	Male	Female	Club/regional	National	International
Years of stretch training	5.79 ± 7.56; 3.00, 5.00	5.06 ± 6.84; 3.00, 4.00~	7.68 ± 8.97; 4.00, 8.50~	4.58 ± 4.71; 3.00, 5.00*	5.32 ± 7.85; 2.00, 4.00#	12.60 ± 12.60; 7.00, 20.00*#
Frequency (days per week)	4.26 ± 1.76; 4.00, 2.00	4.21 ± 1.87; 4.00, 2.00	4.39 ± 1.44; 4.00, 1.00	4.18 ± 1.40; 4.00, 2.00	4.26 ± 2.02; 4.00, 2.00	4.68 ± 2.41; 4.00, 1.00
Session duration (min)	16.91 ± 14.12; 15.00, 10.00	16.53 ± 15.41; 15.00, 10.00	17.89 ± 10.19; 15.00, 10.00	17.17 ± 12.97; 15.00, 10.00	18.31 ± 17.53; 15.00, 10.00	11.85 ± 5.48; 12.50, 8.80

Significant differences marked as: ~ $p < 0.05$; * $p < 0.01$; $ $p < 0.05$ regional-national; # $p < 0.01$ national-international; ^ $p < 0.05$; ! $p < 0.01$

Table 3-5 Static stretching characteristics before versus after or independent of resistance training (mean ± SD; median, IQR)

	Before (n=111)	**Not before** (n=30)
Stretch frequency (per week)	4.27 ± 1.64; 4.00, 1.00	4.13 ± 2.30; 4.00, 4.00
Stretch session length (min)	17.22 ± 14.55; 15.00, 10.00	19.33 ± 15.69; 15.00, 21.30
Number of stretches	6.46 ± 3.22; 6.00, 4.00	6.90 ± 3.73; 6.00, 4.50
Number of repetitions	6.72 ± 10.31; 5.00, 8.00*	4.13 ± 4.16; 2.00, 9.00
Length of hold (sec)	30.82 ± 31.40; 20.00, 15.00^	42.92 ± 30.84; 30.00, 32.50

Significant differences marked as: * $p < 0.05$, ^ $p < 0.01$

Discussion

This study is the first to describe the stretching practices of powerlifters. The main findings from this study are that irrespective of sex or competitive level approximately 50% of powerlifters reported participating in regular stretching. Of those who reportedly stretch, 78% stretched before training and 84% engaged in static stretching. Those who static stretched before resistance training did more repetitions 6.72 ± 10.31; 5.00, 8.00 versus those who stretched after or independent of training 4.13 ± 4.16; 2.00, 9.00 ($p = 0.01$) and held stretches for a shorter duration 30.82 ± 31.40; 20.00, 15.00 versus 42.92 ± 30.84; 30.00, 32.50 ($p = 0.001$); however, the average powerlifter who stretched before resistance training still held stretches for a total of 100 seconds. Previous research suggests that sixty seconds or longer of static stretching is likely to cause significant strength-task performance decrements (16,79). The current findings disagree with the hypothesis that most powerlifters would not engage in regular stretching but highlight the importance of educating athletes and coaches on the acute effects of stretching.

General characteristics of stretching such as if it is regularly practiced, if it is programmed, and type of stretching (static or dynamic) were consistent across both sexes and all competitive levels. The only difference found was that females were more likely to stretch after resistance training ($p < 0.001$). Specific characteristics of stretching such as stretching frequency and session length were not different; however, females had significantly more years of flexibility training than males ($p = 0.028$) and international level powerlifters had significantly more years of flexibility training than both regional/club level ($p = 0.008$) and national level powerlifters ($p = 0.002$). The additional years of flexibility training in international level powerlifters is likely due in part to this group having a greater percentage of females than other groups (41% compared to 24% in club/regional and 21% in National). International level powerlifters also had significantly more years of powerlifting training during which they may have begun stretching; however, the number of years of general training among international powerlifters was not significantly different from other groups, so it is most likely the greater proportion of females among international lifters rather than their training background that contributes to this difference.

Twenty-one percent of powerlifters reported being injured at the time they completed the survey. In a previous study looking specifically at powerlifting injuries, most powerlifters (70%) reported being currently injured (155). The definition of an injury used by Strömbäck et al. (155) was pain or impairment that affected training but did not prevent or cause modifications to training, whereas this study did not give a formal definition and was likely interpreted to be more severe. Systematic reviews have suggested that injury rates are low in powerlifting compared to common team sports (1,84). These studies have accepted multiple definitions of injury, but most included needing to modify or refrain from training. More powerlifters reported having been injured during training than having been injured during competition (67% vs 11%), and the frequency of injuries that occurred during competition increased with the level of competition ($p = 0.016$). Strömbäck and colleagues (18) also found that lifters were more often injured in training than in competition but surveyed only sub-elite powerlifters (ranked below the top 25%) and could not compare competitive levels. It is important to note that powerlifters engage in many more training sessions than competitions throughout their career, and if we were to account for that difference, injury frequency would be greater in competition than training. Years competing in powerlifting also increased significantly with level of competition ($p < .05$), so the increased injuries with increased level of competition may be a result of having more years of competition and likely having done more competitions. More females than males reported being injured (p = 0.025) and more National and International than club/regional level reported being injured (p < 0.016) at the time they completed the survey. Previous studies found no difference in injury occurrence rate (injuries per year) by sex (81,155) or competitive standard (81). This difference may be due to the increase in female participation over recent years, and also the increase in level of competition for both sexes. The heaviest official total for unequipped open males increased from 935kg in 2008 to 1092.5kg in 2018 (~17% increase), for females it increased from 347.5kg to 675kg (~94% increase) in that same timeframe (176). The level of competition for both sexes has increased, but the percentage increase for females is greater, which can potentially be attributed to the increase in participation and may also contribute to increased injury occurrence.

Previous research has shown that powerlifters have both passive (57) and active (34) ROM deficits about the shoulder, hip, and knee joints. Gadomski and colleagues (57) found that ROM deficits were not significant in low level powerlifters (Wilks < 400) but were significant in moderate level powerlifters (Wilks 400-500) and most notable in elite powerlifters (Wilks >500). This suggests that the additional years of flexibility training reported in international level powerlifters may not negate the ROM deficits seen in powerlifters. Stretching practices may not be sufficient to increase ROM, may not target the areas showing deficits, or the small sample of elite lifters in the study by Gadomski et al (6) may not have included those who regularly stretch. This survey did not include questions regarding the specific areas being stretched or the intensity of stretching, which would likely have provided more insight into the connection between stretching practices and ROM deficits and should be included in future research. Additionally, Gadomski and colleagues (6) included only male participants, and the results of this survey indicate that females have more years of flexibility training. Thus, it would be worthwhile for future research on ROM in powerlifters to include a female group.

A negative perception of acute static stretching, specifically prior to strength-tasks, among the sport science community has emerged in recent years as it has repeatedly been shown to impair strength performance (17,79). The National Strength and Conditioning Association recommendations also take into account the potential for performance decrements and suggest that athletes perform static stretches during the cool down or a separate session as opposed to before exercising, unless their sport requires high levels of flexibility (70). If static stretching is required, it is recommended athletes follow static stretching with dynamic movements before training or competing (70). Despite these recommendations negative opinions of static stretching do not seem to have reached the sporting community as a whole. As discussed above, more than 25% of powerlifters report performing static stretching prior to training. Other athletes and personal trainers also seem to value static stretching, for example, Blazevich and colleagues (20) asked a group of 20 team sport athletes to list warm-ups in order of what they thought would be most effective. Given dynamic stretching, 30 seconds static stretching, 5 seconds static stretching and no stretching, 75% of athletes thought that no stretching would be the least effective. Similarly, when asked after the warm-up to rate how effective it was, athletes ranked no stretching as the least effective. A survey of 605 personal trainers revealed a similar favour for stretching. Only 2.4% of the trainers reported not performing stretching, and the most common form of stretching performed was static (80%)(164). Based on these findings and the continued prevalence of static stretching it is not surprising that powerlifters also seem to value stretching and use it in their warm-ups despite the current stretching literature and recommendations.

Practical applications

This research provides novel insights into the stretching practices of powerlifters. Approximately 50% of powerlifters reported participating in regular stretching, of those 78% reported stretching before resistance training and 84% engaged in static stretching. While those who static stretched before resistance training did more repetitions and held stretches for a shorter duration, stretches were still held long enough to cause significant strength-task performance decrements.

To avoid possible performance deficits stretching, particularly static stretching occurring before resistance training or competition, should be implemented into powerlifting training with caution. Coaches and athletes should determine if static stretching is necessary before strength-tasks, for example, if it is needed for the athlete to achieve depth in a squat. If it is deemed necessary, it should be programmed into training and the effects on ROM and performance monitored. This way it can be stopped when it is no longer required or adjusted based on performance. Additionally, if athletes insist on performing statics stretches before training and competition, they should limit repetitions and set a timer to ensure they do not hold stretches for too long. Static stretching after or independent of strength tasks, dynamic stretching, and foam rolling can continue to be practiced without detailed programming as the probability of performance impairment is much less.

Prelude

As discussed in Chapter 3, approximately half of powerlifters reported stretching regularly. Interestingly, this was true regardless of sex or competition level. While previous research identified specific ranges where male powerlifters have less ROM than sedentary men, no studies included female powerlifters. Therefore, the purpose of Chapter 4 was to determine if ROM adaptations would be similar in female powerlifters. Additionally, because ROM adaptations were more pronounced in elite than less competitive male powerlifters, the secondary purpose was to determine if ROM could be used to predict powerlifting performance.

Chapter 4 Range of motion is not reduced in national-level New Zealand female powerlifters

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Introduction

Powerlifting is a strength sport in which competitors are given 3 attempts to move the heaviest weight they can in the squat, bench press, and deadlift. To win, a lifter must accumulate the largest total in their respective weight class which is the sum of their best successful squat, bench press, and deadlift attempts. In competition, the squat must achieve a depth where the hip crease is below the top of the knee joint to be considered successful, and for bench press the head, shoulders, and buttocks, but not the rest of the back, must remain in contact with the bench for the duration of the lift (72). If powerlifters aim to just reach the appropriate depth in a squat and arch their back during the bench press, they may not be utilising all of their available ROM. Such strategies may aid powerlifting performance, but if utilised consistently, could result in powerlifters developing decreased ROM about the shoulder and hip joint. Additionally, this may be reinforced because of the repetitive nature of powerlifting training where competition lifts and close variations of them (e.g., pause squat, extended pause bench, block pulls, etc.) are trained multiple times per week (153).

Previous research evaluated active (34) and passive ROM (57) in male powerlifters. Both studies compared powerlifters to sedentary age-matched controls and found powerlifters had less ROM about the shoulder. Chang et al. (34) measured only flexion, extension, and internal and external rotation at the shoulder and found that powerlifters had significantly less ROM than the controls. Gadomski et al. (57) measured the same ranges as well as horizontal abduction and adduction and showed that powerlifters had significantly less extension and internal and external rotation than controls with no significant differences in flexion or horizontal adduction and abduction. The results at the hip were mixed, as Chang et al. (34) measured hip flexion and internal and external rotation and found powerlifters had significantly less ROM in each of these movements. Whereas Gadomski et al. (57) measured hip flexion, extension, adduction and abduction and found no significant differences between groups. Both Chang et al.

(34) and Gadomski et al. (57) showed that powerlifters actually had greater hamstring flexibility than controls, measured by the sit and reach (34) and knee extension (57). Despite the few differences in findings, both studies indicate that powerlifting training may result in reduced ROM in some shoulder, hip, and knee movements.

The ROM findings correspond with powerlifters having less flexibility in the muscle groups that contribute meaningfully to competition lifts. The gluteus maximus and quadriceps muscles are prime movers of the squat (28) and deadlift (43). These muscles produce hip extension and knee extension, respectively, and powerlifters had decreased hip and knee flexion (34). The prime movers of the bench press are the pectoralis major, anterior deltoid, and triceps brachii (150). These muscles produce shoulder horizontal adduction and flexion, shoulder flexion, and elbow extension, respectively, and powerlifters had decreased shoulder extension (34,57) and elbow flexion (34). Additionally, the rotator cuff and deep hip rotators such as the gluteus medius, minimus, and piriformis work to stabilise the shoulder and hip, respectively and powerlifters had decreased rotation about the shoulder (34,57) and hip (34). The increase in knee extension ROM is an exception. The hamstrings are knee flexors, but they also contribute to hip extension and are very active in the conventional deadlift (5). The increased flexibility in this muscle group may be because these muscles are trained through a comparatively large ROM in the deadlift (43,66). Gadomski et al. (57) found that lower shoulder ROM was more pronounced in elite powerlifters (Wilks >500) than less experienced powerlifters (Wilks 400-500). A Wilks score is an equation to calculate standardised strength relative to body mass, often used in powerlifting as it allows strength comparisons across different weight classes (161). Taken together, these findings suggest that ROM alterations may be a result of long-term powerlifting training and that ROM may be used to predict powerlifting performance. However, all previous studies used exclusively male participants, which may not necessarily translate to female powerlifters.

Currently, there is no information on ROM in female powerlifters. Therefore, the purpose of this study was to determine active single-joint ROM in female powerlifters and to determine if single-joint ROM can be used to predict strength levels in female powerlifters. The research hypothesis was that powerlifters would have less ROM than recreationally trained females, specifically in ranges that would stretch the prime movers of the squat, bench press, and deadlift. It was also hypothesized that these ranges would be predictors of strength levels in the powerlifters.

Methods

Experimental approach to the problem

To compare differences in active ROM between powerlifters and age-matched recreationally trained lifters a cross-sectional examination of active ROM was conducted. Active ROM of the glenohumeral (shoulder), hip, and knee joints was assessed using goniometry. Participants were recruited from local gyms and through social media (Facebook, Twitter, and Instagram) via a recruitment poster.

Subjects

Twenty-four female volunteers participated in this study, 12 powerlifters and 12 recreationally trained controls. To be included in the study powerlifters were required to be actively training for powerlifting, participated in at least 1 unequipped IPF meet, and had a National qualifying total or higher based on the New Zealand Powerlifting Federation requirements. Recreationally trained women were included if they were currently strength training at least once per week. Participant characteristics are summarised in Table 4-1 and all participants were injury-free. All participants were informed of the risks and benefits associated with this study and signed an institutionally approved consent form prior to any data collection. The methods and procedures used in this study were approved by Auckland University of Technology ethics committee, AUTEC Reference number 19/195.

Table 4-1 Participant characteristics (mean ± SD)

	PL	RT	p	g
Age (years)	26.3 ± 6.6	26.5 ± 6.2	0.950	0.03
Height (cm)	162.9 ± 5.7	165.5 ± 7.4	0.345	0.38
Weight (kg)	65.9 ± 9.9	61.7 ± 5.5	0.208	0.51
Training experience (years)	4.0 ±2.6	6.6 ± 4.8	0.109	0.66
Training frequency (per week)	4.1 ± 0.7	3.6 ± 1.3	0.299	0.42
Training duration (min)	150.0 ± 60.0	88.3 ± 24.1	0.003#	1.30
Wilks score	395.2 ± 65.3			

Significant differences marked as # $p < 0.01$; PL = powerlifters, RT = resistance trained

Protocol

Participants completed a single testing session, which took place prior to the participants daily training or on a rest day. During this session participant characteristics were recorded: age, height, and weight. All participants were asked questions about their training, specifically how many years of training experience they had, the frequency of training sessions per week, and the average duration of training sessions. They were asked if they regularly stretched and if they answered yes were asked their weekly stretching frequency. Powerlifters were also asked their best competition total. Following these questions, active ROM measurements were collected using goniometry. The self-reported powerlifting totals were verified using OpenIPF.com and the Wilks score was calculated using the verified competition total and weight at which it was achieved (176).

Range of Motion: Active ROM was measured using a 32cm plastic goniometer. Three measurements were taken at each range and the median was used for analysis. If at least 2 of the 3 measurements were not within 5° a fourth measurement was taken. The same researcher, with more than 8 years of experience measuring ROM as a Registered Massage Therapist, completed all ROM measurements. Measurements were taken at the shoulder (flexion, extension, horizontal adduction and abduction, internal and external rotation), hip (flexion, extension, adduction, abduction, internal and external rotation), and knee (flexion with hip at 0 and extension with hip at 90). Each measurement was taken once before all measurements were repeated. Intrarater reliability of active ROM measurements at the shoulder, hip, and knee using a universal goniometer have previously been established (36,89). The reliability of these measures in our laboratory is high (shoulder ICC = 0.909-0.987, CV = 0.85-5.49%; hip and knee ICC = 0.630-0.981, CV = 1.35-11.22%).

All shoulder measurements were taken in a supine position with the shoulder measured off the side of the table, so it did not restrict movement. Internal and external rotation measurements were taken with the shoulder abducted to 90° and the elbow bent to 90°.

Hip flexion, adduction, abduction, and knee extension measurements were taken in a supine position. To measure adduction participants were asked to hold their opposite thigh with their hands to ensure it did not restrict the movement of the test limb. To measure knee extension the participant was asked to bring their knee over their hip and the researcher ensured that the hip remained at this 90° angle when the participant extended the knee. Hip extension, internal and external rotation, and knee flexion measurements were taken in a prone position. Participants were instructed to keep the knee in line with the hip, and both sides the pelvis in contact with the table for each of these measures. For knee flexion the participant was instructed to keep their thigh on the table.

Statistical analyses

An a priori sample size calculation was performed in G*Power using a two tailed independent t-test. We estimated that 14 subjects (7 in each group) would allow us to detect a difference in shoulder extension ROM of 13 °s, with 80% power and an alpha of 0.05. This difference was obtained from previous work (34), where powerlifters (41.6 ± 8.1°) had less ROM than sedentary adults (54.6 ± 6.8°), equivalent to Cohens d = 1.74. We obtained similar results for hip flexion (131.9 ± 10.2°, 116.5 ± 7.1°, d = 1.75). Data were checked for normality using the Shapiro-Wilk test and homogeneity of variance using Levene's test. Means and standard deviations (SD) were used to represent the centrality and spread of data. Independent t-tests were used to determine if there was a difference in participant characteristics and ROM between the two groups with significance set at ($p \leq 0.05$). Effect size statistics (reported using Hedge's g) were used to determine the magnitude of differences between the two groups with values reported as small (0.2–0.5), moderate (0.51–0.79) or large (>0.8) (53). To examine the relationship between ROM and strength linear regression analyses were performed for the powerlifting group. The dependent variable was strength (Wilks score) and each single joint ROM was entered separately as a predictor variable into the model. The assumptions of residual normality were checked. All data were analysed using IBM SPSS (version 26.0).

Results

Participant characteristics

The specific values for all descriptive measures are shown in Table 4-1. There was no significant difference ($p > 0.05$) between groups for age, height, body mass, training experience, and training frequency; however, there were significantly greater ($p \leq 0.05$) values for powerlifters compared with recreationally trained women for training duration. Eight of the 12 women in each group reported that they regularly static stretch, and there was no significant difference between groups for the reported static stretching frequency (2.38 ± 1.37 versus 3.13 ± 1.66; $p = 0.33$)

Range of motion

The results of all ROM measurements are detailed in Table 4-2. The only significant difference found was that powerlifters had more shoulder horizontal abduction on the right side than recreationally trained women.

Table 4-2 Range of motion (mean ± SD in degrees)

	PL	RT	Mean dif (95% CI)	p	g
Right shoulder					
Flexion	179 ± 15	169 ± 12	10 (-1, 22)	0.079	0.73
Extension	53 ± 9	55 ± 8	-2 (-9, 6)	0.656	0.18
Horizontal adduction	47 ± 7	53 ± 9	-6 (-13, 1)	0.090	0.70
Horizontal abduction	124 ± 8	117 ± 6	7 (1, 13)	0.022*	0.97
Internal rotation	51 ± 13	43 ± 15	8 (-3, 20)	0.153	0.58
External rotation	101 ± 10	97 ± 16	5 (-6, 16)	0.390	0.35
Right hip					
Flexion	116 ± 10	119 ± 9	-3 (-11, 5)	0.424	0.32
Extension	15 ± 7	16 ± 7	-1 (-7, 5)	0.742	0.13
Adduction	26 ± 5	26 ± 7	0.5 (-5, 6)	0.846	0.08
Abduction	54 ± 11	55 ± 7	-1 (-9, 6)	0.753	0.13
Internal rotation	50 ± 10	46 ± 11	3 (-6, 12)	0.461	0.30
External rotation	38 ± 10	43 ± 10	-5 (-13, 3)	0.241	0.47
Right knee					
Flexion	129 ± 5	131 ± 6	-1 (-6, 4)	0.585	0.22
Extension	158 ± 11	166 ± 13	-8 (-19, 2)	0.098	0.68
Left shoulder					
Flexion	178 ± 15	171 ± 12	7 (-5, 18)	0.219	0.50
Extension	50 ± 9	52 ± 7	-2 (-9, 5)	0.583	0.22
Horizontal adduction	48 ± 7	54 ± 10	-6 (-13, 1)	0.109	0.66
Horizontal abduction	119 ± 10	118 ± 10	1 (-7, 10)	0.745	0.13
Internal rotation	50 ± 17	44 ± 11	6 (-6, 18)	0.377	0.44
External rotation	95 ± 5	91 ± 17	4 (-8, 15)	0.529	0.25
Left hip					
Flexion	119 ± 9	124 ± 7	-4 (-11, 3)	0.220	0.50
Extension	11 ± 5	13 ± 5	-2 (-6, 3)	0.405	0.34
Adduction	24 ± 5	23 ± 5	1 (-4, 5)	0.734	0.14
Abduction	54 ± 14	55 ± 8	-1 (-11, 9)	0.807	0.10
Internal rotation	44 ± 10	40 ± 9	3 (-5, 11)	0.417	0.33
External rotation	39 ± 12	46 ± 10	-7 (-16, 2)	0.121	0.64
Left knee					
Flexion	128 ± 6	130 ± 7	-2 (-7, 4)	0.503	0.27
Extension	158 ± 11	165 ± 12	-7 (-17, 3)	0.147	0.59

Significant difference marked as * $p \leq 0.05$; PL = powerlifter; RT = recreationally trained; CI = confidence interval

Relationship of range of motion with strength

Results of the regression analysis are found in Table 4-3. No ranges were significantly related to Wilks score for female powerlifters.

Table 4-3 Relationship between ROM and Wilks in powerlifters

	B	SE	p	R^2
R GH flexion	-0.76	1.37	0.592	0.030
L GH flexion	-1.19	1.36	0.401	0.072
R GH extension	-0.19	2.38	0.937	0.001
L GH extension	0.44	2.21	0.847	0.004
R GH horizontal adduction	2.16	2.77	0.454	0.057
L GH horizontal adduction	1.89	2.99	0.540	0.039
R GH horizontal abduction	-2.64	2.51	0.318	0.099
L GH horizontal abduction	0.77	2.05	0.715	0.014
R GH internal rotation	-0.74	1.56	0.646	0.022
L GH internal rotation	-0.38	1.24	0.768	0.009
R GH external rotation	-0.20	2.13	0.928	0.001
L GH external rotation	1.76	2.17	0.437	0.062
R hip flexion	-2.25	1.95	0.275	0.118
L hip flexion	-2.44	2.26	0.307	0.104
R hip extension	-0.28	2.86	0.925	0.001
L hip extension	1.81	3.83	0.646	0.022
R hip adduction	4.03	3.99	0.335	0.093
L hip adduction	4.51	3.56	0.233	0.139
R hip abduction	-1.12	1.92	0.572	0.033
L hip abduction	-0.47	1.43	0.752	0.010
R hip internal rotation	0.01	2.10	0.997	0.000
L hip internal rotation	-0.22	2.00	0.915	0.001
R hip external rotation	-3.66	1.83	0.074	0.285
L hip external rotation	-1.92	1.67	0.277	0.117
R knee flexion	-0.31	3.83	0.937	0.001
L knee flexion	1.29	3.45	0.716	0.014
R knee extension	-0.32	1.91	0.869	0.003
L knee extension	0.94	1.85	0.623	0.025

R = right, L = left, GH = shoulder

Discussion

This study is the first to measure ROM in female powerlifters. The main finding was that female powerlifters do not have lower active ROM at the shoulder or hip in comparison to recreationally trained age-matched controls. Additionally, single-joint ROM was not a predictor for strength in female powerlifters. These findings disagreed with both hypotheses.

Previous cross-sectional studies have compared ROM in highly trained male populations such as powerlifters (34,57) and body builders (13) to ROM in sedentary and recreationally trained males, respectively. Similar studies have compared ROM in recreationally trained men (86) and women (88) to ROM in sedentary men and women, respectively. In each of these previous studies the trained, or more highly trained group, had less ROM in one or more ranges compared to the control group. Of these, only 3 studies reported the training experience of participants: 8.7 years (86), 8.2 years (88), and 17.9 years (57), all of which had more than double the training experience of the powerlifting participants from the present study (mean 4.0 years). Only Gadomski et al. (57) compared ROM differences based on strength levels. They found that ROM differences were more pronounced in elite powerlifters (>500 Wilks) than those with a Wilks score of 400-500, and that ROM differences were not present between the least competitive group (<400 Wilks) and the control group. The elite group not only had a better Wilks score, but also had more than double the years of powerlifting experience compared to the low Wilks group (6.9 versus 14.8). The results of the current study are consistent with those of the least competitive group examined by Gadomski et al. (57) The powerlifters in the present study had relatively less training experience than those of previous studies, an average Wilks score of less than 400, and ROM was similar to that of the control group. This suggests that ROM decreases may occur following prolonged participation in resistance training as a result of time and/or strength gains, but these changes may require more than 7 years of training and may occur at higher strength levels than were present in this study. However, given the nature of these cross-sectional analyses, the lack of an untrained control group, and the inability to determine the direction of causality, it is also possible that individuals with less ROM may have a better propensity to gain strength. Therefore, more research is needed to determine if time, strength gains, or both contribute to lower ROM in more trained populations.

Some normative reference values for active ROM in the general population have been identified by Gill et al. (59), McKay et al. (114), and Roach and Miles (137). These studies had relatively large samples (n = 119-200) of women aged 25-29, 25-39, and 20-59, respectively. When comparing the results from the present study powerlifters had greater shoulder flexion (8) (Mean difference (MD) 13-14°; g = .97-.99) and external rotation (8,15) (MD 18-28.5°; g = .117-2.52), but less internal rotation (114) (MD -12° g = .86). At the hip, powerlifters had more abduction (137) (MD 14-21°; g = .88), internal rotation (114,137) (MD 10-14° g = 1.02-2.28), and external rotation (114,137) (MD 2-11°; .26-1.32), but less flexion (114,137) (MD -7°; g = .63-75) and extension (137) (MD -7° p = .86). Finally, powerlifters had more knee flexion (114) (MD 21°; g = 1.27). Boone et al. (21) investigated intertester reliability of goniometry on upper and lower limb measurements and determined that to detect changes in ROM increases should exceed five degrees for the upper limb and six degrees for the lower limb. Differences in measurement set-up/positioning would cause additional variability. With these constraints in mind, the differences calculated in most ranges are adequate and the computed effect sizes are large, which suggests the differences are practically relevant. Unlike male powerlifters, female powerlifters seem to have greater ROM in most movements about the shoulder and lower limb. Interestingly, despite the overall increase in ROM, female powerlifters may still have specific movements where ROM is reduced.

Single-joint ROM was not an effective predictor of strength in this study. This may be because of the relative inexperience and competitive level of the powerlifters who participated. Despite requiring a National or higher powerlifting total the average training experience in this study was 4.0 years and the average Wilks score was less than 400. These characteristics and the lack of significant differences in ROM are consistent with the least competitive group from Gadomski et al. (57). Thus, future research should include more experienced powerlifters, especially those at a higher competitive level to determine if single-joint ROM would be an effective predictor for strength in a sample where ROM differences are present.

In conclusion, contrary to previous research (13,34,57,86,88) we did not observe any significant decreases in ROM between female powerlifters and recreationally trained females. However, there was also no significant difference in years of training experience between our groups, where the majority of other comparisons were between trained and untrained groups (34,57,86,88). Therefore, the similarities in ROM in this study may be a result of sex-differences in response to resistance training or may simply be a result of training age.

Practical applications

The results of this investigation suggest that powerlifting training does not affect ROM differently than general resistance training in female athletes with a similar training age as the participants in the present study. We recommend monitoring joint ROM over the span of a lifter's career, if ROM decreases a stretching intervention could be implemented to restore ROM.

Prelude

The review of literature (Chapter 2) provided evidence that male powerlifters tend to have less ROM about certain joints when compared with sedentary age-matched controls. Interestingly, stronger powerlifters displayed less ROM than weaker powerlifters. However, only one study compared ROM based on relative strength. Therefore, the purpose of Chapter 5 was to compare the ROM of competitive male powerlifters to that of recreationally strength-trained men and to determine if ROM could be used to predict strength levels.

Chapter 5 Range of motion predicts performance in national-level New Zealand male powerlifters

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Introduction

In the sport of powerlifting competitors lift the heaviest load possible for one repetition in the squat, bench press, and deadlift. Competitors have three attempts per lift and their best successful attempts for each lift determines their total. To win, lifters need the largest total in their weight class. Additionally, a bodyweight coefficient score such as a Wilks score is used to derive standardised strength relative to body mass (161), which decides the best overall lifter, regardless of weight class. Powerlifters train with a high degree of specificity; typically training the competition lifts 1-3 times weekly (57,153). Bench press and bench press variations account for the majority of upper body exercises (74.8%) and the squat and deadlift account for the majority of lower-body exercises (79.7%) (57). The competition lifts are also prevalent in personal training and strength and conditioning, as strength is an important capacity across a variety of sports (156).

In previous research male powerlifters had less shoulder flexion (34), extension, and rotation than sedentary age-matched controls (34,57). Similarly, in other studies researchers reported recreationally trained men had less shoulder flexion, abduction, and internal rotation but more external rotation than sedentary controls (86), recreationally trained women had less shoulder internal rotation than sedentary controls (88), and body builders had less shoulder rotation than recreationally trained men (13). In each study, the trained or more trained group had significantly less ROM in one or more movements about the shoulder (13,34,57,86,88). Likewise, when reported, the group with more years of training experience had less ROM about the shoulder (57). Conversely, female powerlifters had similar shoulder ROM to age-matched recreationally trained women and significantly more horizontal abduction on the right side (152). Interestingly, in this study the recreationally trained group had more years of training experience (effect size g = 0.66) than the powerlifting group. Three of these studies included directional strength testing (13,86,88). Kolber et al. (86), Kolber et al. (88), and Barlow et al. (13) tested shoulder abduction and internal and external rotation, and Barlow et al. (13) also tested shoulder flexion. The trained or more trained groups had significantly greater strength scores in each movement direction except for recreationally trained men who did not have significantly higher strength scores in external rotation (13). Notably, this exception corresponds with the ROM finding in the same group which had more external rotation than the sedentary controls. Gadomski et al. (57) did not directly test strength, but divided powerlifters into groups based on Wilks scores. The results showed that ROM differences were greatest in elite powerlifters (Wilks >500), less pronounced but still present in intermediate powerlifters (Wilks 400-500), and not present in powerlifters with scores under 400, all compared to sedentary males (57). These results suggest that resistance training could cause reductions in ROM in some movements about the shoulder. However, it is unclear if these differences in ROM are related to strength, training type, years of training experience, or instead, if individuals with less ROM have a better propensity to gain strength.

Previous studies have examined lower limb ROM in powerlifters with mixed results. In two studies, researchers reported greater sit and reach scores (34,57) and knee extension ROM with the hip flexed at 90 degrees (57) in male powerlifters compared to sedentary age-matched controls. However, Chang et al. (34) measured hip flexion, internal and external rotation, and knee flexion and found powerlifters had significantly less ROM in these movements compared to the controls. Whereas Gadomski et al. (57) measured hip flexion, extension, adduction, and abduction and found no significant differences between groups. Most recently, no significant differences were observed between female powerlifters and recreationally trained controls in any movements about the hip and knee (152). With limited study in this area, more research is needed to elucidate these relationships.

Given the necessity for additional research in this area, the purpose of this study was to determine if shoulder, hip, and knee ROM were different in male powerlifters compared to recreationally strength-trained men. A secondary purpose was to see if there were any relationships between ROM and strength or average eccentric velocity (AEV) at submaximal loads. It was hypothesized that powerlifters would have significantly greater strength and significantly less ROM about the shoulder and lower limb compared to age-matched recreationally strength-trained men. It was also hypothesized that movements that lengthen the prime movers of the squat (hip flexion lengthens the gluteus maximus) and bench press (shoulder extension lengthens the anterior deltoid and horizontal abduction lengthens the pectoralis major) would be predictors of strength. Finally, powerlifters only need to squat to competition-depth and may be able to lift heavier loads by limiting ROM to this depth. Therefore, it was hypothesized participants with greater hip flexion ROM would have a slower squat AEV, reflecting efforts to control squat depth.

Methods

Experimental approach to the problem

A cross-sectional examination of active ROM, maximal dynamic strength, and AEV of submaximal squat repetitions were conducted on powerlifters and age-matched recreationally strength-trained men. Goniometry was used to assess active ROM of the shoulder, hip, and knee joints. Maximal strength was assessed with back squat and bench press 1RM testing. AEV was measured at 50, 70, and 80% of 1RM for back squat.

Subjects

Twenty-five males participated in this study, 12 powerlifters and 13 recreationally strength-trained men. One recreationally strength-trained participant was excluded from analysis as we were unable to recruit a powerlifter of a similar age. To be included, powerlifters needed to be actively training for powerlifting, have participated in at least 1 unequipped IPF affiliated meet, and have a New Zealand National qualifying total or higher. Recreationally strength-trained men were included if they regularly trained the back squat and bench press, and could squat at least 1.5 times, and bench press at least their body weight. All participants were injury-free. Participant characteristics are summarised in Table 5-1. All participants were informed of the risks and benefits associated with this study and signed an institutionally approved written consent prior to data collection The methods and procedures used in this study were approved by Auckland University of Technology ethics committee, AUTEC Reference number 19/195.

Table 5-1 Participant characteristics (mean ± SD)

	PL (n = 12)	RT (n = 12)	p	g
Age (y)	27.1 ± 4.5	27.1 ± 5.1	1.00	<0.01
Height (cm)	174.9 ± 8.9	180.1 ± 7.7	0.141	0.60
Body weight (kg)	86.6 ± 16.3	90.0 ± 10.1	0.542	0.24
Training experience (y)	8.1 ± 4.8	7.8 ± 6.2	0.898	0.05
Training frequency (per week)	4.4 ± 0.8	4.2 ± 1.0	0.506	0.21
Training duration (min)	108.8 ± 24.9	84.4 ± 21.6	0.018*	1.01
1RM Squat (kg)	194.0 ± 26.4	154.4 ± 18.4	<0.001#	1.66
1RM Bench press (kg)	138.3 ± 23.2	113.3 ± 12.9	<0.001#	1.29
Relative Squat (1RM/bw)	2.29 ± 0.43	1.73 ± 0.22	<0.001#	1.51
Relative Bench press (1RM/bw)	1.62 ± 0.25	1.27 ± 0.20	<0.001#	1.59
2-lift Wilks	221.53 ± 28.19	172.42 ± 17.81	<0.001#	2.01
Competition Wilks	406.38 ± 52.81			

Significant differences marked as * $p \leq 0.05$; # $p < 0.01$; PL = powerlifter; RT = recreationally trained; bw = body weight

Procedures

Participants completed 2 testing sessions at the same time of day, separated by 72 to 96 hours. During the first session, age, height, and weight were recorded. Participants reported their years of training experience, average training frequency, and duration. Powerlifters reported their best competition total. Following these questions 1RM back squat and bench press were assessed. During the second session, active ROM was measured using goniometry, and then velocity was collected during submaximal squat repetitions. Participants in the recreationally strength-trained group attended 1 additional familiarisation session 48 hours prior to testing. Self-reported powerlifting totals and body weight at which they were achieved were verified using OpenIPF.com and Wilks scores were calculated using the verified information.

1 Repetition Maximum Testing: Participants were shown a resistance training specific repetitions in reserve (RIR) based rating of perceived exertion (RPE) scale (175). This scale was used along with average concentric velocity (ACV), measured by GymAware PowerTool (GymAware, Kinetic Performance Technology, Canberra, Australia), to determine attempt selection. RIR/RPE and ACV were recorded for the last warm-up and all subsequent attempts. Participants performed a standardised dynamic warm-up, followed by a specific warm-up consisting of up to 10 repetitions with the barbell, 5 repetitions with 50% of estimated 1RM, 4 repetitions with 60% estimated 1RM, 3 repetitions with 70% estimated 1RM, 2 repetitions with 80% estimated 1RM, and 1 repetition with 90% estimated 1RM. A 1RM was recorded if the participant successfully completed a lift at a 10RPE, or successfully completed a lift at a lower RPE but failed the next attempt. To ensure uniformity, the squat was performed to IPF standards (72) reaching a depth where the hip crease was below the top of the knee joint. The bench press was performed in a touch and go style, and participants had to keep their head, shoulders, and buttocks in contact with the bench for the duration of the lift. A provincial level IPF referee was present to give commands “start/squat” and “rack”) and to ensure IPF standards were met.

Range of Motion: All ROM measurements were taken by the same researcher, who had over 8 years of experience measuring ROM as a Registered Massage Therapist. Measurements were taken at the shoulder, hip, and knee. Three measurements were taken unless 2 of the 3 were not within 5° at which point a fourth was taken, all measurements were taken once before the procedure was repeated, and the median was used for analysis. Detailed ROM procedures can be found in a previous study (152) (Chapter 4). Intrarater reliability of ROM measurements is high in our laboratory (shoulder ICC = 0.909-0.987, CV = 0.85-5.49%; hip and knee ICC = 0.630-0.981, CV = 1.35-11.22% (152) Chapter 4).

Velocity: Velocity data were collected using a linear position transducer (PT5A, Celesco, Adelaide, Australia) attached to the furthest position of the grip section of the barbell (7) and set to sample at 1000 Hz. Six trials were completed with 2 sets of 3 reps at 50, 70, and 80% of 1RM for the back squat. The first 3 trials were completed in ascending order and the second 3 trials were randomized. The greatest AEV at each load, as well as the AEV of the last repetition at 80% were used for analysis. Data were collected and key variables were extracted using a custom LabView programme.

Statistical analyses

G*Power was used for an a priori same size calculation. Based on previous work where powerlifters had less shoulder ROM (41.6 ± 8.1° versus 54.6 ± 6.8°, d = 1.74) and less hip extension ROM (131.9 ± 10.2° versus 116.5 ± 7.1°, d = 1.75 (34) than sedentary adults, we estimated that 14 subjects (7 in each group) would allow us to detect a difference in shoulder extension ROM of 13°s, with 80% power and an alpha of 0.05. Data were checked for normality and homogeneity of variance using the Shapiro-Wilk test and Levene's test, respectively. Means and standard deviations (SD) were used to represent the centrality and spread of data, and independent t-tests were used to determine if there was a difference in participant characteristics and ROM between the two groups. Significance was set at ($p \leq 0.05$). Effect size statistics (reported using Hedge's *g*) were used to determine the magnitude of differences between the two groups with values reported as small (0.2–0.5), moderate (0.51–0.79) or large (>0.8) (53). To investigate the relationship between ROM and strength, a linear regression analysis was performed using the 2-lift Wilks score (calculated from the 1RM back squat and bench press) for all participants. A separate linear regression analysis was performed using the powerlifters best competition Wilks score. Another linear regression analysis was performed to determine if there was a relationship between hip flexion ROM and eccentric velocity, this was adjusted to control for strength. For each regression analysis each single joint ROM was entered as predictor variable into the model separately. The assumptions of residual normality were checked. All data were analysed using IBM SPSS (version 26.0).

Results

Participant characteristics

Descriptive measures are shown in Table 5-1. There was no significant difference ($p > 0.05$) between groups for age, height, body mass, training experience and training frequency. However, there were significantly greater ($p \leq 0.05$) values for powerlifters compared with recreationally strength-trained men in training duration and absolute back squat and bench press 1RM.

Table 5-2 Range of motion (mean ± SD in degrees)

Right shoulder	PL	RT	Mean dif. (95% CI)	p	g
Flexion	166 ± 14	163 ± 13	3.33 (-8.30, 14.96)	0.558	0.23
Extension	42 ± 7	51 ± 9	-9.08 (-16.25, -1.92)	0.015*	1.04
Horizontal adduction	43 ± 9	40 ± 9	2.25 (-5.29, 9.79)	0.542	0.24
Horizontal abduction	108 ± 9	115 ± 7	-6.50 (-13.40, 0.403)	0.064	0.77
Internal rotation	38 ± 14	40 ± 14	-2.00 (-14.08, 10.08)	0.735	0.14
External rotation	93 ± 13	99 ± 6	-5.83 (-14.42, 2.75)	0.179	0.56
Right hip					
Flexion	105 ± 6	111 ± 8	-6.25 (-0.23, -12.27)	0.043*	0.85
Extension	11 ± 4	18 ± 5	-7.5 (-11.40, -3.60)	0.001#	1.57
Adduction	21 ± 5	24 ± 4	-3.42 (-7.04, 0.21)	0.064	0.77
Abduction	46 ± 8	43 ± 7	3.08 (-3.18, 9.34)	0.318	0.40
Internal rotation	29 ± 11	29 ±10	0.17 (-8.78, 9.12)	0.970	0.01
External rotation	40 ± 12	41 ± 8	-1.67 (-10.33, 7.00)	0.694	0.16
Right knee					
Extension	145 ± 9	150 ± 12	-5.25 (-14.40, 3.90)	0.247	0.46
Flexion	124 ± 6	123 ± 6	1.08 (6.12, -3.95)	0.660	0.16
Left shoulder					
Flexion	165 ± 13	166 ± 10	-0.42 (-10.16, 9.33)	0.930	0.04
Extension	41 ± 10	50 ± 11	-8.75 (-17.51, 0.013)	0.050*	0.82
Horizontal adduction	44 ± 9	43 ± 8	0.50 (-6.66, 7.66)	0.886	0.06
Horizontal abduction	108 ± 8	115 ± 6	-7.00 (-13.25, -0.75)	0.030*	0.92
Internal rotation	39 ± 14	49 ± 14	-10.42 (-22.16, 1.33)	0.079	0.73
External rotation	88 ± 13	92 ± 10	-4.75 (-14.51, 5.01)	0.324	0.40
Left hip					
Flexion	108 ± 6	114 ± 8	-6.33 (-0.34, -12.33)	0.039*	0.86
Extension	10 ± 4	15 ± 4	-5.58 (-9.34, -1.83)	0.005#	1.22
Adduction	17 ± 6	22 ± 4	-5.25 (-9.46, -1.04)	0.017*	1.02
Abduction	46 ± 9	43 ± 7	3.58 (-3.23, 10.40)	0.287	0.43
Internal rotation	25 ± 10	29 ± 10	-3.42 (-12.01, 5.17)	0.418	0.33
External rotation	43 ± 12	43 ±7	-0.25 (-8.43, 7.93)	0.950	0.02
Left knee					
Extension	145 ± 12	152 ± 12	-6.83 (-16.88, 3.22)	0.172	0.56
Flexion	123 ± 6	124 ± 8	-0.75 (5.04, -6.54)	0.791	0.14

Significant differences marked as * p ≤ 0.05; # p < 0.01; PL = powerlifter; RT = recreationally trained; CI = confidence interval

Range of motion

The results of all ROM measurements are detailed in Table 5-2. Powerlifters had significantly less ($p \leq 0.05$) shoulder extension than recreationally strength-trained men. Powerlifters had significantly less ($p \leq 0.05$) shoulder horizontal abduction range on the left side and moderately lower, albeit non-significantly ($p = 0.064$; g = 0.77) on the right side.

Powerlifters had significantly less ($p \leq 0.05$) hip flexion and extension than recreationally strength-trained men. Powerlifters had significantly less ($p < 0.05$) hip adduction on the left side and moderately, albeit non-significantly ($p = 0.064$; g = 0.77) on the right side.

Relationship of range of motion with 2-lift Wilks scores

Results of the regression analysis are shown in Table 5-3. Significant negative relationships were found between strength and shoulder extension (R^2 = 0.392-0.422; $p = 0.001$) and horizontal abduction (R^2 = 0.317-0.430; $p < 0.01$), as well as hip flexion (R^2 = 0.158-0.212; $p < 0.05$), extension (R^2 = 0.377-0.507; $p < 0.01$), adduction (left side R^2 = 0.308; $p = 0.005$), and internal rotation (left side R^2 = 0.172; $p = 0.044$).

Relationship of range of motion with competition Wilks scores in powerlifters

Results of the regression analysis are shown in Table 5-4. Significant negative relationships were found between strength and shoulder extension (R^2 = 0.343-0.495; $p < 0.05$), horizontal adduction (right side R^2 = 0.360; $p = 0.039$), horizontal abduction (left side R^2 = 0.395; $p = 0.029$), as well as hip flexion (R^2 = 0.354-0.461; $p < 0.05$) and knee extension (left side R^2 = 0.410; $p = 0.025$).

Eccentric velocity and range of motion

Hip flexion ROM was not a significant predictor of AEV at 50%, 70%, 80%, or in the last repetition at 80% of squat 1RM with or without an adjustment for strength (p = 0.180 – 0.695).

Table 5-3 Relationship between ROM and 2-lift Wilks in all participants

	B	SE	p	R^2
R GH flexion	-0.14	0.54	0.796	0.003
L GH flexion	-0.53	0.64	0.412	0.031
R GH extension	-2.33	0.58	0.001#	0.422
L GH extension	-1.93	0.51	0.001#	0.392
R GH horizontal adduction	-0.85	0.81	0.301	0.049
L GH horizontal adduction	-1.28	0.84	0.141	0.096
R GH horizontal abduction	-2.22	0.70	0.004#	0.317
L GH horizontal abduction	-2.77	0.68	0.001#	0.430
R GH internal rotation	-0.34	0.51	0.519	0.019
L GH internal rotation	-0.93	0.46	0.054	0.158
R GH external rotation	-1.30	0.64	0.056	0.157
L GH external rotation	-1.07	0.59	0.082	0.132
R hip flexion	-2.05	0.84	0.024*	0.212
L hip flexion	-1.97	0.85	0.031*	0.158
R hip extension	-4.10	0.86	<0.001#	0.507
L hip extension	-4.03	1.11	0.001#	0.377
R hip adduction	-0.96	1.59	0.552	0.016
L hip adduction	-3.41	1.09	0.005#	0.308
R hip abduction	0.12	0.98	0.906	0.001
L hip abduction	0.22	0.90	0.812	0.003
R hip internal rotation	-1.25	0.65	0.068	0.143
L hip internal rotation	-1.40	0.66	0.044*	0.172
R hip external rotation	-0.69	0.71	0.339	0.042
L hip external rotation	-0.84	0.75	0.274	0.054
R knee flexion	-1.79	1.18	0.143	0.095
L knee flexion	-1.18	1.06	0.276	0.054
R knee extension	-0.55	0.66	0.408	0.031
L knee extension	-0.90	0.57	0.130	0.101

Significant differences marked as * $p \leq 0.05$; # $p < 0.01$; R = Right; L = Left; GH = Shoulder

Table 5-4 Relationship between ROM and competition Wilks in powerlifters

	B	SE	p	R^2
R GH flexion	-1.88	0.99	0.087	0.265
L GH flexion	-1.44	1.20	0.258	0.126
R GH extension	-5.00	1.60	0.011*	0.495
L GH extension	-3.06	1.34	0.045*	0.343
R GH horizontal adduction	-3.43	1.44	0.039*	0.360
L GH horizontal adduction	-3.25	1.61	0.071	0.290
R GH horizontal abduction	-3.27	1.57	0.064	0.302
L GH horizontal abduction	-3.95	1.55	0.029*	0.395
R GH internal rotation	-0.95	1.13	0.420	0.066
L GH internal rotation	-1.68	1.07	0.148	0.197
R GH external rotation	-1.32	1.21	0.301	0.106
L GH external rotation	-1.76	1.14	0.157	0.190
R hip flexion	-4.87	2.08	0.041*	0.354
L hip flexion	-6.44	2.20	0.015*	0.461
R hip extension	-4.70	3.82	0.247	0.131
L hip extension	-5.33	3.36	0.144	0.201
R hip adduction	3.79	3.23	0.268	0.121
L hip adduction	-5.07	2.47	0.067	0.297
R hip abduction	-3.47	1.83	0.088	0.263
L hip abduction	-3.21	1.60	0.073	0.287
R hip internal rotation	-2.38	1.35	0.109	0.236
L hip internal rotation	-1.28	1.64	0.454	0.057
R hip external rotation	-1.26	1.34	0.370	0.081
L hip external rotation	-2.08	1.25	0.127	0.217
R knee flexion	-5.29	2.47	0.058	0.315
L knee flexion	-0.92	2.86	0.755	0.010
R knee extension	-3.51	1.59	0.052	0.327
L knee extension	-2.84	1.08	0.025*	0.410

Significant differences marked as * $p \leq 0.05$; R = Right; L = Left; GH = Shoulder

Discussion

The main findings of this study were that male powerlifters had less ROM in several movements about the shoulder (extension and horizontal abduction) and hip (flexion, extension, and adduction) when compared to recreationally strength-trained men. Additionally, some of these movements (shoulder extension and horizontal abduction, hip flexion and extension) were useful to predict strength using linear regression; however, hip flexion was not a significant predictor of submaximal squat AEV. These results agree with the hypotheses regarding ROM and the relationship with strength, but disagree with the hypothesis regarding the relationship between ROM and velocity.

Similar to the results of Gadomski et al. (57) and Chang et al. (34), ROM was significantly less in several movements about the shoulder in powerlifters; however, the ranges of interest varied between studies. Powerlifters had less extension in all three studies, but had less rotation only compared to sedentary men (34,57) with no significant difference compared to well-trained men in the current study. This may be attributed to the training status of the control group. Horizontal abduction was less in the powerlifters than well-trained men in the present study but was not different than sedentary men in previous research (57). Unfortunately, horizontal abduction was not measured by Chang et al. (34) so it is difficult to infer if this may be different due to the training status of the control group.

Hip ROM measures and results in strength athletes have not been consistent across studies. Gadomski et al. (57) did not observe any significant differences between powerlifters and sedentary men at the hip but did not measure rotation. Whereas Chang et al. (34) found powerlifters had less hip flexion and rotation but did not measure adduction or abduction. In the present study all ranges were measured, and powerlifters had less flexion, extension, and adduction. The limited information makes it difficult to draw any conclusions, more research is needed to measure all ranges at the hip in strength trained populations. Results at the knee differ, but similar to the shoulder, may be due to the difference in training status of the control group. Powerlifters had greater sit and reach scores (34,57) and knee extension (57) than sedentary men but in the present study had similar knee extension to well-trained men. Gadomski et al. (57) suggested that the greater ROM compared to sedentary men could be due to regular performance of the squat and deadlift which require the hamstrings to activate along a wide ROM. To participate in this study the recreationally strength-trained group had to be able to squat 1.5 times their bodyweight. Although they were not asked to detail what other lower body exercises they regularly performed, it is likely that the hamstrings were trained through a large ROM in this group as well, which could explain the similar ranges found in the present study.

The ROM findings of male and female powerlifters are heterogeneous. Female powerlifters had similar ROM about the shoulder, hip, and knee to recreationally trained females (152), whereas male powerlifters had significantly less range in several movements about the shoulder and hip in the present study as well as previous research (34,57) and significantly more hamstring flexibility (34,57). Sex differences in ROM have been inconsistent across many studies (See Gill et al. for summary (59)). Gill et al. (59) suggested that ROM may depend on the activities of daily living as opposed to the sex of individuals. Research directly comparing ROM between male and female powerlifters would be useful to establish if there are significant sex differences in this highly trained population.

Shoulder extension on the right and left side was a significant predictor of strength for both the 2-lift Wilks and competition Wilks. Interestingly, shoulder extension ROM was less in powerlifters than sedentary and recreationally trained men, and this was the only consistent finding across all studies. Hip flexion was the only other significant predictor of strength in both models across both sides of the body, and hip flexion ROM was less in powerlifters in two out of three studies. Shoulder extension and hip flexion constitute the bottom positions for the bench press and squat, respectively.

Finally, it was hypothesized that lifters with a greater hip flexion range would have a slower AEV during squats. However, hip flexion was not a significant predictor of squat AEV at any of the sub-maximal intensities measured, or for the last repetition completed at 80% of 1RM. With that said, it is possible that the hypothesized relationship, whereby more flexible lifters consciously slow the eccentric phase to control depth, only occurs during more challenging repetitions. The mean concentric velocity of the final repetition at 80% 1RM (0.41 ± 0.07) was significantly ($p < 0.001$) faster than the participants' concentric velocity at 1RM (0.24 ± 0.05), indicating this repetition was submaximal for the majority of participants. Thus, future research is needed to determine if this relationship is observable at or near maximal intensity.

Practical applications

Males who participate in powerlifting tend to have less ROM in several movements about the shoulder and hip, the most consistent of these being shoulder extension and hip flexion. Both of these ranges are also significant predictors of strength and correspond to the bottom position of the bench press and back squat, respectively. When programming mobility for male powerlifters this should be considered. It may be best to ensure that shoulder extension and hip flexion are just sufficient, such that joint positions are not compromised in order to achieve the bottom position of a squat and bench press, rather than attempting to increase these ranges beyond what is necessary.

Prelude

The review of literature lent support to the apparent importance of stiffness for athletic performance, and specifically for the bench press. As such, stiffness assessment was undertaken as an intended component of Chapter 5. Unfortunately, during analysis it became evident that the method chosen may not provide a useful metric. Therefore, the purpose of Chapter 6 was to describe the stiffness methodology and the issues that arose.

Chapter 6 Measuring stiffness in the squat and bench press: a technical note

Introduction

Powerlifting competitions consist of three lifts: the squat, bench press, and deadlift. To win an athlete must accumulate the greatest total comprised of the heaviest successful attempt at each of the three competition lifts. Two of the competition lifts, the bench press and squat, are slow stretch shortening cycle (SSC) movements and therefore a more compliant musculotendinous unit may be optimal (166,167). However, to investigate the relationship between stiffness and powerlifting performance, a valid method to measure stiffness during barbell lifts is needed.

Stiffness is the relationship between load placed on a structure and the subsequent deformation that occurs (14). In the human body it can be measured passively or actively within individual structures or globally at one or many joints. There may be an optimal stiffness for athletic performance (25), but this is likely task specific (25,167). Moreover, both excessive and limited stiffness are associated with injury risk (25,30). While current methods of measuring stiffness appear effective for running and jumping movements (27), they may not be for barbell sports such as powerlifting. The scant research examining stiffness during barbell lifts (69,166) means there is no current consensus on measurement approaches.

The free-oscillation technique is a popular in-vivo method to measure active stiffness as it simulates the loading used in sporting situations. With this method musculotendinous units are loaded, a perturbation is applied, and stiffness is derived from the resulting oscillations as measured by force plate (166), load cell (122), or accelerometer (40). Previous research involving the bench press used a perturbation of approximately 100 Newtons implemented with a downward push of an experimenter's hand (165,166). This method was used by Wilson et al. (166) where they implemented an eight-week stretching intervention in competitive male powerlifters. A significant increase in ROM, a decrease in stiffness, and an increase in 1RM bench press was observed in the intervention group. The authors postulated that bench press performance was enhanced due to a more compliant musculotendinous unit, that could more effectively store energy. However, recently it was demonstrated that the impulse applied during the perturbation affects stiffness and should be standardised (46). Thus, the findings of Wilson et al. (166,167) need to be confirmed using an alternative method. Furthermore, use of the free-oscillation technique during the squat and bench press to obtain measurements of stiffness appear to be impractical due to the challenge of standardising perturbations.

An alternative in-vivo method to estimate active stiffness was proposed by Hernández-Davó et al. (69). This method involves measuring barbell velocity with a linear position transducer (LPT) during the final 50ms of the eccentric phase. The data can then be used in the vertical stiffness equation: stiffness ($k) = F/d$ where $F = m \times a$. During the last 50 ms of the eccentric phase the musculoarticular complex undergoes minimal length change, and the stiffness of the complex will theoretically influence the velocity of the barbell (69). This proposed method allows for task-specificity of movement and loading; for this reason, it was thought that it could be used to estimate active stiffness in recreationally strength-trained men and competitive powerlifters during the bench press. While this method does not directly measure structural stiffness, it is a practical performance measure which may give valuable insight into stiffness levels during the bench press and squat. Therefore, the purpose of this study was to determine if the vertical stiffness equation could be used to establish a practical performance measure of squat and bench press stiffness.

Methods

Experimental approach to the problem

A cross-sectional examination of maximal dynamic strength and velocity of submaximal repetitions was conducted. Powerlifters and recreationally strength-trained men were recruited from local gyms and through social media via a recruitment poster. Maximal strength was assessed with back squat and bench press 1RM testing in a single session. Barbell velocity was measured at 50, 70, and 80% of 1RM for back squat and bench press in a subsequent session.

Participants

Twelve male powerlifters and 13 recreationally strength-trained men participated in this study (age 27.1 ± 4.7 years; height 177.5 ± 8.5 cm; weight 88.3 ± 13.4 kg; 1RM squat 174.2 ± 30.1 kg; relative squat 1RM 2.0 ± 0.4; 1RM bench press 125.8 ± 22.3 kg; relative bench press 1RM 1.4 ± 0.3). Two recreationally trained participants were excluded from analysis due to technical issues that compromised the data. To be included, powerlifters needed to be actively training for powerlifting, have participated in at least one unequipped IPF meet, and have a New Zealand National qualifying total or higher. Recreationally strength-trained men were included if they regularly trained the back squat and bench press, and could squat at least 1.5x, and bench press at least 1x body weight. All participants were injury-free and were informed of the risks and benefits associated with this study and signed a written consent prior to data collection. The methods and procedures used in this study were approved by Auckland University of Technology ethics committee, AUTEC Reference number 19/195.

Procedures

Participants completed two testing sessions at the same time of day, separated by 72 to 96 hours. During the first session, age, height, and weight were recorded and 1RM back squat and bench press were assessed. During the second session velocity was collected during submaximal squat and bench press repetitions.

1 Repetition Maximum Testing: Testing was performed as described in Chapter 5. To ensure uniformity, the squat was performed to IPF standards (72) reaching a depth where the hip crease was below the top of the knee joint. The bench press was performed in a touch-and-go style, and participants had to keep their head, shoulders, and buttocks in contact with the bench for the duration of the lift.

Stiffness: Stiffness measures were obtained during the last 50 ms of the eccentric phase of the bench press and squat using the methodology of Hernández-Davó et al. (69). Stiffness was estimated as:

K = F/d where $F = m \times \Delta v_{ecc,pre50\text{-}0ms}/0.05$

$F = m \times a;\ a = v/t;\ v = d/t;\ t = 50\ ms$

m = mass; a = acceleration; v = velocity; t = time

Velocity was calculated by a LPT (PT5A, Celesco, Adelaide, Australia) attached to the furthest position of the grip section of the barbell (7) which sampled at 1000 Hz. Six trials were completed, two at 50, 70, and 80% of 1RM for each lift. The first three trials were completed in ascending order to ensure sufficient warmup and the second three trials were randomised. Data were collected and key variables were extracted using a custom LabVIEW programme.

Stiffness index: To represent an index of stiffness characteristics of individual athletes across the different loading conditions, the absolute load-stiffness relationship was fit with a linear least-squares regression and its slope extracted. This was calculated for each participant's unique load and stiffness data, for both squat and bench press, netting two distinct stiffness values representing total-body and upper limb spring stiffness, respectively.

Statistical analyses

Data were checked for normality and homogeneity of variance using the Shapiro-Wilk test and Levene's test, respectively. Means and standard deviations were used to represent the centrality and spread of data. Significance was set at ($p \leq 0.05$). Pearson's correlation coefficients (r) were used to determine the relationships between stiffness and barbell load, and SI and 1RM strength. All data were analysed using IBM SPSS (version 26.0).

Results

Stiffness was significantly correlated with barbell load r = 0.998, $p < 0.001$ (Figure 6-1). Stiffness index was not significantly correlated with 1RM strength, squat r = 0.092, p = 0.677; bench press r = 0.093, p = 0.674 (Figure 6-2).

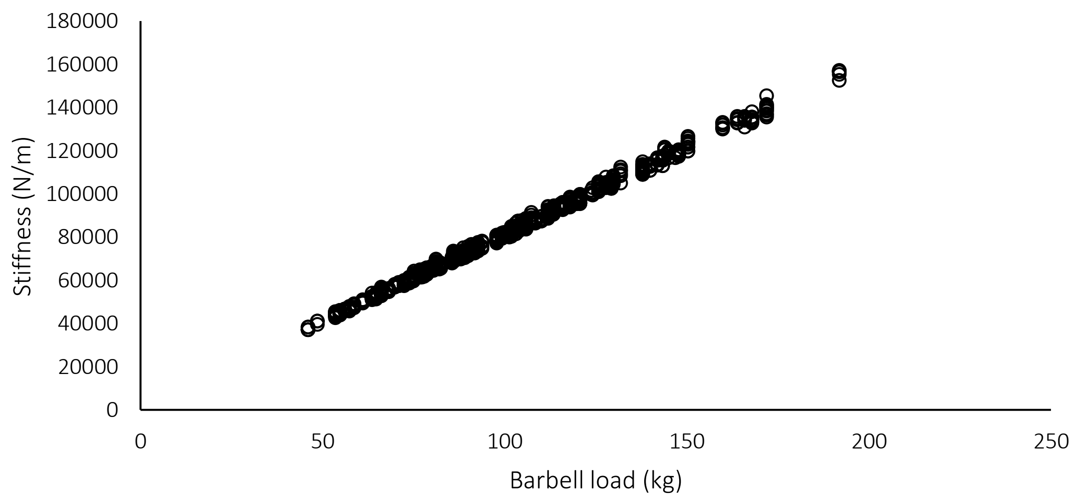

Figure 6-1 The relationship between stiffness and barbell load for the squat and bench press

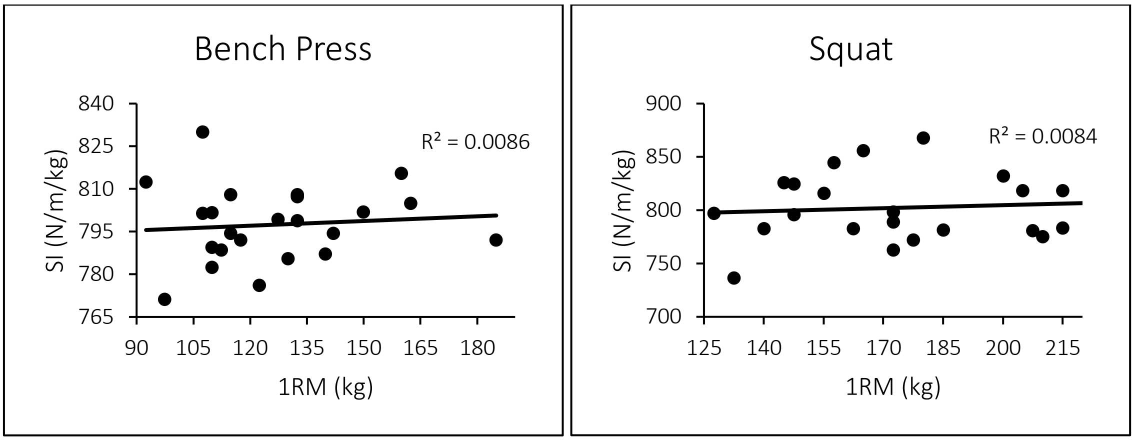

Figure 6-2 The relationship between stiffness index and 1RM

Discussion

Stiffness is an important task-specific characteristic for athletic performance and injury risk management (25). Currently, there is no practical method to determine stiffness for barbell sports such as powerlifting. Therefore, the purpose of this study was to evaluate a recently proposed method of estimating stiffness during barbell lifts. Using this method, bench press and squat stiffness were almost perfectly correlated with barbell load (r = 0.998, p < 0.001; figure 6-1). The degree of correlation prompts the question of whether this method is valid and/or useful as stiffness calculated in this way is almost entirely be explained by barbell load.

Hernández-Davó et al. (69) observed an increase in stiffness following bench throw training using this method; however, the loads used to determine stiffness were adjusted based on 1RM bench press tests pre- and post-training. The bench press 1RM increased following training, thus, it is possible that the increase in stiffness was a direct result of increased loads. Although it was not discussed by Hernández-Davó et al. (69), the load-stiffness relationship could be determined via digitisation and also appears to be linear (Figure 6-2).

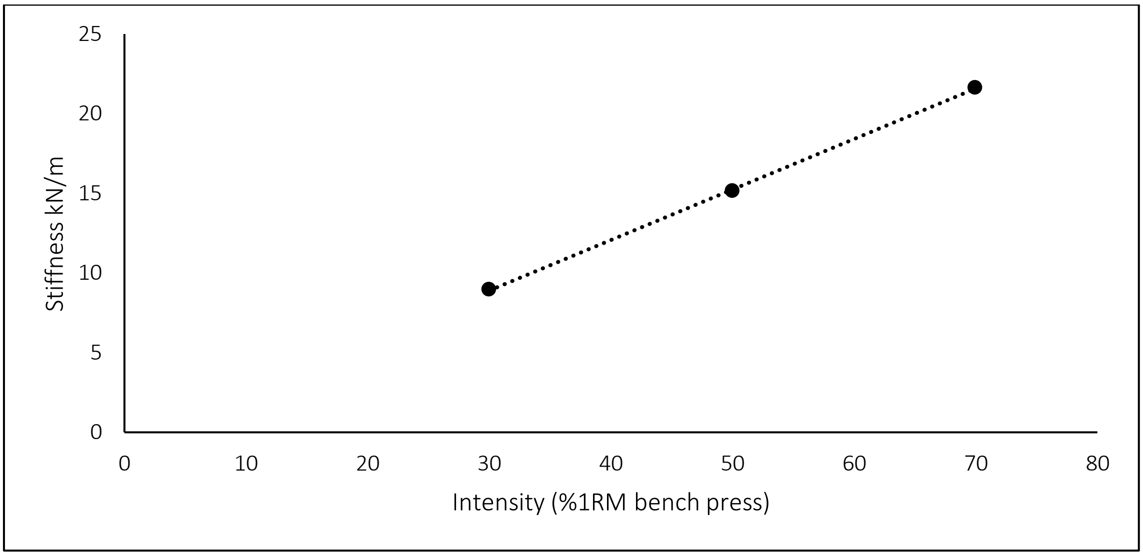

Figure 6-3 Load-stiffness relationship adapted from Hernández-Davó et al. (69) using WebPlotDigitizer

The rationale for creating a stiffness index, was that stiffness in multi-articular assessments (e.g., running) is performed without applied loads (117), and that understanding the athletes' response across loading conditions could provide insight into their global stiffness characteristics. Specifically, while most variability in output stiffness was explained by load, the remaining variation, although small, could be due to general stiffness characteristics. However, stiffness index was not associated (r = 0.092-0.093, p = 0.674-0.677) with 1RM for the squat or bench press (Figure 6-2).

It is also worth noting that the relationship between load and stiffness as assessed via the free-oscillation technique is curvilinear with a plateau at higher loads (Figure 6-4) (39,40,168). This curvilinear relationship was demonstrated alongside acceptable technique reliability (ICC = 0.62–0.89; CV = 8.1–13.1%) (40). The loads used in the present study were 50, 70, and 80% of 1RM and may begin after the plateau; however, Hernández-Davó et al. (69) began stiffness measurements at a lower load (30%) and there was still no evidence of a curvilinear relationship. This may indicate a problem with the proposed stiffness measurement or may be a result of the narrow range of assessed loads (30, 50, and 70%).

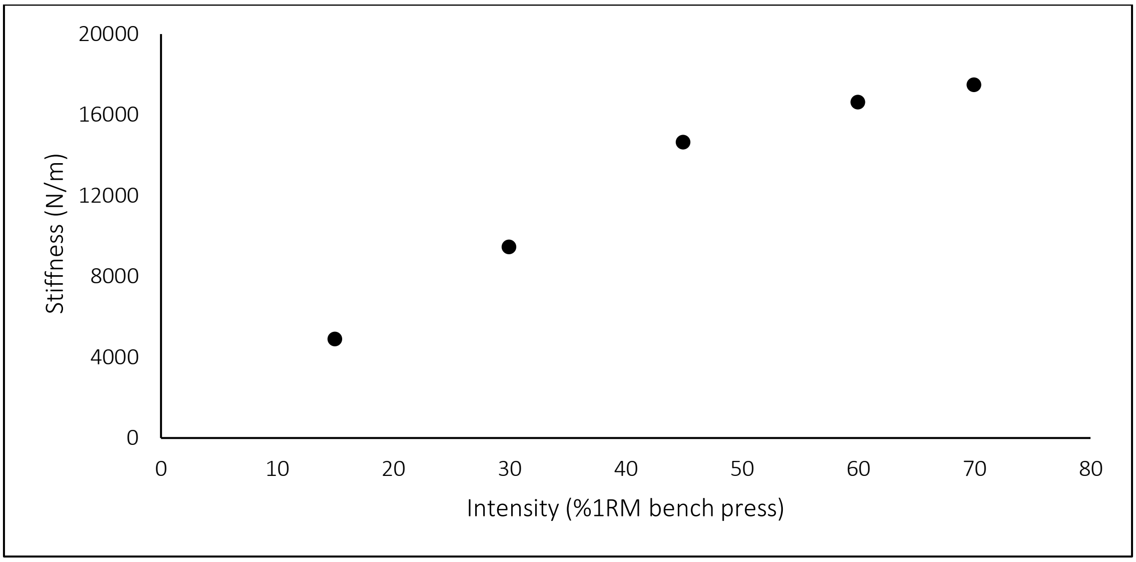

Figure 6-4 Load-stiffness relationship adapted from Wilson et al. (168)

Conclusion

Bench press and squat stiffness, as estimated from the modified vertical stiffness equation, were almost perfectly correlated with barbell load. As such, this metric provides no additional information beyond what would be found through 1RM testing. For this reason, stiffness was not included in the remaining studies in this thesis. Further research is needed to establish a method that can evaluate stiffness during barbell lifts such as the squat and bench press.

Prelude

The findings from Chapter 5 agreed with previous research that male powerlifters have less ROM than non-powerlifters in movements that stretch the prime movers of the squat, bench press, and deadlift. Therefore, the purpose of Chapter 7 was to investigate the effects of chronic stretching that targets the bench press prime movers (pectoralis major, triceps brachii, and anterior deltoid) on powerlifting performance.

Chapter 7 Chronic stretching after powerlifting training: a case study

Introduction

Chronic static stretching is an effective way to increase ROM (104,166). Additionally, chronic stretching can improve performance in stretch-shortening cycle (SSC) movements (85,102,166), increase maximal dynamic strength (85), and increase hypertrophy (116). These adaptations could be beneficial for powerlifters; however, most research investigating the effects of long-term stretching on performance have included sedentary or recreationally trained participants and may not be generalisable to strength athletes.

The observed effects of chronic stretching on SSC movements tend to be positive in sedentary and recreationally active individuals as well as powerlifters (85,102,166). Wilson et al. (166) recruited powerlifters to perform a combination of static and dynamic stretching exercises targeting the pectoralis and deltoid muscles twice a week for eight weeks. The intervention significantly increased one 1RM bench press (166). No research groups have investigated the effects of stretching on 1RM squats, but Kokkonen et al. (85) and Levenez et al. (102) found that chronic stretching improved drop jump, and vertical jump performance, respectively.

The effects of chronic stretching on strength are mixed. Kokkonen et al. (85) and Nelson et al. (126) found that ten weeks of static stretching of agonist muscles in sedentary and recreationally active individuals significantly improved 1RM performance in knee flexion and extension, and standing plantar flexion, respectively. Li et al. (103) combined static, dynamic, and peripheral neuromuscular facilitation hamstrings stretching and found increased concentric knee flexion strength in female but not male participants after 8 weeks. Whereas Simao et al. (147) implemented a variety of upper and lower body static stretches and found no significant difference in leg press or bench press 10RM in sedentary women after 16 weeks.

Preliminary research on the effects of chronic stretching is varied but demonstrates potential benefits. Therefore, the purpose of this case study was to investigate the effects of chronic post-training stretching on bench press performance in an international grade powerlifter. A secondary goal was to observe ROM in the lower body of a high-level strength athlete in the absence of stretching.

Methods

Participant

An international grade male powerlifter (body mass: 79.3 kg, age: 29 years, training age: 15 years, best Wilks score: 407) participated in this study. He was actively training for powerlifting at the time and had not regularly (at least once per week) engaged in static stretching for at least three months prior to the study. The participant was informed of the risks and benefits associated with this study and signed a written consent prior to data collection. The methods and procedures used in this study were approved by Auckland University of Technology ethics committee, AUTEC Reference number 20/40.

Procedures

Two testing sessions were conducted at the same time of day, separated by eight weeks. Active ROM was measured at the shoulder, hip, and knee. Following a dynamic warm-up three CMJs were completed on a force plate, and finally 1RM back squat and bench press were assessed.

Stretching: The stretching programme was adapted from previous research (166) and is described in Tables 7-1 and 7-2. All stretches were performed to the point of maximum discomfort, without any pain. A researcher demonstrated the stretches and ensured the participant was comfortable with each movement. The participant was instructed to perform the stretches at the end of his scheduled training sessions three times weekly and recorded the stretches once per week to ensure proper form was maintained.

Powerlifting training: The training programme (Appendix D) had a 2-3-2 lift frequency for the competition squat, bench press, and deadlift, respectively. Volume was based on weekly working sets and included 10 sets of squats, 15 sets of bench press, and eight sets of deadlifts per week. Intensity was periodised and ranged from 6-10 RPE or 70-95% 1RM for competition lifts. Accessory lifts (Appendix E) were categorised (e.g., vertical push, vertical pull, core, etc.) to give options in case of limited equipment availability. One exercise from each category was programmed once per week, with eight total accessory lifts.

Table 7-1 Upper body stretching protocol

Stretch	Description	Duration (sec)	Sets	Reps
1. Supine dumbbell fly	Lower two 5-10kg dumbbells in horizontal abduction as far as possible.	20-30	3-4	-
2. Increased range pushup	Place hands on 2 benches, lower body as far as possible.	20-30	3-4	-
3. Wall chest stretch	Place straight arm horizontally against wall, rotate body away from wall until moderate discomfort is felt.	20-30	3-4	-
4. Dowel stretch	Grasp dowel with double overhand grip. Keep arms straight as you lift the dowel overhead and behind the back, then return to start position. Have hands as close together as possible.	-	2	16-30

Table 7-2 Stretching progressions

	Stretches 1, 2, and 3	Stretch 4
	Duration (sec) x Sets	Repetitions x Sets
Weeks 1-2	20 x 3	8 x 2
Weeks 3-4	25 x 3	10 x 2
Weeks 5-6	30 x 3	12 x 2
Weeks 7-8	30 x 4	15 x 2

Range of Motion: Active ROM was measured using a 32 cm plastic goniometer. Three measurements were taken at each range and the median was used for analysis. If at least two of the three measurements were not within five degrees a fourth measurement was taken. The same researcher, with more than eight years of experience measuring ROM as a registered massage therapist, completed all ROM measurements. Shoulder horizontal abduction, hip flexion with the knee bent and extended, and knee flexion were measured. Each measurement was taken once before all measurements were repeated. Intrarater reliability is high in our laboratory (shoulder ICC = 0.909-0.987, CV = 0.85-5.49%; hip and knee ICC = 0.630-0.981, CV = 1.35-11.22%).

All measurements were taken in a supine position. Hip flexion was measured with the knee bent while the opposite leg remained extended and relaxed on the table. Knee flexion was measured at the edge of the table, the participant held the opposite leg to their chest to avoid lumbar extension while the researcher held the knee being measured in line with the hip and at zero degrees.

Countermovement jump: All jumps were performed with a dowel in the back squat position. The participant performed two warm-ups at 50 and 75% of perceived maximum, then three maximum effort CMJs to a self-selected depth with 30 seconds of rest between each jump. The researcher gave the instructions "3, 2, 1, jump!" (157). All jumps were performed on a triaxial force plate (Accupower by Advanced Mechanical Technologies Inc., 176 Waltham Street, Watertown, MA., USA). Analogue channels were sampled at 1,000 Hz using a USB-6009 I/O device at 13 bit resolution (National Instruments). Labview software (National Instruments) was used to record and process the force data. CMJ jump height has demonstrated acceptable reliability in similar populations (ICC = 0.94; CV = 5.8%) (151).

One Repetition Maximum Testing: Back squat and bench press 1RM were tested using the same methods as outlined in Chapter 5.

Statistical analysis

Change and percent change were reported. Differences greater than 5° were required to indicate meaningful changes in ROM, reflecting the typical error of measurement.

Results

Horizontal shoulder abduction increased on the right side (121° to 130°, 7.44% change) to match ROM on the left side, which did not change. Straight leg hip flexion decreased (Right: 72° to 58°, -19.4% change; Left: 75° to 62°, -17.3% change), while bent knee hip flexion did not change. Knee flexion decreased (Right: 104° to 88°, -15.4% change; Left 107 to 89, -16.8% change).

Squat and bench press 1RM decreased (Squat: 205 to 200 kg, -2.44% change; Bench press: 140 to 135 kg, -3.57% change), there was no change in CMJ height (40cm).

Discussion

The stretching programme did not reliably increase ROM. Horizontal shoulder abduction improved on only one side so that symmetry was achieved, but there were no further improvements. This may be due to the stretching programme, but that is unlikely since the stretches were previously shown to be effective in male powerlifters (166). Additionally, the same stretching frequency (three times per week) was previously sufficient to significantly improve ROM (109,125). Marques et al. (109) compared stretching frequencies of one, three, and five times per week for four weeks; while both three and five times significantly improved ROM, there was no significant difference between them. Stretching durations implemented in this study also replicated those previously used effectively (138). This indicates there are other reasons for the lack of ROM improvements, such as a possible ceiling effect. Interestingly, the participant was more flexible than average when compared to cross sectional powerlifter data (Chapter 5). Specifically, the participant had a maximum of 130° of shoulder horizontal abduction, which is 20° more than the average for male powerlifters of a similar age (108 ± 9°) (Chapter 5).

Resistance training and stretching may have similar effects on ROM (for review (3)). Several studies implementing resistance training programmes in sedentary and recreationally active samples observed significant increases in ROM (103,142,147). No similar studies investigated the effect of resistance training on ROM in resistance-trained individuals; however, the present results indicate there are likely caveats to that proposal. The participant was highly experienced (15 years), but ROM did not increase in areas that were not targeted by the stretches. Moreover, straight leg hip flexion and knee flexion ROM decreased despite squatting and deadlifting twice per week, resulting in a qualitatively observed change in squat technique. This change was noticed by the research team and confirmed by the participant who stated he purposefully modified his stance due to subjectively feeling tight and uncomfortable in the previous stance.

While it is impossible for ROM to continue to increase consistently with resistance training over years, if it were as effective as stretching at increasing ROM, one might expect to see a plateau rather than a decrease in ROM.

The purpose of this study was to investigate the effects of chronic post-training stretching on powerlifting performance. However, since the stretching programme did not improve ROM, it seems unwise to attribute any performance changes to the stretches. While there is great deal of evidence that stretching improves ROM, there is much less evidence and more controversy around the effect of stretching on performance.

Practical applications

Stretching programmes similar to those implemented in the current study may not be sufficient to improve ROM in more flexible strength trained individuals. More research is needed to determine if chronic post-training stretching would effectively increase flexibility in individuals with ROM more typical of powerlifters, and to determine how this might affect powerlifting performance.

Prelude

After the completion of Chapter 7 with a single participant it was evident that the stretching intervention did not improve ROM. At this time the data from Chapter 5 had been analysed and the average ROM for powerlifters was less than that of the participant from Chapter 7 in all comparable ranges. Based on these findings, exclusion criteria were added for future participants such that they would not be able to participate unless they had similar ROM to the powerlifters in Chapter 5 in one or more movements about the shoulder and/or hip. To allow for more comparisons the ROM measurements were adjusted to match those used in Chapter 5. The disruption in data collection due to initial stages of the COVID-19 pandemic did allow for the addition of new measures that might help determine the mechanisms underpinning any change in squat and bench press 1RM. Unfortunately, COVID-19 alert level guidelines caused the powerlifting competition schedule to change for the year, which in turn effectively eliminated the powerlifting offseason. To compensate for these changes the inclusion criteria were extended to include strength trained men.

Chapter 8 Chronic stretching after strength training: a case series

Introduction

Stretching may be beneficial for individuals trying to improve their squat and bench press 1RM (166), as both lifts are augmented by the stretch-shortening cycle (SSC). The SSC increases concentric force output when it is preceded by an eccentric contraction, beyond what can be produced through a concentric-only contraction (32). One possible mechanism of the SSC is storage and use of elastic energy (22,23). Stretching has the potential to enhance the SSC by increasing tissue compliance and therefore, improving its capacity to store energy (166). This was investigated by Wilson et al. (166) who had powerlifters perform chest and shoulder stretches after upper body resistance training for eight weeks. Following the intervention, rebound bench press 1RM and concentric work significantly increased, and the improvement was attributed to decreased active musculoarticular stiffness (166). Chronic stretching may also improve strength (85,103,126) and hypertrophy (45,116). However, the research in this area is equivocal and primarily includes sedentary to recreationally active individuals (45,85,103,116,126). It has also been suggested that stretching may need to be loaded or combined with resistance training to induce hypertrophy (128). While there have been some positive results from inter-set stretching (45,124), stretching immediately prior to resistance training can cause acute force decrements (16,79,148), so it may be preferable to implement stretching after resistance training to elicit strength and hypertrophy adaptations. Therefore, the purpose of this study was to investigate the effects of chronic post-training stretching on squat and bench press performance in highly advanced resistance-trained men. A secondary goal was to observe any changes in SSC performance and muscle thickness to help elucidate mechanisms underpinning any squat and bench press improvement.

Methods

Experimental approach to the problem

This case-series was designed to investigate the effects of chronic post-training stretching on squat and bench press 1RM. Two men visited the laboratory at the same time of day, on three occasions, each separated by eight weeks (Figure 8-1).

Participants were randomly assigned to either upper or lower body stretching first and switched at the half-way point. Each participant performed a designated series of stretches (Table 8-1) three times per week after strength-training sessions. ROM at the shoulder, hip, and knee were measured to ensure the stretching programmes were effective. Back squat and bench press 1RM were the primary outcome measures, and muscle thickness, CMJ, and plyometric push-up were measured to elucidate possible mechanisms for 1RM changes.

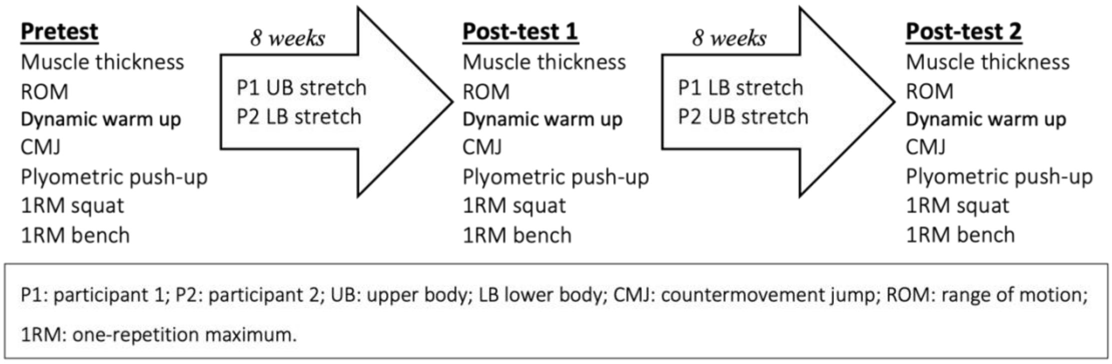

Figure 8-1 Study design

Participants

Two highly advanced resistance-trained men (classification from (143)) participated in this study and are reported as individual cases. This classification system has been designed to help researchers better describe participants and is based on training experience, detraining time, exercise technique, and strength levels (143). Participant 1 was assigned to upper body stretching first (age: 25 years; height 175.3 cm; weight: 79.9 kg; training age: 6 years; squat 1RM: 165 kg; relative squat 1RM = 2.1; bench press 1RM 107.5 kg; relative bench 1RM = 1.3). Participant 2 was assigned to lower body stretching first (age: 27 years; height: 180.5 cm; weight: 68.5 kg; training age: 5 years; squat 1RM: 125 kg; relative squat 1RM = 1.8); bench press 1RM: 100 kg; relative bench 1RM = 1.5). Participants were actively training the squat and bench press and had not regularly (at least once per week) performed static stretches for at least three months prior to the study. Participants were informed of the risks and benefits associated with this study and signed a written consent prior to data collection. The methods and procedures used in this study were approved by Auckland University of Technology ethics committee, AUTEC Reference number 20/40.

Procedures

Stretching: The stretching programmes were adapted from previous research (166) and are described in Tables 8-1 and 8-2. Total stretching duration increased over the eight-week period (Table 8-3). All stretches were performed to the point of maximum discomfort without pain. A researcher demonstrated the stretches and had the participants practice until they were comfortable with the movements prior to beginning the training. Participants were instructed to perform the stretches at the end of their training sessions and to record the stretches at least once per week to ensure they maintained proper form. A researcher viewed the weekly recordings and gave feedback prior to the next stretching session when feedback was needed.

Powerlifting training: The training programme used was outlined in Chapter 7 (for full programme and guidelines for changes or substitutions see appendices D and E).

Table 8-1 Upper body stretching protocol

Stretch	Description	Duration (sec)	Sets	Reps
1. Supine dumbbell fly	Lower two 5-10kg dumbbells in horizontal abduction as far as possible.	20-30	3-4	-
2. Increased range pushup	Place hands on 2 benches, lower body as far as possible.	20-30	3-4	-
3. Wall chest stretch	Place straight arm horizontally against wall, rotate body away from wall until moderate discomfort is felt.	20-30	3-4	-
4. Dowel stretch	Grasp dowel with double overhand grip. Keep arms straight as you lift the dowel overhead and behind the back, then return to start position. Have hands as close together as possible.	-	2	16-30

Table 8-2 Lower body stretching protocol

Stretch	Description	Duration (sec)	Sets	Reps
1. Goblet squat	Holding a 10-20kg dumbbell, lower as far down into a squat as possible while maintaining a neutral spine.	20-30	3-4	-
2. Standing quad stretch	Bend knee and take hold of ankle, draw heel toward buttock while keeping glutes engaged.	20-30	3-4	-
3. Glute stretch	Bend one knee and place the foot of that leg on top of the opposite thigh, then draw the legs toward the chest.	20-30	3-4	-
4. Lizard rock	In a low lunge bend front knee and lower hips toward the floor, then rock hips back to straighten the front knee as much as possible, and repeat.	-	2	16-30 per side

Table 8-3 Stretching progressions

	Stretches 1, 2, and 3	Stretch 4
	Duration (sec) x Sets	Repetitions x Sets
Weeks 1-2	20 x 3	8 x 2
Weeks 3-4	25 x 3	10 x 2
Weeks 5-6	30 x 3	12 x 2
Weeks 7-8	30 x 4	15 x 2

Ultrasound: Vastus lateralis, gluteus maximus, and pectoralis major muscle thickness were measured on the right side of the body via 2-dimensional B-mode ultrasonography using an ultrasound transducer and built-in software (45 mm linear array, 10 MHz; GE Healthcare, Vivid S5, Chicago, IL, USA) (29,38,51). Two images were captured at each site and the nearest two were averaged. If the difference between the two scans was > 2 mm a third image was captured and the two values within 2 mm were averaged (67). Sufficient water-soluble gel was applied to the scanning head of the ultrasound probe to achieve acoustic coupling and to avoid the deformation of muscle.

The site for vastus lateralis was 50% of the distance from the greater trochanter to the lateral border of the femoral condyle (51). The site for gluteus maximus was 50% of the distance from the posterior superior iliac spine to the greater trochanter (38). The site for pectoralis major was 50% of the distance from the lateral border of the sternum at the level of the second rib to the superior aspect of the axillary fold (29). Ultrasound imaging has demonstrated acceptable muscle thickness reliability (ICC = 0.83-0.99) (51,75).

Range of motion: ROM measurements were taken with a 32 cm plastic goniometer. Movements that stretched muscles directly involved in the squat and bench press were targeted (shoulder flexion, extension, and horizontal abduction; hip flexion and extension; and knee flexion and extension). Three measurements were taken at each range and the median was used for analysis. If at least 2 of the 3 measurements were not within 5° a fourth measurement was taken. Detailed protocols are reported in Chapter 4. The reliability of these measures in our laboratory is acceptable (shoulder ICC = 0.912-0.987, CV= 0.85-5.49%; hip and knee ICC = 0.881-0.941, CV = 1.35-11.22%).

Plyometric push-up: Participants performed three maximal plyometric push-ups with two minutes rest between each attempt (132). The participant started in a push-up position with both hands on the force plate, once the participant was completely still the researcher gave the instructions "3, 2, 1, go!" The participants then lowered their chest toward the force plate and immediately pressed as hard and fast as they could vertically away from the force plate. All plyometric push-ups were performed on a triaxial force plate (Accupower by Advanced Mechanical Technologies Inc., 176 Waltham Street, Watertown, MA., USA). Analogue channels were sampled at 1,000 Hz using a USB-6009 I/O device at 13 bit resolution (National Instruments). LabVIEW software was used to record and process the force data. Plyometric push-up jump height has demonstrated acceptable reliability in similar populations (ICC = 0.964; CV = 6.9%) (132).

Countermovement jump: Participants performed three maximal CMJs on a force plate (described above) using the same methods as outlined in Chapter 7. CMJ jump height has demonstrated acceptable reliability in similar populations (ICC = 0.94; CV = 5.8%) (151).

Reactive strength index–modified (RSImod): RSImod is an indicator of SSC performance (157). It was determined for CMJ and plyometric push-up as the quotient of jump height and time to take off where Jump height was calculated from flight time (157).

One repetition maximum: Back squat and bench press 1RM were tested using the methods described in Chapter 5. 1RM testing of the upper and lower body have demonstrated acceptable reliability (Upper body ICC = 0.64 to 0.99, median ICC = 0.98, CV = 1.0 to 7.9%, median CV = 4.1%; Lower body ICC = 0.64 to 0.99, median ICC = 0.97, CV = 0.5 to 12.1%, median CV = 4.7%) (64).

Statistical analyses

Change and percent change were reported for all measurements. Meaningful differences were determined using 95% minimum detectable change ($1.96 \times \sqrt{2} \times SEM$) calculated from reliability data collected in our laboratory and from previous research (31,51,75,93,120). Meaningful differences were defined as those greater than the 95% minimum detectable change which was 5° for ROM, 0.13 cm for vastus lateralis and pectoralis major muscle thickness, 0.42 cm for gluteus maximus muscle thickness, 1.6 cm for jump height and 0.04 for RSImod. The threshold for weight gain was set at 1% (131).

Results

Participant 1

Results are presented in Tables 8-4 and 8-6. Following upper body stretching left shoulder flexion (179° to 193°) and extension (32° to 50°), and bilateral horizontal shoulder abduction (right: 115° to 137°; left: 98° to 136°) increased. There was no change in pectoralis major muscle thickness, plyometric push-up height or RSImod. Bench press 1RM (107.5 kg to 120 kg) increased.

Following lower body stretching left hip flexion (116° to 129°) increased, as did vastus lateralis muscle thickness (2.08 cm to 3.08 cm). CMJ height (42.6 cm to 40.5 cm) and RSImod (0.44 to 0.34) decreased, while squat 1RM (177.5 kg to 182.5 kg) increased.

Stretching and resistance training effects on range of motion

Following the first block of training, ROM in both the intervention area (shoulder) and control areas (hip and knee) increased. Following the second block of training only left hip flexion increased in the intervention areas. In the control area shoulder flexion and horizontal abduction decreased whereas shoulder extension continued to increase.

Participant 2

Results are presented in Tables 8-5 and 8-7. Following lower body stretching right hip flexion (113° to 124°), bilateral hip extension (right: 6° to 25°; left: 5° to 23°), knee flexion (right: 131° to 152°; left: 126° to 149°) and knee extension (right: 122° to 130°; left: 123° to 132°) increased. There was a decrease in vastus lateralis (2.28 cm to 2.12 cm) and no change gluteus maximus muscle thickness. CMJ height did not change, there was a decrease in RSImod (0.55 to 0.49) and an increase in squat 1RM (125 kg to 137.5 kg).

Following upper body stretching shoulder flexion (right: 142° to 182°; left: 146° to 178°) increased bilaterally. Pectoralis major muscle thickness decreased (2.18 cm to 2.04 cm). Plyometric push-up height and RSImod did not change, and bench press 1RM (110 kg to 115 kg) increased.

Stretching and resistance training effects on range of motion

Following the first block of training, ROM in the intervention areas (hip and knee) increased while ROM in the control area (shoulder) stayed the same other than a small decrease in extension on the right side. Following the second block of training only shoulder flexion improved in the intervention area. In the control areas ROM at the hip decreased whereas knee flexion continued to increase

Table 8-4 Participant 1 range of motion

	Pre		Mid		Δ°after UBS (%Δ)		Post		Δ° after LBS (%Δ)	
Shoulder	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
Flexion	191	179	188	193	-3 (1.6)	**14 (7.8)**	158	164	**-30 (16.0)**	**-29 (15.0)**
Extension	49	32	53	50	4 (8.2)	**18 (56.3)**	63	56	**10 (18.9)**	**6 (12.0)**
Horizontal Abduction	115	98	137	136	**22 (19.1)**	**38 (38.8)**	126	119	**-11 (8.0)**	**-17 (12.5)**
Hip										
Flexion	108	110	122	116	**14 (13.0)**	**6 (5.4)**	122	129	0	**13 (11.2)**
Extension	12	4	8	11	-4 (33.3)	7 (175.0)	13	14	5 (62.5)	3 (27.2)
Knee										
Flexion	151	143	169	168	**18 (12)**	**25 (17)**	168	165	-1 (0.6)	-3 (1.8)
Extension	129	130	133	135	4 (3.1)	5 (3.8)	134	135	1 (0.8)	0

UBS = upper body stretching; LBS = lower body stretching; Δ = change; **Bold** indicates meaningful change

Table 8-5 Participant 2 range of motion

	Pre		Mid		**Δ° after LBS (%Δ)**		Post		**Δ° after UBS (%Δ)**	
Shoulder	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
Flexion	140	145	142	146	2 (1.4)	1 (0.7)	182	178	**40 (28.2)**	**32 (21.9)**
Extension	58	52	51	50	**-7 (12.1)**	-2 (3.8)	50	49	-1 (2.0)	-1 (2.0)
Horizontal Abduction	118	113	116	113	-2 (1.7)	0	113	115	-3 (2.3)	2 (1.8)
Hip										
Flexion	113	117	124	120	11 (9.7)	3 (2.7)	113	115	**-11 (8.9)**	-5 (4.2)
Extension	6	5	25	23	**19 (316.7)**	**18 (360.0)**	9	10	**-16 (64)**	**-13 (57)**
Knee										
Flexion	131	126	152	149	**21 (16.0)**	**23 (18.3)**	168	165	**16 (10.5)**	**16 (10.7)**
Extension	122	123	130	132	**8 (6.6)**	**9 (7.3)**	134	135	4 (3.1)	3 (2.3)

UBS = upper body stretching; LBS = lower body stretching; Δ = change; **Bold** indicates meaningful change

Table 8-6 Participant 1 results

	Pre	Mid	Δ after UBS	Post	Δ after LBS (%Δ)
Vastus lateralis MT (cm)	2.30	2.08	**-0.22 (9.6)**	3.08	**1.00 (48.1)**
Gluteus maximus MT (cm)	2.46	2.94	**0.48 (19.5)**	3.53	**0.59 (20.1)**
Pectoralis major MT (cm)	1.99	2.06	0.07 (3.5)	2.35	**0.29 (14.1)**
Weight (kg)	79.9	81.9	**2.0 (2.5)**	82.5	0.6 (0.7)
CMJ (cm)	39.8	42.6	**2.8 (7.0)**	40.5	**-2.1 (4.9)**
Plyometric push-up (cm)	19.3	17.3	**-2.0 (10.3)**	19.0	**1.7 (9.8)**
RSI_{mod} CMJ	0.51	0.44	**-0.07 (13.7)**	0.34	**-0.1 (22.7)**
RSI_{mod} Plyometric Push-up	0.18	0.13	**-0.05 (27.8)**	0.16	0.03 (23.1)
Squat 1RM (kg)	165	177.5	**12.5 (7.6)**	182.5	**5.0 (2.8)**
Bench 1RM (kg)	107.5	120	**12.5 (11.6)**	127.5	**7.5 (6.3)**

MT = muscle thickness; UBS = upper body stretching; LBS = lower body stretching; Δ = change; **Bold** indicates meaningful change

Table 8-7 Participant 2 results

	Pre	Mid	Δ after LBS (%Δ)	Post	Δ after UBS (%Δ)
Vastus lateralis MT (cm)	2.28	2.12	**-0.16 (7.0)**	2.41	**0.29 (13.7)**
Gluteus maximus MT (cm)	3.15	3.11	-0.04 (1.3)	3.33	**0.22 (7.0)**
Pectoralis major MT (cm)	2.09	2.18	0.09 (4.3)	2.04	**-0.14 (6.4)**
Weight (kg)	68.5	69.2	**0.7 (1.0)**	69.6	0.4 (0.6)
CMJ (cm)	43.9	43.6	-0.3 (0.7)	41.8	**-1.8 (4.1)**
Plyometric Push-up (cm)	21.5	18.0	**-3.5 (16.3)**	19.3	1.3 (7.2)
RSI_{mod} CMJ	0.55	0.49	**-0.06 (10.9)**	0.46	-0.03 (6.1)
RSI_{mod} Plyometric Push-up	0.21	0.16	**-0.05 (23.8)**	0.20	0.04 (25.0)
Squat 1RM (kg)	125	137.5	**12.5 (10.0)**	142.5	**5 (3.6)**
Bench 1RM (kg)	100	110	**10 (10.0)**	115	**5 (4.5)**

MT = muscle thickness; UBS = upper body stretching; LBS = lower body stretching; Δ = change; **Bold** indicates meaningful change

Discussion

This case-series was designed to investigate the effects of chronic post-training stretching on squat and bench press 1RM and to elucidate possible mechanisms for 1RM changes. The stretching intervention was effective as evidenced by an increase in ROM in one or more of the movements measured in the stretching intervention area in every training bock. Interestingly, resistance training alone improved ROM in the control area in three of the four training blocks. This differs from the results of Wilson et al. (166) where a ROM improvement was only observed in the stretching group. In the two instances where the stretching intervention was completed in the first 8 weeks, there was a loss of ROM in some of the movements in the following 8 weeks when stretching was ceased. However, when the stretching intervention was implemented in the second 8 weeks ROM was either maintained or increased with the addition of stretching. These results support the use of resistance training as a method of increasing ROM in recreationally trained men (2). However, stretching was more effective than resistance training for increasing or maintaining ROM in this study. This may be due to participants only needing to meet IPF depth guidelines for the squat and bench press; ROM may have improved more with resistance training if they were required to move through their full active ROM in each exercise.

CMJ height and plyometric push-up jump height seemed to decrease with stretching and improve in the absence of stretching for participant 1. However, the changes in ROM did not occur exclusively following the targeted stretches. Upper body ROM increased in 4 of 6 measures after stretching, but further increased in 2 of 6 measures when stretching was ceased. The other 4 of 6 measures decreased when stretching was ceased. Lower body ROM increased in 5 of 8 measures initially when there was no lower body stretching and increased in only 1 of 8 measures after stretching was added. It is possible that the changes in jump height are related to the changes in ROM as opposed to stretching. Increased CMJ jump height following lower body stretching has been observed by Kokkonen et al. (85), unfortunately there was minimal flexibility testing which does not allow for direct comparison. Furthermore, greater hip extension has been positively correlated with CMJ height ($r = 0.39$; $P = 0.02$) (91). This relationship was not present in participant 2. More research is needed to investigate the possible association between CMJ and plyometric push-up jump height, and flexibility.

Strength improved in the squat and bench press at the end of both training blocks for both participants irrespective of the area targeted by the stretching intervention. There was no apparent influence of stretching regardless of the magnitude of ROM gained on 1RM strength. Additionally, there were no clear patterns connecting muscle thickness or SSC performance to strength or ROM changes. It is possible that with a larger sample size patterns would have emerged. Future research of this nature should include a larger sample size.

Practical applications

Chronic stretching post-training can effectively improve or maintain ROM without any clear effect on 1RM squat and bench press, muscle thickness, or SSC performance in highly advanced resistance-trained men. Resistance training alone can improve ROM but does not seem sufficient to maintain ROM gained through stretching when the ROM requirements for the exercises are well within a participant's capability.

Chapter 9 General discussion

The overall purpose of this thesis was to determine the relationship between strength, flexibility, and stiffness in powerlifters. The review of literature (Chapter 2) revealed how little is known about the stretching practices and current levels of flexibility and stiffness in powerlifters, as well as the difficulties associated with estimating stiffness in this context. The potential benefits of chronic stretching were identified with the caveat that most benefits have been identified in sedentary or recreationally active individuals and may not be generalisable to highly trained athletes. Therefore, a series of investigations were undertaken to systematically address the gaps in the literature.

The first investigation established the stretching practices of powerlifters (Chapter 3). Despite current recommendations to avoid long duration (> 60 per muscle group) static stretching prior to strength-tasks (16,79,148), particularly before competition and in high performance athletes (33), this practice is still prevalent in powerlifters (Chapter 3). Powerlifters' self-reported stretching frequency ranged from approximately two (57) to four (Chapter 3) times per week. Approximately 50% of powerlifters reported regularly stretching, irrespective of sex or competitive level (Chapter 3). The majority (78%) of those who stretched did so before training and 84% reported static stretching with an average duration of 100 seconds (Chapter 3). The widespread use of stretching, as well as the proportion of those implementing stretching in a potentially detrimental way, confirmed the importance of investigating favourable stretching practices for powerlifters.

Previous research identified movements about the shoulder and hip where male powerlifters have less ROM than sedentary men (34,57). However, ROM in female powerlifters and possible associations between ROM and strength had not been established. Therefore, Chapter 4 and 5 were designed to fill these gaps. In agreement with previous research comparing male powerlifters with sedentary men, male powerlifters had less ROM in several movements about the shoulder (extension and horizontal abduction) and hip (flexion, extension, and adduction) than recreationally strength-trained men (Chapter 4). Some movements with less ROM (shoulder extension and hip flexion) were also useful for predicting strength based on powerlifting Wilks scores with linear regression. In contrast to male powerlifters, female powerlifters did not have less ROM than recreationally strength-trained females and ROM could not predict strength (Chapter 4). The cross-sectional nature of these studies does not identify causation, but it is possible that the contrasting results are due to sex differences, or differences in strength level or training age of the samples. To provide insight into these theories, direct comparisons of male and female (Tables 9-1 and 9-2), as well as stronger (Wilks > 400; n = 12, 6 male and 6 female) and weaker (Wilks < 400; n = 12, 6 male and 6 female) powerlifters were undertaken.

Table 9-1 Participant characteristics from Chapter 4 and 5 (mean ± SD)

	Male	Female	p	g
Age (years)	27.1 ± 4.5	26.3 ± 6.6	0.749	0.13
Height (cm)	174.9 ± 8.9	162.9 ± 5.7#	<0.001	1.56
Weight (kg)	86.6 ± 16.3	65.9 ± 9.9#	0.001	1.48
Training experience (years)	8.1 ± 4.8	4.0 ±2.6*	0.014	1.05
Training frequency (per week)	4.4 ± 0.8	4.1 ± 0.7	0.278	0.44
Training duration (min)	108.8 ± 24.9	150.0 ± 60.0*	0.039	0.87
Wilks	406.4 ± 52.8	395.2 ± 65.3	0.648	0.18

Significant differences marked as * $p \leq 0.05$; # $p < 0.01$; g = hedges g.

The male powerlifters had approximately twice the training experience of the female powerlifters, although the relative strength (Wilks) scores were not significantly different. Female powerlifters had significantly greater ROM in 17 of the 28 movements measured. These findings agree with previous studies, where participants with more training experience had less ROM in some movements (57,86,88).

Table 9-2 Range of motion (mean ± SD in degrees)

	Male	Female	Mean dif. (95% CI)	p	g
Right shoulder					
Flexion	166 ± 14	179 ± 15*	13 (0.4, 25)	0.043	0.85
Extension	42 ± 7	53 ± 9#	11 (4, 18)	0.004	1.28
Horizontal Adduction	43 ± 9	47 ± 7	4 (-3, 11)	0.241	0.47
Horizontal Abduction	108 ± 9	124 ± 8#	16 (8, 22)	<0.001	1.77
Internal rotation	38 ± 14	51 ± 13*	13 (1, 24)	0.035	0.89
External rotation	93 ± 13	101 ± 10	8 (-2, 18)	0.096	0.69
Right hip					
Flexion	105 ± 6	116 ± 10#	11 (4, 18)	0.005	1.23
Extension	11 ± 4	15 ± 7	4 (-0.5, 10)	0.077	0.74
Adduction	21 ± 5	26 ± 5*	5 (1, 9)	0.015	1.04
Abduction	46 ± 8	54 ± 11	8 (-0.4, 15)	0.061	0.78
Internal rotation	29 ± 11	50 ± 10#	21 (11, 29)	<0.001	1.89
External rotation	40 ± 12	38 ± 10	-2 (-11, 8)	0.709	0.15
Right knee					
Extension	145 ± 9	158 ± 11#	13 (5, 21)	0.034	1.26
Flexion	124 ± 6	129 ± 5*	5 (0.4, 10)	0.004	0.89
Left shoulder					
Flexion	165 ± 13	178 ± 15*	13 (1, 24)	0.036	0.88
Extension	41 ± 10	50 ± 9 *	9 (1, 18)	0.029	0.92
Horizontal Adduction	44 ± 9	48 ± 7	4 (-3, 11)	0.206	0.51
Horizontal Abduction	108 ± 8	119 ± 10#	11 (3, 19)	0.009	1.12
Internal rotation	39 ± 14	50 ± 17	11 (-2, 24)	0.084	0.71
External rotation	88 ± 13	95 ± 5	7 (-3, 17)	0.142	0.60
Left hip					
Flexion	108 ± 6	119 ± 9#	11 (6, 18)	<0.001	1.57
Extension	10 ± 4	11 ± 5	1 (-3, 6)	0.462	0.30
Adduction	17 ± 6	24 ± 5#	7 (2, 12)	0.006	1.19
Abduction	46 ± 9	54 ± 14	8 (-2, 18)	0.114	0.15
Internal rotation	25 ± 10	44 ± 10#	19 (10, 27)	<0.001	0.65
External rotation	43 ± 12	39 ± 12	-4 (-13, 7)	0.494	0.27
Left knee					
Extension	145 ± 12	158 ± 11*	13 (3, 23)	0.046	1.09
Flexion	123 ± 6	128 ± 6*	5 (0.1, 10)	0.011	0.84

Significant differences marked as * p ≤ 0.05; # p < 0.01; CI = confidence interval; g = hedge's g

The stronger powerlifters, unsurprisingly, had significantly higher Wilks scores (444.4 ± 39.6 compared with 357.2 ± 37.4, $p < 0.001$, g = 2.19). No other differences were significant, although between group effect sizes were moderate for height (Wilks > 400: 166.3 ± 8.4 cm; Wilks < 400: 171.5 ± 10.3 cm, p = 0.190, g = 0.53) and experience (Wilks > 400: 7.2 ± 4.1 years; Wilks < 400: 4.9 ± 4.4 years, $p = 0.190$, g = 0.53). Only two ROM differences were present: left shoulder extension (Wilks > 400: 42° ± 10°; Wilks < 400: 50 ± 10°, $p = 0.05$, g = 0.82) and right knee flexion (Wilks > 400: 124° ± 6°; Wilks < 400: 129 ± 5°, $p = 0.041$, g = 0.86). There were many differences between male and female powerlifters with similar relative strength levels, but there was a large discrepancy in years of training experience. However, there were very few differences between stronger and weaker powerlifters with similar training experience. This may indicate ROM is associated with years of training experience as opposed to strength; however, more research is needed to confirm these findings.

Stiffness levels of the powerlifters may have contributed to the different ROM findings in Chapters 4 and 5. Additionally, it was thought that stiffness levels may be associated with strength (Chapter 5). However, the method undertaken to estimate stiffness during the squat and bench press did not provide any additional information beyond what was found through 1RM testing. Therefore, the purpose of Chapter 6 was to describe the methodology used and the issues that arose. The lack of a useful stiffness metric was the reason the relationship between stiffness and both flexibility and strength were not examined in this thesis.

Having established the levels of flexibility in powerlifters in Chapters 4 and 5, and having also identified areas where ROM was lower in male powerlifters in Chapter 5, Chapters 7 and 8 investigated the effects of 8 weeks of targeted post-training stretching on squat and bench press performance. Despite being competitive (international level, Wilks 407) and experienced (15 years), the powerlifter recruited for Chapter 7 did not have limited shoulder ROM. There were no changes in shoulder ROM following the intervention and thus, changes in bench press performance could not be attributed to the stretching programme. Subsequently, the recruitment criteria were amended to include recreationally trained men and exclude those without areas of limited ROM, similar to what was observed in powerlifters in Chapter 5. The upper body and lower body stretching programmes were effective among the participants meeting the new criteria as evidenced by increases in ROM in one or more movements targeted with the stretching intervention in every training bock (Chapter 8). Strength improved in the squat (2.8 – 10%) and bench press (4.5 – 11.6%) for both participants irrespective of the body area targeted by the stretching intervention. However, there was no apparent influence of stretching, regardless of the magnitude of ROM gained on 1RM strength. It is possible that with more participants and greater statistical power patterns would have emerged. Thus, future research of this nature should include larger sample sizes.

Limitations

Several limitations arose due to the unforeseen scheduling changes caused by COVID-19 alert level guidelines. The pivotal limitation being the small sample sizes for Chapters 7 and 8. These studies were originally designed as parallel group training studies but the considerable time where data collection was prohibited, and subsequent narrowing of the powerlifting competition calendar effectively eliminated the offseason when powerlifters were available for research and prevented sufficient recruitment. Therefore, to account for these changes and increase participant numbers, resistance-trained men were recruited for Chapter 8. While the men who participated in Chapter 8 were well trained, they were not powerlifters, recruitment was still limited resulting in a case series rather than a parallel group trial, and results from this study may not be generalisable to high level powerlifters. Additionally, the stiffness metric described in Chapter 6 was almost perfectly correlated ($r = 0.998$, $p < 0.001$) with barbell load and did not provide any novel information. Stiffness was intended as a primary outcome measure throughout the thesis; however, this analysis was postponed as a result of data collection delays caused by COVID-19 guidelines. As such, there was not sufficient time to find a more suitable method to estimate stiffness and stiffness was not included in Chapters 5, 7, and 8 as was intended.

Practical applications

Based on the findings of this thesis, several practical recommendations can be made:

- Static stretching prior to strength training may be necessary for athletes to successfully execute lifts. More ROM may be needed for an athlete to comfortably reach squat depth, or to achieve a sumo deadlift or bench press set-up. If this is the case, stretching should be programmed into training

(Chapter 3). Ideally this should start with a total stretching time of less than 60 seconds per muscle group (16).

- The effects of stretching on ROM and performance should be monitored so that it can be stopped if it is no longer required to maintain or improve ROM or adjusted based on performance. The measures of flexibility used in this thesis (active ROM measured via goniometry) were reliable and can be used by coaches to monitor specific joint ROM of athletes. Ideally, all measurements should be performed by the same practitioner as this will improve accuracy.
- It may be best to ensure that shoulder extension and hip flexion are just sufficient, such that joint positions are not compromised in order to achieve the bottom position of a squat and bench press, rather than attempting to increase these ranges beyond what is necessary is male powerlifters.
- No negative effects of chronic stretching were evident in Chapters 7 or 8. However, preventing athletes from stretching may result in a loss of ROM (Chapter 7 and 8) which could then influence lifting technique (Chapter 7). Therefore, athletes who enjoy stretching and those who need to improve ROM should consider stretching after or independent from training, as opposed to before training if possible.

Recommendations for future research

- Chapter 2 established that approximately 50% of powerlifters stretch regularly and that more than 25% stretch in a potentially detrimental way (long duration static stretching prior to training). Future research is needed to determine the rationale powerlifters have for this practice so that alternative solutions can be specified based on the needs of the athletes. For example, if athletes feel they need long duration static stretching prior to training to achieve their optimal sumo deadlift set-up, a stretching programme implemented after or independent of training could be used to improve ROM.
- Chapters 3 and 4 identified flexibility levels of male and female powerlifters. When compared with recreationally strength-trained age matched controls, male powerlifters had less ROM in several movements about the shoulder and hip, but female powerlifters did not. Future research is needed to determine the

source of these differences, and to identify the cause of the limited ROM observed in male powerlifters.

- It was hypothesized that more flexible lifters (greater hip flexion ROM) would slow the eccentric phase of squats to control or limit depth (Chapter 5). A slower eccentric would expend more energy and could negatively affect 1RM squat performance. While hip flexion ROM was a significant predictor of strength (less hip flexion, greater Wilks), it was not a significant predictor of average eccentric velocity during submaximal repetitions (≤ 80% 1RM). Future research is needed to determine if this relationship is observable at higher loads at or near 1RM.
- Decreased musculotendinous unit stiffness has been identified as a possible mechanism of stretch-induced improvement in SSC performance and injury reduction. However, as discussed in Chapter 6 there is no consensus on methods to measure stiffness during barbell lifts. Future research is needed to develop a way to effectively measure stiffness during barbell lifts. Following this, more research is needed to investigate the relationship between stiffness and powerlifting performance.
- Future research is needed to clearly establish the mechanisms underpinning the benefits of chronic stretching including SSC, strength, and hypertrophy enhancement. Additionally, research is needed to determine the elements needed (stretching protocol, target muscles, target populations, etc.) to reliably elicit these adaptations.
- More research is needed to investigate the effects of chronic post-training stretching on powerlifting performance. As demonstrated in Chapter 7, stretching may not improve ROM in individuals who already have relatively high levels of flexibility. Therefore, recruitment should focus on those with ROM similar to the average ranges observed in powerlifters in Chapter 5.

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Appendices

Appendix A Ethics approval (Chapter 3)

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Auckland University of Technology Ethics Committee (AUTEC)

Auckland University of Technology
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T: +64 9 921 9999 ext. 8316
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8 May 2019

Michael McGuigan
Faculty of Health and Environmental Sciences

Dear Michael

Ethics Application:19/150 **The relationship between strength, flexibility, and stiffness in powerlifters**

I wish to advise you that a subcommittee of the Auckland University of Technology Ethics Committee (AUTEC) has **approved** your ethics application.

This approval is for three years, expiring 8 May 2022.

Non-Standard Conditions of Approval

1. The committee observes that the application form may have been re-purposed as it refers to signed Consent Forms. Please ensure future applications are specific to the research being considered.

Non-standard conditions must be completed before commencing your study. Non-standard conditions do not need to be submitted to or reviewed by AUTEC before commencing your study.

Standard Conditions of Approval

1. A progress report is due annually on the anniversary of the approval date, using form EA2, which is available online through http://www.aut.ac.nz/research/researchethics.
2. A final report is due at the expiration of the approval period, or, upon completion of project, using form EA3, which is available online through http://www.aut.ac.nz/research/researchethics.
3. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form: http://www.aut.ac.nz/research/researchethics.
4. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
5. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.

Please quote the application number and title on all future correspondence related to this project.

AUTEC grants ethical approval only. If you require management approval for access for your research from another institution or organisation then you are responsible for obtaining it. If the research is undertaken outside New Zealand, you need to meet all locality legal and ethical obligations and requirements. You are reminded that it is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard.

For any enquiries please contact ethics@aut.ac.nz

Yours sincerely,

Kate O'Connor
Executive Manager
Auckland University of Technology Ethics Committee

Cc: alyssajoyspence@gmail.com; eric.helms@aut.ac.nz

Appendix B Ethics approval (Chapters 4 and 5)

Auckland University of Technology Ethics Committee (AUTEC)

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8 July 2019

Michael McGuigan
Faculty of Health and Environmental Sciences

Dear Michael

Re Ethics Application: **19/195 The relationship between strength, flexibility, and stiffness in powerlifters**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 8 July 2022.

Standard Conditions of Approval

1. The research is to be undertaken in accordance with the Auckland University of Technology Code of Conduct for Research and as approved by AUTEC in this application.
2. A progress report is due annually on the anniversary of the approval date, using form EA2, which is available online through http://www.aut.ac.nz/research/researchethics.
3. A final report is due at the expiration of the approval period, or, upon completion of project, using form EA3, which is available online through http://www.aut.ac.nz/research/researchethics.
4. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form: http://www.aut.ac.nz/research/researchethics.
5. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
6. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.

Please quote the application number and title on all future correspondence related to this project.

AUTEC grants ethical approval only. If you require management approval for access for your research from another institution or organisation, then you are responsible for obtaining it. You are reminded that it is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard.

For any enquiries, please contact ethics@aut.ac.nz

Yours sincerely,

Kate O'Connor
Executive Manager
Auckland University of Technology Ethics Committee

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Appendix C Ethics approval (Chapters 7 and 8)

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19 May 2020

Michael McGuigan
Faculty of Health and Environmental Sciences

Dear Michael

Ethics Application: 20/40 **The relationship between strength and flexibility in powerlifters**

We advise you that the Auckland University of Technology Ethics Committee (AUTEC) has **approved** your ethics application at its meeting of 11 May 2020.

This approval is for three years, expiring 11 May 2023.

Standard Conditions of Approval

1. The research is to be undertaken in accordance with the Auckland University of Technology Code of Conduct for Research and as approved by AUTEC in this application.
2. A progress report is due annually on the anniversary of the approval date, using the EA2 form.
3. A final report is due at the expiration of the approval period, or, upon completion of project, using the EA3 form.
4. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form.
5. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
6. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.
7. It is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard and that all the dates on the documents are updated.

AUTEC grants ethical approval only. You are responsible for obtaining management approval for access for your research from any institution or organisation at which your research is being conducted and you need to meet all ethical, legal, public health, and locality obligations or requirements for the jurisdictions in which the research is being undertaken.

Please quote the application number and title on all future correspondence related to this project.

For any enquiries please contact ethics@aut.ac.nz. The forms mentioned above are available online through http://www.aut.ac.nz/research/researchethics

(This is a computer-generated letter for which no signature is required)

The AUTEC Secretariat
Auckland University of Technology Ethics Committee

Cc: alyssajoyspence@gmail.com; eric.helms@aut.ac.nz

Appendix D Powerlifting training protocol (Chapters 7 and 8)

Week 1	Day 1: Planned (load given is %1RM)	Day 2: Planned (load given is %1RM)	Day 3: Planned (load given is %1RM)	Day 4: Planned (load given is %1RM)
Squat	5x7x70 RPE 6-7	NA	5x4x80 RPE 6-7	NA
Bench Press	5x7x70 RPE 6-7	5x3x77.5 RPE 5-6	5x4x80 RPE 6-7	NA
Deadlift	NA	4x3x77.5 RPE 5-6	NA	4x4x80 RPE 6-7
Accessory	Lat Pulldown 4x8-12 RPE 8	Cable Row 4x8-12 RPE 8	Belt Squat 3x10-15 RPE 8	Kettlebell Windmills 3x6-10 RPE 8
Accessory	DB Shoulder Press 3x10-15 RPE 8	Reverse Hyper 3x10-15 RPE 8	DB Bench 3x8-12 RPE 8	Single Leg Press 3x8-12 RPE
Accessory	NA	NA	NA	Tricep Pushdown 3x8-12 RPE 8-10
Week 2	Day 1: Planned	Day 2: Planned	Day 3: Planned	Day 4: Planned
Squat	5x6x72.5 RPE 6-7	NA	5x3x85 RPE 7-8	NA
Bench Press	5x6x72.5 RPE 6-7	5x2x82.5 RPE 5-6	5x3x85 RPE 7-8	NA
Deadlift	NA	4x2x82.5 RPE 5-6	NA	4x3x85 RPE 7-8
Accessory	Lat Pulldown 4x8-12 RPE 8	Cable Row 4x8-12 RPE 8	Belt Squat 3x10-15 RPE 8	Kettlebell Windmills 3x6-10 RPE 8
Accessory	DB Shoulder Press 3x10-15 RPE 8	Reverse Hyper 3x10-15 RPE 8	DB Bench 3x8-12 RPE 8	Single Leg Press 3x8-12 RPE 8
Accessory	NA	NA	NA	Tricep Pushdown 3x8-12 RPE 8-10
Week 3	Day 1: Planned	Day 2: Planned	Day 3: Planned	Day 4: Planned
Squat	5x5x75 RPE 6-7	NA	5x2x90 RPE 8-9	NA
Bench Press	5x5x75 RPE 6-7	5x1x87.5 RPE 5-6	5x2x90 RPE 8-9	NA
Deadlift	NA	4x1x87.5 RPE 5-6	NA	4x2x90 RPE 8-9
Accessory	Lat Pulldown 4x8-12 RPE 8	Cable Row 4x8-12 RPE 8	Belt Squat 3x10-15 RPE 8	Kettlebell Windmills 3x6-10 RPE 8
Accessory	DB Shoulder Press 3x10-15 RPE 8	Reverse Hyper 3x10-15 RPE 8	DB Bench 3x8-12 RPE 8	Single Leg Press 3x8-12 RPE 8
Accessory	NA	NA	NA	Tricep Pushdown 3x8-12 RPE 8-10
Week 4 Deload	Day 1: Planned	Day 2: Planned	Day 3: Planned	Day 4: Planned
Squat	3x5x70 RPE 5	NA	3x2x80 RPE 5	NA
Bench Press	3x5x70 RPE 5	3x1x77.5 RPE 5	3x2x80 RPE 5	NA
Deadlift	NA	2x1x77.5 RPE 5	NA	2x2x80 RPE 5
Accessory	Lat Pulldown 3x8-12 RPE 7	Cable Row 3x8-12 RPE 7	Belt Squat 2x10-15 RPE 7	Kettlebell Windmills 2x6-10 RPE 7
Accessory	DB Shoulder Press 2x10-15 RPE 7	Reverse Hyper 2x10-15 RPE 7	DB Bench 2x8-12 RPE 7	Single Leg Press 2x8-12 RPE 7
Accessory	NA	NA	NA	Tricep Pushdown 2x8-12 RPE 7
Week 5	Day 1: Planned	Day 2: Planned	Day 3: Planned	Day 4: Planned
Squat	5x6x75 RPE 7-8	NA	5x3x85 RPE 7-8	NA
Bench Press	5x6x75 RPE 7-8	5x3x80 RPE 6-7	5x3x85 RPE 7-8	NA
Deadlift	NA	4x3x80 RPE 6-7	NA	4x3x85 RPE 7-8
Accessory	Lat Pulldown 4x8-12 RPE 8	Seal Row 4x6-10 RPE 8-10	Front Squat 3x6-10 RPE 8	Ab Roll Out 3x6-10 RPE 8
Accessory	OHP 3x8-12 RPE 8	RDL 3x8-12 RPE 8	CG Bench 3x8-12 RPE 8	Walking Lunge 3x8-12/side RPE 8
Accessory	NA	NA	NA	Skull Crusher 3x8-12 RPE 8
Week 6	Day 1: Planned	Day 2: Planned	Day 3: Planned	Day 4: Planned
Squat	5x5x77.5 RPE 7-8	NA	5x2x90 RPE 8-9	NA
Bench Press	5x5x77.5 RPE 7-8	5x2x85 RPE 6-7	5x2x90 RPE 8-9	NA
Deadlift	NA	4x2x85 RPE 6-7	NA	4x2x90 RPE 8-9
Accessory	Lat Pulldown 4x8-12 RPE 8	Seal Row 4x6-10 RPE 8-10	Front Squat 3x6-10 RPE 8	Ab Roll Out 3x6-10 RPE 8
Accessory	OHP 3x8-12 RPE 8	RDL 3x8-12 RPE 8	CG Bench 3x8-12 RPE 8	Walking Lunge 3x8-12/side RPE 8
Accessory	NA	NA	NA	Skull Crusher 3x8-12 RPE 8
Week 7	Day 1: Planned	Day 2: Planned	Day 3: Planned	Day 4: Planned
Squat	5x4x80 RPE 7-8	NA	5x1x95 RPE 9-10	NA
Bench Press	5x4x80 RPE 7-8	5x1x90 RPE 6-7	5x1x95 RPE 9-10	NA
Deadlift	NA	4x1x90 RPE 6-7	NA	4x1x95 RPE 9-10
Accessory	Lat Pulldown 4x8-12 RPE 8	Seal Row 4x6-10 RPE 8-10	Front Squat 3x6-10 RPE 8	Ab Roll Out 3x6-10 RPE 8
Accessory	OHP 3x8-12 RPE 8	RDL 3x8-12 RPE 8	CG Bench 3x8-12 RPE 8	Walking Lunge 3x8-12/side RPE 8
Accessory	NA	NA	NA	Skull Crusher 3x8-12 RPE 8
Week 8 Taper	Day 1: Planned	Day 2: Planned	Day 3: Planned	Day 4: Planned
Squat	3x1x90 RPE 8	NA	3x2x80 RPE 5	1RM Testing
Bench Press	3x1x90 RPE 8	3x2x85 RPE 7	3x2x80 RPE 5	1RM Testing
Deadlift	2x2x80 RPE 5	2x2x85 RPE 7	NA	1RM Testing
Accessory	Lat Pulldown 3x8-12 RPE 7	Seal Row 3x6-10 RPE 7	Front Squat 2x6-10 RPE 7	NA
Accessory	OHP 2x8-12 RPE 7	RDL 2x8-12 RPE 7	CG Bench 2x8-12 RPE 7	NA
Accessory	NA	NA	NA	NA

Appendix E Training study programme guidelines (Chapters 7 and 8)

Training frequency: 3-6 days per week

Competition lifts:

- Weekly frequency: squat x2, bench press x3, deadlift x2
- Volume: working sets lift: Back squat x 10 (6 during deload), bench press x 15 (9 during deload), deadlift x 8 (4 during deload)
- Intensity:
  - 1st mesocycle: 6-9 RPE and/or 70-90%
  - 2nd mesocycle: 7-10 RPE and/or 75-95%
  - Deload at 5 RPE and/or 70-80%, taper at 5-8 RPE and/or 80-90%

Accessories:

- Volume: 3 sets of one exercise from each category, once per week, excluding vertical and horizontal pull exercises which will have 4 sets per week (decrease all accessory exercise sets by 1 per session for deload/taper)
- Intensity: at 8-10 RPE (at RPE 7 during deload/taper).

Table 9-3 List of accessories

Vertical push	**Vertical pull**	**Core**
Barbell overhead press	Pull-up	Kettlebell windmill
Dumbbell shoulder press	Lat pulldown	Ab roll out
Horizontal pull	**Triceps accessory**	**Squat accessory**
Dumbbell row	French press	Hack squat
Seal row	Pushdown	Belt squat
Barbell row	Skull crusher	Front squat
		Leg press
Deadlift accessory	**Bench accessory**	**Single-leg accessory**
Romanian deadlift	Close grip bench press	Lunge
Reverse hyper	Slingshot	Bulgarian split squat
Back extension	Dips	Single-leg leg press
Good morning	Board press	Step up
Hip thrust		

Accessories not on this list should be approved before substituting; accessories can change from 1st to 2nd mesocycle