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Research article

Effect of Stretching during the Inter-Set Rest Periods on the Kinematics and Kinetics of High and Low Velocity Resistance Loading Schemes: Implications for Hypertrophy

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Abstract
*Journal of Sports Science and Physical Education 2(*1): 45–57, 2014 - The time that muscle is under tension (TUT) during a session is thought an important strength and hypertrophic stimulus. Session TUT can be increased if stretching is undertaken during the inter-set rest periods. However, the stretching may interfere with the ensuing set and session kinematics and kinetics. Consequently the purpose of this study was to determine if the session kinematics and kinetics of 35% 1RM and 70% 1RM loading schemes equated by volume differed significantly when stretching was undertaken during the inter-set rest periods. Twelve male student-athletes were recruited for this study. Squat average force (AF), peak force (PF), average power (AP), peak power (PP), work (TW) and total impulse (TI) were quantified during the eccentric and concentric phases of two interventions, one involving stretch during the interset rest period and the other a non-stretch intervention. Total session kinematics and kinetics differed by ~0-7% between interventions; however, none of these differences were found to be significant ($P < 0.05$). It was concluded that lower limb active interset stretching of 12-15 s duration during a ~90 s rest period did not adversely affect squat kinematics and kinetics.

Key words: active stretch, load, volume, force, power, time under tension, work

Introduction

A strength training session consists of work and rest periods in its simplest form. It would make sense that to improve strength and power an understanding of how to maximize the effects of the work and rest periods to produce the desired neuromuscular adaptation associated with various loading schemes is needed. With the advent of linear position transducer and force plate technology there is an increased awareness of the kinematics and kinetics associated with a single repetition, set and workout (Crewther, Cronin, & Keogh, 2008). Improving our mechanical (kinematic and kinetic) understanding of the training stresses that will be imposed upon muscle is important as it is thought that strength and power adaptation is mediated by mechanical stimuli and their interaction with other hormonal and metabolic factors. In terms of rest, apart from research that has investigated the effect of rest durations between sets on kinematics and kinetics (Denton & Cronin, 2006; Parcell, Sawyer, Tricoli, & Chinevere, 2002; Richmond & Godard, 2004; Robinson et al., 1995) there has been a lack of research that has investigated how athletes might optimise the rest period to enhance session kinematics

and kinetics. That is, there may be activities that can be engaged in during the rest period that may enhance the ensuing set and total workout kinematics and kinetics. The net result could be a session with increased mechanical, hormonal and metabolic responses and hence the opportunity for improved strength and power adaptation.

Of interest to these researchers therefore is how one may engage in activity during the rest period that maximises the mechanical stimuli associated with a training session to optimise the outcomes of training. Of specific interest is the role of stretching in the rest period between sets as a means of increasing hypertrophic adaptation and subsequent strength and power performance. In order to achieve this some understanding of the stimuli that determine hypertrophic adaptation is needed. There is no doubt that there are many interacting factors responsible for hypertrophic adaptation. To ensure that protein synthesis exceeds protein degradation, appropriate loading needs to optimize: the muscles mechanical, metabolic and hormonal responses; signalling pathways; nutrition; and, recovery (Biolo, Tipton, Klein, & Wolfe, 1997; Burd, Tang, Moore, & Phillips, 2009; Carraro, Stuart, Hartl, Rosenblatt, & Wolfe, 1990; Tipton, Borsheim, Wolf, Sanford, & Wolfe, 2003; Tipton et al., 2001; Wilkinson et al., 2008)

In terms of maximizing the mechanical stimuli for adaptation, loading the muscle with moderate to high loads (high forces/tensions i.e. > 60-70% 1RM) with 8-12 repetitions per set for one to three sets per exercise, is thought fundamental to the development of maximal strength and an important stimulus for muscle hypertrophy (Atha, 1981; Kraemer et al., 2002; McDonagh & Davies, 1984; Ratamess et al., 2009). Furthermore slow to moderate repetition velocities are recommended (Kraemer et al., 2002), with slow tempos of 1-5s concentric and 1-5s eccentric (Keogh, Wilson, & Weatherby, 1999). In terms of time under tension, these slower tempos and contraction velocities result in significantly greater time under tension (Keogh et al., 1999) than other forms of resistance strength training e.g. power training. However, the importance of these higher loading intensities (> 70% 1RM) in inducing maximal strength and hypertrophic changes, may be questioned in relation to some research in this area that has found strength and hypertrophic adaptation with lighter loads (Dahl, Aaserud, & Jensen, 1992; Harris, Stone, O'Bryant, Proulx, & Johnson, 2000; Lyttle, Wilson, & Ostrowski, 1996; Moss, Refsnes, Abildgaard, Nicolaysen, & Jensen, 1997).

Given that force is the product of mass and acceleration, it may be that the higher velocities and accelerations associated with lighter load training may compensate for the lighter mass, the subsequent force thereafter not substantially different to a more typical higher load hypertrophic program. Certainly when heavy load-low velocity (HLLV ~70% 1RM) and light load-high velocity (LLHV ~ 35% 1RM) loading schemes are equated by volume and compared, superior kinematics and kinetics are for the most part associated with the LLHV scheme (Cronin & Crewther, 2004). In terms of mechanical loading, Toigo and Boutellier (Toigo & Boutellier, 2006) identified the distinct role of active tension in generating muscle hypertrophy, reporting that time under tension is one of the important stimuli in promoting cross-sectional or radial growth of skeletal muscle. They summarized that elongated muscles placed under tension triggered protein synthesis, which is important for muscle growth and is the reverse process to what can be observed during muscle atrophy associated with immobilisation. Certainly the literature on stretch induced hypertrophy (Coutinho, Gomes, França, Oishi, & Salvini, 2004; Goldspink, 1977; Goldspink et al., 1995; Holly, Barnett, Ashmore, Taylor, & Mole, 1980; Vandenburgh, 1987; Yang, Alnaqeeb, Simpson, & Goldspink, 1997), the effect of stretch on hypertrophic signalling pathways (Farthing & Chilibeck, 2003; Russ, 2008; Sakamoto, Aschenbach, Hirshman, & Goodyear, 2003; Sandri, 2008) and stretch activated channels (Russ, 2008; Spangenburg & McBride, 2006) support this contention. Furthermore stretching of muscle has produced greater hormonal responses

(Perrone, Fenwick-Smith, & Vandenburgh, 1995; Takarada et al., 2000; Takarada, Tsuruta, & Ishii, 2004) and metabolite accumulation due to the restricted blood flow associated with stretch (Manini & Clark, 2009; Meyer, 2006; Poole, Musch, & Kindig, 1997; Rodney, Herbert, & Balnave, 1994; Schott, McCully, & Rutherford, 1995). It would seem stretch in and of itself and the subsequent time under tension can have substantial influence on hypertrophic adaptation.

It seems that moderate to high forces and time under tension, particularly during lengthening contractions, and the subsequent hormonal and metabolic responses are important stimuli for the radial growth of muscle. Therefore if hypertrophy is the goal of training it would seem important to maximize these stimuli during a training session. There is no doubt that this occurs throughout the work periods during a resistance strength training session, however it may be that what practitioners do during the rest period may provide an additional hypertrophic response, this contention providing the focus this investigation. There seems compelling reasons to stretch (active and/or passive) during the inter-set rest periods whilst hypertrophic strength training, as it is likely to increase the total time under tension of the muscle, which may have a number of mechanical, neural, metabolic and hormonal advantages as compared to not stretching. However, at this stage it is yet to be determined if the stretching protocol will adversely affect the kinematics and kinetics of the ensuing sets (i.e. magnitude of the tension) given variables such as force are also thought critical to adaptation. The status of the stretching literature does not assist our understanding in any great depth as to the negative influence of stretching on a traditional strength session as the literature for the most part has focused on the influence of stretch on one off expressions of force and power over excessively long stretch durations (Fowles, Sale, & MacDougall, 2000; Rubini, Costa, & Gomes, 2007; Shrier, 2004; Weir, Tingley, & Elder, 2005; Young, Elias, & Power, 2006). Consequently the purpose of this study was to determine if the session kinematics and kinetics of two loading schemes (HLLV and LLHV) would differ significantly when stretching is undertaken during the interset rest periods.

Methods

Experimental Approach to the Problem

In this acute randomized within-subject cross-over design, 12 recreationally trained male student-athletes were recruited to investigate the effects of load on set and session free weight squat kinematics and kinetics, with and without stretching during the interset rest periods. Two loading schemes were equated by volume (3 sets of 12 reps at 70% 1RM vs. 6 sets of 12 reps at 35% 1RM) and the dependent variables of interest that were quantified during the eccentric and concentric phases were: average force (AF), peak force (PF), average power (AP), peak power (PP), work (TW) and total impulse (TI). The average repetition value for each set as well as the total set and session values of each of the variables for both the eccentric and concentric phases were then used for statistical analysis.

Subjects

Twelve recreationally trained male student-athletes volunteered to participate in this research. Subject mean (±SD) age, height, mass and 1RM squat strength were 26.0 (3.5) years, 173.4 (5.9) cm, 79.3 (10.2) kg and 119.8 (30.5) kg respectively. All subjects recruited were considered injury free as indicated by no lower limb and spine injury record for the past two years and had at least six months strength training experience. Subjects completed an informed consent form prior to the experiment. Ethics approval from the Human Research Committee of Edith Cowan University was also obtained prior to commencing the study.

Equipment

Subjects performed the squat on a force plate (400 Series, Fitness Technology, Australia) in a Power Cage (FT 700, Fitness Technology, Australia). The Olympic bar was interfaced with the Ballistic Measurement System (BMS, Fitness Technology, Australia), which

consisted of a position transducer (Celesco, PT5A-0150-V62-UP-1K-M6, USA), computer interface (XPV Interface, Fitness Technology, Australia) and the BMS software (BMS, Version 2007.2.3, Innervations, Australia). Sampling frequency of the BMS system was set at 200 Hz. Inter-set rest durations were determined by an electronic stopwatch.

Procedures

The procedures involved one familiarisation and four testing sessions. The testing sessions were randomized to eliminate any learning, order or fatigue effects that could confound the statistical analysis. A minimum of 72 hours rest was given between all sessions to ensure full recovery. Participants were asked to replicate exercise and dietary intake 24-hours prior to each testing occasion.

Preliminary Assessments and Familiarisation. During the first session, technique and maximum squat strength (1RM) were assessed and anthropometric measurements taken. The anthropometric variables of interest included standing height (cm) and body mass (kg). Movement for the half-squat was analysed and corrections to technique were made as necessary. Participants were asked to provide their estimated half-squat 1RM based on previous performance. A five minute general warm-up was undertaken. Each participant was then required to perform two warm-up sets of 8 reps at 50% of estimated 1RM and 3 reps at 70% of estimated 1RM respectively. After a five minute rest each subjects 1RM was determined (4-5 minute rest in between 1RM lifts).

Squat Technique. The squat movement began from a standing position with the feet approximately shoulder width apart. The squat was initiated by a controlled downward eccentric knee bend until the tops of the thighs became parallel with the floor, which was followed by a concentric phase.

Stretching exercise. The exercises involved stretching the quadriceps, hamstrings and gluteals muscle groups, which were performed in a standing position next to the Power Cage during the 90 s inter-set rest period. Subjects actively stretched each limb for 15 s i.e. 6 x 12-15 s stretches each rest period. Thus total duration of stretching time for 35% 1RM loading was 450 s and 180 s for 70% 1RM loading scheme.

Intervention. Subjects were randomly allocated to one of four interventions [(35% of 1RM (stretch and non-stretch) and 70% of 1RM (stretch and non-stretch)]. Participants warmed up as described previously prior to each testing session e.g. jogging and warm-up sets. The subjects then performed either 6 sets of 12 reps at 35% of 1RM or 3 sets of 12 reps at 70% of 1RM loading. A 90 s inter-set rest period was used for both conditions. For the stretching intervention sessions, subjects utilized the 90 s of the rest period to stretch the muscles described previously, before continuing the next squat set.

Data Analysis

The force plate was synchronized with a linear position transducer attached to the bar to measure the various dependent variables of interest at a sampling frequency of 200 Hz. The eccentric (maximum to minimum vertical displacement), and concentric (minimum to maximum vertical displacement) phases were determined from the linear position transducer. All variables of interest (AF, PF, AP, PP, TW and TI) were calculated for each eccentric and concentric contraction for each set and session, via the BMS software data analysis program. The summed repetition and set values for each session were used as the total session kinematics and kinetics and compared between loading schemes.

Statistical Analysis

Means and standard deviations were used to represent centrality and spread of data. The analysis of interest was whether the stretching intervention affected the session kinematics and kinetics of each loading scheme (i.e. 35% 1RM with and without stretch and 70% 1RM with and without stretch). With this in mind Paired sample t-test comparisons were used to determine if significant differences existed between the dependent variables (eccentric and concentric AF, PF, AP, PP, TW and TI) across the two loading schemes. The percent

difference between loading schemes were calculated (% Difference = (1 – Lowest Variable/Highest Variable)*100. An alpha level of 0.05 was set to assess statistical significance for all tests.

Results

As can be observed from Table 1 (eccentric contraction) and Table 2 (concentric contraction) the percent differences between variables for the 35% 1RM condition ranged from 0.13 to 7.08% and most of the variables apart from average force (3.53%) and impulse at 100 ms (0.13%) were less after the stretching intervention. However, none of these values were statistically significant.

Table 1: Average total eccentric values (mean ± SD) for the 35% 1RM schemes with no stretching (NS) and stretching (S) interventions between sets.

Variable	35% 1RM (NS)	35% 1RM (S)	% Difference	Significance
TUT (s)	6.48 ± 0.76	6.35 ± 0.76	2.01	0.570
Average Force (N)	4729 ± 2371	4902 ± 2549	3.53	0.612
Peak Force (N)	14623 ± 2037	14263 ± 2368	2.46	0.204
Average Power (W)	10907 ± 2628	10329 ± 2796	5.30	0.244
Peak Power (W)	21313 ± 6134	20559 ± 6216	3.54	0.455
Total Work (J)	5483 ± 844	5253 ± 1017	4.20	0.179
Total Impulse	7794 ± 1295	7669 ± 1499	1.60	0.547
Impulse 100 ms	754 ± 249	755 ± 292	0.13	0.978
Impulse 200 ms	1772 ± 284	1732 ± 350	2.26	0.613
Impulse 300 ms	3352 ± 558	3155 ± 703	5.89	0.168

Table 2: Average total concentric values (mean ± SD) for the 35% 1RM schemes with no stretching (NS) and stretching (S) interventions between sets.

Variable	35% 1RM (NS)	35% 1RM (S)	% Difference	Significance
TUT (s)	6.01 ± 0.68	5.99 ± 0.72	0.33	0.924
Average Force (N)	13965 ± 1837	13624 ± 2193	2.44	0.196
Peak Force (N)	22318 ± 3329	21471 ± 3378	3.79	0.130
Average Power (W)	10752 ± 2015	10152 ± 2127	5.58	0.093
Peak Power (W)	22178 ± 6220	20608 ± 5802	7.08	0.123
Total Work (J)	103169 ± 20676	97906 ± 24072	5.10	0.253
Total Impulse	7064 ± 1326	6957 ± 24072	1.52	0.589
Impulse 100 ms	2360 ± 344	2272 ± 347	3.73	0.131

Impulse 200 ms	4301 ± 651	4114 ± 637	4.35	0.070
Impulse 300 ms	5723 ± 799	5590 ± 970	2.32	0.291

With regards to the 70% 1RM condition, it can be observed from Table 3 (eccentric contraction) and Table 4 (concentric contraction) that the percent differences between variables for the 70% 1RM condition ranged from 0.09 to 6.95%. Interestingly the stretching intervention at this load had less of a negative effect than at the lighter load, seven of the variables greater after stretching. However, once more none of these percent differences were statistically significant.

Table 3: Average total eccentric values (mean ± SD) for the 70% 1RM schemes with no stretching (NS) and stretching (S) interventions between sets.

Variable	70% 1RM (NS)	70% 1RM (S)	% Difference	Significance
TUT (s)	10.94 ± 2.18	10.07 ± 2.15	7.95	0.107
Average Force (N)	12654 ± 3506	11998 ± 4252	5.18	0.490
Peak Force (N)	19126 ± 3136	19025 ± 3641	0.53	0.641
Average Power (W)	7521 ± 1535	7838 ± 2068	4.04	0.524
Peak Power (W)	14395 ± 2921	14396 ± 3531	6.95	0.526
Total Work (J)	6948 ± 2119	6501 ± 1685	6.43	0.166
Total Impulse	17455 ± 5659	16529 ± 5625	5.31	0.337
Impulse 100 ms	1761 ± 362	1768 ± 425	0.40	0.951
Impulse 200 ms	3352 ± 649	3278 ± 709	2.21	0.419
Impulse 300 ms	4975 ± 978	4866 ± 1241	2.19	0.504

Table 4: Average total concentric values (mean ± SD) for the 70% 1RM schemes with no stretching (NS) and stretching (S) interventions between sets.

Variable	70% 1RM (NS)	70% 1RM (S)	% Difference	Significance
TUT (s)	8.77 ± 1.71	8.40 ± 1.68	4.22	0.376
Average Force (N)	18831 ± 3151	18702 ± 3583	0.69	0.522
Peak Force (N)	23384 ± 2956	23362 ± 3872	0.09	0.964
Average Power (W)	8789 ± 1320	9122 ± 1605	3.65	0.386
Peak Power (W)	16507 ± 3545	17409 ± 3766	5.18	0.307
Total Work (J)	96523 ± 19704	97457 ± 22917	0.96	0.731
Total Impulse	14321 ± 4402	13672 ± 4460	4.53	0.314
Impulse 100 ms	2503 ± 318	2487 ± 390	0.64	0.707
Impulse 200 ms	4712 ± 608	4704 ± 755	0.17	0.923
Impulse 300 ms	6848 ± 950	6869 ± 1176	0.31	0.868

Discussion

There is a substantial body of literature that has documented that static stretching may negatively influence kinematics and kinetics, and athletic performance (Behm, Bambury, Cahill, & Power, 2004; Kokkonen, Nelson, & Cornwell, 1998; Marek et al., 2005; McMillian, Moore, Hatler, & Taylor, 2006; Rubini et al., 2007; Shrier, 2004; Warren & Simon, 2001; Young et al., 2006; Young & Behm, 2003). However, closer investigation of this research indicates that most of the protocols use stretch protocols/durations unlike those used in sporting performance where stretching is used to prepare the muscle for performance rather than changing the extensibility of the musculo-tendinous unit. Furthermore the literature for the most part has focused on the influence of stretch on one off expressions of force and power (McBride, Deane, & Nimphius, 2007; Power, Behm, Cahill, Carroll, & Young, 2004; Young & Behm, 2003). The results obtained from this study certainly contradict these findings as we found no statistically significant differences in stretching and non-stretching conditions for total session kinematics and kinetics of the eccentric and concentric phases over two loading schemes. That is, a 15 second passive-active stretching protocol of the quadriceps, hamstring and gluteals in the inter-set rest period, did not significantly affect the total session kinematics and kinetics when compared to the non-stretching intervention.

There was a trend for the stretching to have a greater negative effect on the variables in the 35% 1RM condition. This may be attributed to the greater stretch durations as compared to the 70% 1RM condition (450 s vs. 180 s). It is interesting to note however, that even with substantially longer stretch durations, the ensuing kinematics and kinetics were not substantially affected ($p > 0.05$). These findings may be explained by a number of factors already alluded to. First, this study used stretch durations of less than 30 seconds, other studies having found that such stretch durations did not have a negative effect on muscle force production (Alpkaya & Koceja, 2007; Behm et al., 2004; Behm, Button, & Butt, 2001; Kokkonen et al., 1998; Ogura, Miyahara, Naito, Katamoto, & Aoki, 2007). Second, while other studies (Behm et al.,

2001; Herda, Cramer, Ryan, McHugh, & Stout, 2008; Herda et al., 2009; Kokkonen et al., 1998; Weir et al., 2005) have used mostly passive stretching alone (i.e. holding an extended range of motion with little or no neural activation), our study used a combination of passive and active stretching. In this study the subjects passively extended the involved muscles (e.g. hamstring muscles) to end range of motion and then activated (isometric contraction) the already stretched muscles. Thus this type of contraction may be more advantageous in optimising ensuing kinematics and kinetics. Third, as alluded to previously a lot of the research reports the effect of stretch on one off expressions of force (Behm et al., 2001; Kokkonen et al., 1998; Young & Behm, 2003) and not multiple expressions as was the case in this study. That is, it maybe that the initial contractions are affected by stretch and other contractions less so. Certainly visual analysis of our data supports such a contention especially in the 70% 1RM loading scheme. Finally, in this study different stretches were cycled over multiple muscles in the inter-set breaks and not one or two muscles only as in other studies (Behm et al., 2001; Kokkonen et al., 1998; Warren & Simon, 2001). This cycling over the muscle groups would decrease the likely negative effect of static stretching. Certainly if the athlete was stretching the antagonist of the exercising agonist, the effect on session kinematics and kinetics would be expected to be minimal (Edwards, Huntsman, Marmesh, & Signorile, 2007; McBride et al., 2007). Another variation of this would be to stretch the lower body whilst training the upper body and vice versa. The net effect of such work:rest paradigms warrants further investigation.

Stretching in the inter-set ret periods is a means by which the total time under tension of a session may be increased. For example, in the stretching intervention the total time under tension of the muscles used for leg squats was increased by ~180 s for the 70% 1RM condition and 450 s for the 35% 1RM condition. The threshold durations and adaptive effect of such stretch training however, needs a great deal more investigation.

Practical applications

The principle findings of this study were that a stretching intervention did not significantly affect session kinematics and kinetics of a squat. In terms of strength and conditioning practice, these findings are likely most beneficial for those interested in hypertrophic training and tissue adaptation. The tension developed within a session (i.e. the magnitude and time under tension) appear to be critical mechanical stimuli in the hypertrophic process. Our understanding of how to develop tension throughout the work period during resisted strength training has been well researched i.e. using slow contraction velocities (slow tempos), maximizing both the eccentric and concentric contraction durations. Using stretch to maximize the time under tension in the rest period however is not well researched and may be beneficial in optimizing total session time under tension. The problem with this approach is that stretching may negatively affect the ensuing repetition and set kinematics and kinetics given variables such as force are also thought critical to hypertrophic adaptation. However, it was established that stretching protocols similar to this study did not adversely affect session kinematics and kinetics. Thus, there seems compelling reasons to stretch (active and/or passive) during the inter-set rest periods whilst hypertrophic strength training, as it is likely to increase the total time under tension of the muscle, which may have a number of mechanical, neural, metabolic and hormonal advantages as compared to not stretching. However, a longitudinal randomized control research design is needed to ascertain the validity of this contention. Furthermore, the differential influences of active and passive tension/stretching also need investigation and how one can maximize tension during the work period also is worthy of research i.e. using weights to stretch muscles at extended positions e.g. pause training at long muscle lengths. Once a greater understanding of these questions is gained, the application of the findings into

long term training protocols assessing hypertrophic adaptation is suggested.

Another implication of the findings of this study pertains to optimizing tissue adaptation for improved stability and mobility. Movement requires the effective interaction of mechanisms which stabilize and those which mobilize at and given instance during a joints motion. In this regards the strength and length of muscle and connective tissue are thought critical, so in terms of training efficiency being able to stretch during a strength training session knowing that stretching will not affect the strength goals of that session is desirable. However, once more a great deal of research is needed in this area, the effect of different stretching techniques and the required loading thresholds for tissue adaptation are not well understood. Furthermore the blending of strength and stretch training to achieve certain outcomes is for the most part unexplored.

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