Original Research

DOES STRETCHING THE ANTAGONIST MUSCLE INCREASE POWER OUTPUT IN AN AGONIST MUSCLE CONTRACTION?

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INTRODUCTION

In an athletic setting, it is not uncommon to see athletes participating in stretching prior to physical activity. The American College of Sports Medicine (ACSM) recommends stretching all major muscle groups twice per week for 10-30 seconds per exercise (ACSM, 2013). Stretching is frequently adopted by those aiming to reduce risk of injury and improve athletic performance by increasing Range of Motion (ROM) (Brandy, Irion, & Briggler, 1997). However, information is increasingly coming to light that stretching does not in fact reduce the risk of local muscle injury (Shrier, 1999) and actually reduces athletic performance (Shrier, 2004).

Multiple studies have been completed of the relationship between stretching and ROM, and stretching and risk of injury, as well as stretching and athletic performance; however, few have studied the relationship between stretching the antagonist muscle prior to an agonist muscle contraction. The late Charles Poliquin, world-renowned strength and conditioning coach, long advocated that the antagonist muscle should always be stretched prior to completing an agonist muscle contraction in order to increase power output (Poliquin, 2017). He urged:

> Always stretch the quadriceps between hamstrings sets. Increasing the range of motion of your quadriceps prior to a leg curl exercise will increase the amount of motor units used in the hamstrings during the exercise and therefore the effectiveness of the chosen exercise. Since the quadriceps is the antagonist muscle to the hamstrings, and that stretching will allow it to relax, the force of the contraction in the hamstrings will be much greater in the subsequent contraction.(T-Nation, 2008, Website)

LITERATURE REVIEW

To the best of the authors' knowledge, there has only been one previous study published on the relationship between antagonist stretching and enhanced power in subsequent muscle contractions (Sandberg, 2012). This study is mentioned later in the literature review and will serve as a guideline to support the current study and motivate further investigation of this topic. The theory, anecdotally promoted by Charles Poliquin, has been frequently discussed by strength and conditioning coaches in recent times. With the limited amount of research on this subject, the authors decided to review the factors that inform the reasoning behind Poliquin's theory; these include stretching and ROM, as well as stretching and its relationship to power and force production.

Stretching and ROM

Amiri-Khorasani and Kellis (2015) examined the effects of different agonist and antagonist stretching arrangements within a pre-exercise warm up on static and dynamic ROM. Sixty trained male subjects volunteered to participate in this study. Dynamic and static stretching of both the hip flexor and extensor muscle was completed, leading to an increase in both static and dynamic ROM at the hip. It was concluded that dynamic stretching of the hip flexors and static stretching of the hip extensors was the best arrangement, producing more post-activation potentiation on agonist muscles and less muscle stiffness in antagonist muscles. It can be assumed that with a decrease in antagonist muscle stiffness, agonist muscles will travel through an unrestricted ROM.

Buchbinder, Burns, Cook, Landorf and Randford (2006) completed a systematic review of randomised trials to examine the effects of static calf muscle stretching compared with no stretching. Results showed that calf muscle stretching provided a small yet significant increase in dorsi flexion, with optimal stretching sessions lasting up to 30 minutes in length. It can be assumed that with an extended range of motion of an unrestricting antagonist muscle group, this will allow for greater motor recruitment and force production in the angonist via reciprocal inhibition.

Godges, Longdon, MacRae, MacRae and Tinberg (1989) completed a study to compare two commonly practiced stretching techniques to establish which is most effective in gaining hip ROM and gait economy. Seven young males aged between 18 and 22 participated in the study, where they completed both static and proprioceptive neuromuscular facilitation (PNF). The results showed that both the static stretching and PNF resulted in significant improvement of both hip flexion and hip extension. These results suggest that a single bout of either stretching technique will result in an effective improvement in hip ROM.

Stretching and Power

Cornwell, Kokkonen and Nelson (1998) completed a study analyzing the effects of acute muscle stretching on maximal strength performance. Fifteen female and 15 male untrained individuals participated in the study, which required them to perform a one repetition max (1RM) prone-knee flexion and 1RM seated-knee extension on two successive days. On each day, one of two treatments was adopted (stretch vs. non stretch) before the testing was repeated to note any variance in results. For both the knee flexion and knee extension, a decrease in the participants' 1RM was noted after adopting the stretching protocol. The authors suggest that acute stretching of the prime (agonist) mover muscles should be avoided prior to maximal strength output.

Behm, Cahill, Carroll, Power and Young (2004) analysed the effects that an acute bout of static stretching have on force and jumping performance. Twelve participants took part in the experiment and were tested either before and after static stretching of the quadriceps and plantar flexors or tested on a similar period for control (no stretch group). The tests included (but were not limited to) maximal voluntary force, electromyography activity and vertical jump measurements. The results showed that after static stretching, there were significant decrements in torque/force of the quadriceps on maximal voluntary force; however, there were no significant changes on vertical jump height. The authors concluded that the parallel duration of changes in ROM and force output might offer further evidence suggesting that static stretching reduces force production.

Beck, Coburn, Cramer, Housh, Johnson and Weir (2005) completed a study on the acute effects of static stretching on peak torque, mean power output, electromyography and mechanomyography. The authors ran 21 volunteers through maximal voluntary concentric isokentic leg extensions for the dominant and non-dominant limbs. Following the tests, the dominant leg extensors muscles were stretched with four different static stretching exercises before the initial tests were repeated. The study findings suggested that stretching induced decreases in both force production and muscle activation; the authors attributed these decreases to the central nervous system inhibitory mechanism.

Reliability and Validity of GymAware Software

Drinkwater, Galna, Hunt, McKenna and Pyne (2007) completed a study to analyse the reliability and validity of the GymAware optical encoder to measure displacement data. Three GymAware sensors were attatched to a calibration rig, specifically designed to accurately calibrate dynamometry equipment. The study concluded that the GymAware optical encoder validised its ability as a linear position tranducer which can calculate other strength and power variables through the differentiation of measured displacement data. The encoder was highly reliable, with little to no variation between sets or different sensors.

Antagonist Stretching on Agonist Power

Sandberg (2012) completed a study of the acute effects of antagonist stretching on jump height and knee extension peak torque. Sixteen active males participated in the study, which required them to be tested for both vertical jump height and isokintic torque production in a knee extension. Participants performed these tests in a randomised counter-balanced order with and without prior antagonist stretching. Post antagonist stretching, vertical jump height and power was significantly higher. The results suggest that stretching the antagonist hamstrings prior to knee extension increases torque production, and that stretching the hip flexors and dorsi flexors may enhance jump height and power. This strengthens the theory that antagonist stretching increases agonist force and power. This is the first published study on this subject and will serve as a guideline for the current study.

METHODS

The aim of our study was to test Charles Poliquin's anecdotally promoted theory that antagonist stretching should be performed prior to agonist muscle activation, as this will allow for a more powerful and forceful contraction. We sought to use Sandberg's (2012) study as guideline and further validate the results found in his study. It was then hoped that the results could be used by the researcher as anecdotal evidence for future implementation and to aid the participants' future athletics endeavours. Following consultation with the Kaitohutohu Research Committee, ethical consent was granted by the Otago Polytechnic Ethics Committee.

Study Design

The study took the form of a within-subjects design and involved participants completing a series of trial tests and stretching protocols in a randomised counter-balanced order.

Participants

The study recruited 16 trained and active participants who are frequently required to perform explosive power or plyometric exercises such as jumping and weightlifting. This approach was essential to reduce any improvements in jumps or in either of the lifting exercises through minimal practice alone – known as the learning effect. As a result, basketball and volleyball players, as well as Olympic weightlifters, were recruited for the study. Not only did this result in more reliable results, but also the findings of the study would be relevant to the participants in increasing their athletic performance. All participants were free of injuries or illnesses, had received an information sheet and provided written consent..

Equipment/Materials

The equipment required in the trial was all freely available at the Otago Institute of Sport and Adventures Tapuae gym facility. It included: (a) a leg extension machine, (b) a cable curl machine, (c) a Vertex vertical jump device, (d) a stationary bike, (e) GymAware optical encoder and software, and (f) a laptop (researchers' personal password-protected device).

Procedure

This within-subject design study involved 16 trained and active Olympic weightlifters, basketball and volleyball players completing a series of trial tests and stretching protocols in a randomised counter-balanced order. Two series of tests were undertaken each day and were split into two categories, isolation and compound. Before testing began, participants performed a basic aerobic warm up which involved them riding a stationary bike for five minutes. For the isolation trials, GymAware software was used to calculate maximum velocity. The first isolation test was the standing strict cable curl (performed at 15 kilograms for males and 10 kilograms for females;), in which the bicep performs the role of agonist and triceps the role of antagonist. The second isolation test involved the single-legged seated leg extension (performed at 15 kilograms for males and 10 kilograms for females), in which the quadriceps plays the role of agonist and hamstrings the role of antagonist. The isolation trial tests were repeated five times for each movement to determine an average.

The compound trial involved only one test, the vertical jump, in which the gluteus maximus, quadriceps and gastrocnemius serve as the main agonists and the hip and dorsi flexors serve as the main antagonists. The vertical jump was selected due to its ease of performance and its common use in the field for measuring power. Participants repeated jump attempts five times to determine an average. Jump heights were recorded by the Vertec Jump Device and the Harman Equation was used to calculate power (Frykman, Harman, Kraemer, Rosenstein, & Rosenstein, 1991). Both Team A and Team B performed all test trials on day one, Team A with the stretching protocol and Team B without. Three days later, the roles were reversed.

Stretching Protocols

Stretching treatments were performed in both the isolation and the compound trials. The standing strict cable curl test involved the participants performing a standing behind the head tricep stretch (Appendix 7). The leg extension required the participants to perform a lying partner-assisted hamstring stretch (Appendix 8). Lastly, the vertical jump required the participants to perform a kneeling Sanson-style hip flexor stretch (Appendix 9) and split stance dorsi flexor stretch (Appendix 10). The treatment of stretches required participants to perform three sets of 30-second stretch intervals with 20 seconds rest between sets – previous research recommends 30-second holds for static stretching (Chan, Hong, & Robinson, 2011).

Data Management, Process and Analysis

All data was stored and managed in a password-protected, electronic format. Analysis of the raw data was completed by comparing the differences between un-stretched results and results after completing the stretching protocol for individual participants. Data was recorded into a template for analysis through the use of a simple, structured table (Appendix 12).

RESULTS

In total, 16 trained participants were recruited based on their athletic pursuits and capabilities. All participants (Mean [*M*] = 24 years, Standard Deviation [*SD*] = 3.3 years, Range [*R*] = 13 years) completed both the non-stretching and stretching trials for the strict cable curl, leg extension and vertical jump. The average height and weight of the participants was *M* = 173 centimeters (cm), *SD* = 9.9cm, *R* = 26cm and *M* = 80 kilograms (kg), *SD* = 14.4kg, *R* = 42kg, respectively.

Statistical analysis of both the control (pre-testing/non-stretch) and intervention (post-testing/stretch) groups was completed for both orders of the counterbalanced experiment. Data was recorded as a Mean ± Standard Deviation; change between control and experimental trials as well as statistical significance through probability values ($P \leq 0.05$) and effect size using Cohen's *D* for all dependent variables were calculated and summarised in Table 1 below.

Exercise:	Non Stretch:	Stretch:	Change:	*P:*	*ES:*
Cable Curl (M/PS)	0.51925 ± 0.16504	0.63288 ± 0.20093	0.11363	0.0907	0.688
Leg Extension (M/PS)	0.62663 ± 0.1022	0.64813 ± 0.12985	0.0215	0.6039	0.214
Vertical Jump (CM)	51.825 ± 9.76739	53.025 ± 10.69875	1.2	0.7427	0.122
Vertical Jump (Watts)	7938.875 ± 973.85727	8010.9375 ± 1061.24464	72.0625	0.8427	0.0739
NB: All trials represented as Mean ± Standard Deviation					

Table 1: Statistical analysis on both the control (pre-testing/non-stretch) and intervention (post-testing/stretch) groups.

Isolation Trials

Both the strict standing cable curl and leg extension recorded a perceptible increase in power (M/PS) from adopting the stretching protocol (see Figure 1). Probability value ($P > 0.05$) suggested that the results were not statistically significant, and effect size was small and trivial for the cable curl (*ES:* 0.35-0.8) and leg extension (*ES* > 0.35) respectively.

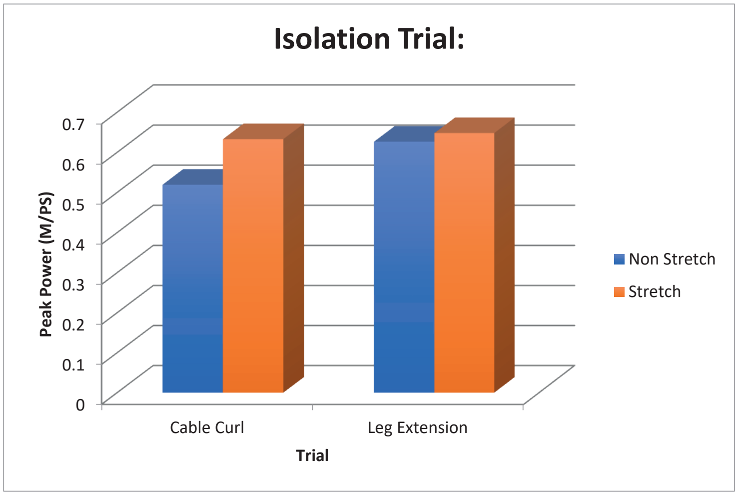

Figure 1: Isolation Trail Results (means represented)

Compound Trial

Vertical jump testing recorded a perceptible increase not only in jump height (cm), but also in power (w) between the control and intervention trials (see Figures 2 and 3). Statistical analysis found that probability value was not significant (*P* >0.05) and effect size was trivial (*ES* > 0.35).

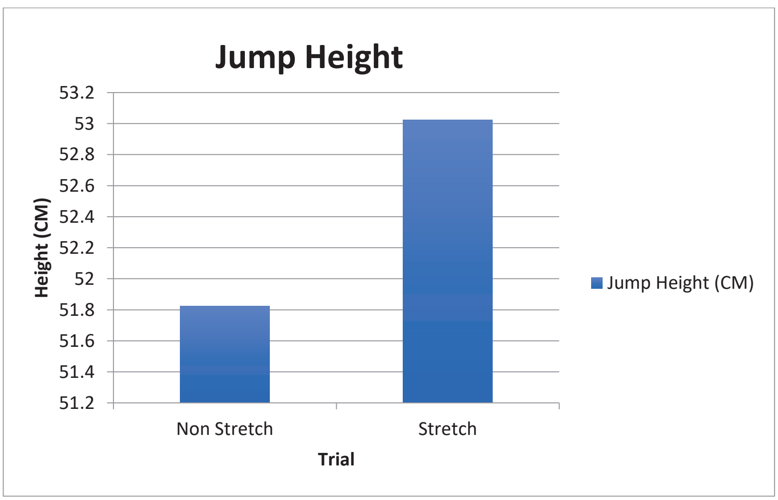

Figure 2: Jump Height (means represented)

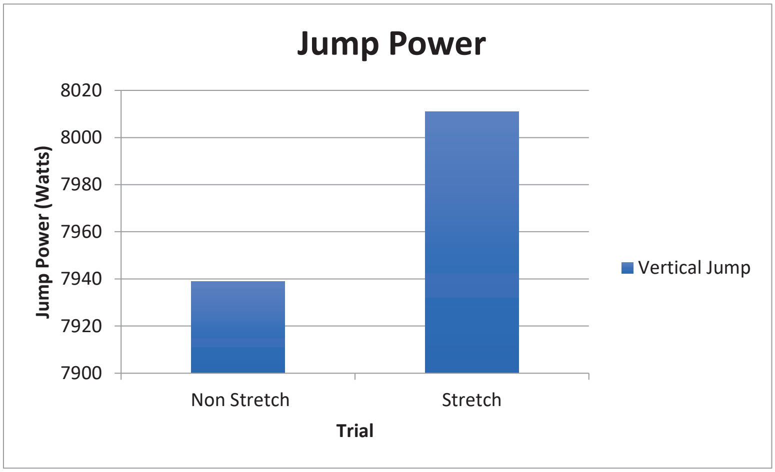

Figure 3: Jump Power (means represented)

DISCUSSION

Isolation Trials

The strict standing cable curl and seated leg extension isolation trials provided the first key findings of this study. These trials showed that performing antagonist stretching of the triceps and hamstrings (three sets of 30 seconds on, followed by 20 seconds rest) may increase power output in elbow flexion and knee extension-based movements. The strict standing cable curl and seated leg extension saw a mean increase of 0.11363m/ps or 11.3cm per second and 0.0215m/ps or 2.15cm per second respectively. Statistical analysis was completed and showed that probability value was not significant (*P* >0.05) and that effect size, according to Rhea (2004), was small and trivial for the cable curl (*ES:* 0.35-0.8) and leg extension (*ES* > 0.35) respectively. These results give evidential support to back Poliquin's anecdotally based theory that antagonist stretching will increase power; this may be due to the increased range of motion now available throughout a contraction, and thus the potential to recruit greater number of motor units (Poliquin, 2017).

Compound Trials

The vertical jump provided a further two important findings that are more applicable to an athletic setting. This trial showed that performing the aforementioned stretching protocols of the hip flexor and ankle dorsi flexor musculature may improve jump height and power output. The vertical jump recorded a mean increase of 1.2cm in height and 72.0625w. Statistical analysis found that probability value was not significant (P >0.05) and effect size was trivial (ES > 0.35) according to Rhea (2004). However, it can still be assumed that performing antagonist stretching prior to completing power-based exercises such as the vertical jump may result in increased performance such as jump height and power output. These results further support Poliquin's theories and give additional weight to Sandberg's (2012) findings, with an uncanny similarity in results. The current study recorded a 1.2cm increase in means from the control trial's 51.825cm to the intervention trial's 53.025cm, while Sandberg's control trial's 58.6cm also recorded a 1.2cm increase in means, with his intervention trials averaging 59.8cm. In a further case of uncannily similar results, a study by Church, Crist, Moode and Wiggins (2001) examined the effects of PNF stretching on two agonist muscles (hamstrings and quadriceps) prior to performing the vertical jump. PNF stretching of the hamstrings and quadriceps saw a 1.47cm decrease in jump height.

Limitations

The authors aimed to minimise as many limitations of the present study as possible through rigorous research on the previous literature, pre-planning, supervisor and tutor mentorship and ethical consultation. However, as with all studies, limitations were still present and were controlled to the highest degree possible. They were divided into one of three categories: participants, equipment and study protocol.

The participant criteria for this study provided the first complication. The study recruited a mix of intermediate to advanced trainees with experience in volleyball, basketball or weightlifting to minimise the learning effect. However, this meant that the participants were heavily involved in their own athletic pursuits and still actively training and competing. Although the author attempted to minimise the complications arising from this by scheduling selected testing slots and recommending that training or competing the week of testing be avoided, he still heard of participants experiencing delayed onset muscle soreness (DOMS) and muscular fatigue on testing days, which may have adversely effected testing performance. Another issue that could have potentially effected results was nutritional choices and sleeping patterns around testing days.

The second area of limitation related to the equipment used in the study, specifically the GymAware Optical Encoder. Halfway through pilot testing, problems arose with the encoder cord and tassel retractor. To address this issue, the owner sent the device overseas to its country of origin to be repaired under warranty. Unfortunately, this occurred during testing of the isolation movements and meant that one group had a seven-day intermission period between control and intervention trials. Whether or not this had an effect on the results cannot be determined; it did, however, prompt an alteration in testing procedures.

The third area of limitation related to the study's choice of exercise selection for testing. The vertical jump was adopted due to its common use in the field for determining power in athletes; however, it made it difficult to establish a true antagonist for such a full-body, multi-joint, compound movement. According to Van De Graaff (1998), and also noted by Sandberg (2012), the role of the rectus femoris in the vertical jump is that of a hip flexor, but it also acts as a knee extensor, so can be labeled an agonist and antagonist during different phases of the movement. To minimise this potential confounding factor, the Sanson stretch was utilised to reduce the involvement of quadriceps when preforming the hip flexor stretching protocol.

Interpretation

The key results of the isolation trials in this study support Poliquin's anecdotally based theory of stretching antagonist musculature before performing an agonist-based movement to increase joint and exercise ROM and thus increase motor unit activation. However, it is important to note that the increased peak power output noted between the control and intervention trials cannot be interpreted as a result of increased motor unit recruitment without the use of electromyography testing, as seen in Sandberg's (2012) study. T-Nation (2008) and Poliquin (2017) envisaged that Poliquin's theory would be utilised in a hypertrophy-based setting where trainees will be performing isolation exercises with the goal of maximum musculature activation, resulting in muscular hypertrophy. The current study noted an increased force production represented by an increase in peak power output; whether or not this was a result of increased motor unit activation (and therefore future muscular hypertrophy) would have to be further investigated in future research. The use of isolation trials in this study was intended to provide a setting where the theory could be tested in the simplest environment possible.

The key results of the compound trials were the most important for the authors, as coaches and athletes, as they took Poliquin's theory from the realm of the anecdotal to a practical athletic setting which can be utilised in the field of practice or game play. The study's stretching protocol produced precisely the same performance increases in jump height as seen in previous research (Sandberg, 2012). With the increase in not only jump height, but also power output, the results of the compound trials further validate Poliquin's claims and, through replication, back up Sandberg's prior research. According to both the current study and Sandberg's previous research, stretching the antagonists to the hip extensors and ankle plantar flexors before performing a vertical jump produces significantly higher jump height and power. However, it should be emphasised that the mechanisms of these improvements, as with the isolation trials, cannot be determined without future research.

Practical Application

With the results of the current study validating and replicating the previous research undertaken by Sandberg (2012) and the anecdotally based theory of Charles Poliquin, we can conclude that stretching antagonist musculature before performing an agonist muscle contraction may result in increased power output and thus performance. According to Sandberg (2012), antagonist stretching works best at improving strength at high velocities. The results of the current study back this up, with increased peak power output seen after stretching the triceps and quadriceps before performing the strict standing cable curl and seated leg extension respectively. Similarly, stretching the hip flexors and ankle dorsi flexors during a high-velocity vertical jump resulted in a significant increase in not only jump height, but also in absolute jump power.

It appears that antagonist stretching may result in increased peak power output in isolation-based exercises, as well as in performance and absolute power in high-velocity movements such as the vertical jump. Trainees wishing to achieve muscular hypertrophy may want to incorporate antagonist stretching into their regimen before performing isolation-based exercises with the goal of incorporating heavier weights.

It is vital to note, however, that the mechanisms for these improvements cannot be determined from the current study. Although Poliquin believes that these increases are a result of increased motor unit activation, this is yet to be proven and begs the question of whether or not the implementation of this stretching protocol will result in muscular hypertrophy. Hypertrophy is the result of tension through muscular activation (Andrews et al., 2011), and this study did not look at muscular activation as a mechanism for increased power. Strength and conditioning coaches and athletes may wish to use this information to incorporate antagonist stretching in the field of play to increase performance in high-velocity movements such as jumping, lifting and throwing. It is recommended however, that these methods should first be implemented in training, as responses seem to be individual. With the increase in performance seen in both Sandberg's (2012) research and the current study, the adoption of this method may drastically improve an athlete's field performance and results.

Further research is needed to advance this topic; the authors suggest investigation of different styles of stretching, such as PNF and dynamic, on muscle groups and movements that have not been previously researched. In addition, future research should investigate the possible mechanisms that have resulted in the improvements in peak power output, jump height and absolute jump power.

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