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Original Article

Improvements in the range of motion, power and agility in active people utilizing multiple muscle contract-relax-antagonist-contract (CRAC) stretches

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Abstract:
Flexibility is one of the major components of fitness. However, current research demonstrates that static stretching can limit or even reduce physical performance, with power the most significantly affected. Traditional PNF (proprioceptive neuromuscular facilitation) has shown significant improvements in flexibility only, while dynamic stretching has shown a slight improvement in power and flexibility. The purpose of this paper is to investigate the effects of partner-assisted, PNF - contract-relax antagonist contract (CRAC) method on flexibility, agility, and power. Existing literature supports that PNF is the most effective method of stretching when the aim is to increase range of motion, particularly for short-term improvements; however, there is currently no evidence to support improvements in agility or power. This case study revealed that there is not only a significant increase in flexibility from the CRAC method but there is also a significant increase in power, with some improvement in agility. Results show an average improvement of 47% in the sit and reach exercise, 10% improvement in the long jump exercise, and 4% reduction in agility run time. These findings may suggest an expansion of the neuromuscular network during the static contractions of both target and antagonist muscle in extreme ranges of motion. This increased length gives a greater range of movement of the muscle, which then engages more muscle fibres to perform. The greater engagement of the neuromuscular network and the longer the trajectory the muscle can fire at maximum voluntary contraction, combined with increasing muscle speeds is called contractile velocity and could explain the overall increase in power.
Keywords: Agility, Flexibility, PNF Stretching, Power, Sport Performance

Introduction

Dynamic stretching is the predominant warmup stretching method used by elite athletes to improve range of motion (ROM) and power. While most studies regarding dynamic stretching have reported only small effect sizes in power (Opplert & Babult, 2018) – other studies have found a reduction in power output using dynamic stretching (Jones et al., 2014).

PNF Stretching was developed over 70 years ago to treat polio, multiple sclerosis, and physical injury (Sandel, 2013). The most well-known form of PNF is the contract-relax or hold-relax method. However, an alternate version of PNF - CRAC (Contract-Relax-Antagonist-Contract) has had limited widespread knowledge or use. The comparatively few studies on this technique have shown it to be superior for increasing ROM, and some studies have shown to enhance muscle excitability leading to improved strength, fine motor skills, coordination and balance at extreme ranges of motion (Ryan et al., 2010; Shahabi et al., 2016; Osternig et al., 1990).

Definitions About CRAC:

Proprioceptive Neuromuscular Facilitation (PNF). PNF is a stretching technique that aims to maximise muscle flexibility and "involves a series of contractions and relaxations with enforced stretching during the relaxation phase" (Merriam-Webster, n.d.). PNF is used to improve muscle elasticity and improve both passive and active range of motion (Hindle et al., 2012).

Contract-Relax-Antagonist-Contract (CRAC). CRAC stretching is a form of PNF stretching that takes advantage of reciprocal inhibition to relax the muscle further, allowing for deeper stretching, increased range of motion, and increased flexibility. CRAC stretching is performed in two phases. The target muscles are maximally contracted against resistance and then relaxed in the first phase. In the second phase, the opposing muscle is contracted against resistance.

Contract-Reciprocal-Contract (CRC). CRC is similar to the CRAC protocols without the relaxation component during the first phase of the exercise. In the second phase, the opposing muscle is contracted against resistance. This is a more time efficient method than CRAC.

Flexibility. "Flexibility is the ability of a joint or series of joints to move through an unrestricted, pain-free range of motion" (UC Davis Health, 2021). Flexibility and range of motion typically go hand in hand.

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Range of Motion. Range of motion is how far a joint can move (UC Davis Health, 2021).

Strength. Strength is the amount of force a muscle can produce (LibreTexts, 2020).

Power. Power is defined as strength times speed (LibreTexts, 2020).

Endurance. Endurance is the ability of a muscle or group of muscles to perform continuously without fatiguing.

Agility. Agility is the ability to change direction at high speed. The faster someone can change direction, the greater their agility (LibreTexts, 2020).

Stretch Reflex. The stretch reflex or myotatic reflex refers to the contraction of a muscle in response to its passive stretching by increasing its contractility as long as the stretch is within physiological limits (Bhattacharyya, 2017)

Stretch Barrier. The stretch barrier is the limit of a muscles' pain-free end range. (McAtee, Charland, 2007).

Reciprocal Inhibition. "Reciprocal inhibition is the spinal process of inhibition of a motor neuron pool when the antagonist motor neuron pool is activated" (Hallet, 2012). Reciprocal inhibition is the concept that when a muscle is contracted against resistance, the muscles on the other side of the joint (the antagonists) relax.

Isometric Contractions. Isometric contractions are a form of resistance or strength training that strengthens the muscle at a particular joint angle. Isometric contractions "generate force without changing the length of the muscle" (LibreTexts, 2020).

Contractile Velocity. Contractile velocity is "the speed at which a muscle changes length during a contraction" (LibreTexts, 2020).

How CRAC Works: The Basics

CRAC stretching protocols vary in time, intensity, and procedure protocol. A literary review performed by Sharman et al. in 2006 found that the most common and effective variation of CRAC procedure involves a static contraction of the target muscle (TM) for a duration of anywhere between 3 and 15 seconds. Sharman et al. found that in most cases, ROM increased when any duration between this range was included (Sharman et al., 2006). This contraction is immediately followed by a 6 to 15-second concentric contraction of the antagonist muscle. This may be followed by 20 seconds of rest before the cycle is repeated four to five times. Rowlands et al. highlighted that a longer contraction time (10 seconds versus 5 seconds) led to greater increases in flexibility (Rowlands et al., 2003). Many studies have used the Maximum Voluntary Contraction (MVC) of the TM to fatigue the fast-twitch fibres and sensory receptor stimulation (Burgess et al., 2019). On the contrary, Feland and Marin's recommendation of 20% contraction of MVC as gains appear to be independent of static contraction intensities (Feland et al., 2004) because low intensity limits the possibility of injury. Unfortunately, there is no standardised protocol for the users of PNF, leaving room for many variations in technique and results.

The purpose of this case study is to examine the effectiveness of PNF - CRAC stretching on Flexibility, Agility and Power using a modified CRAC Protocol. This particular CRAC Protocol is a middle ground of the majority of protocols used in the research and closely follows the CRC principles. The participant isometrically contracts a stretched TM for 10 seconds at 15% of their Rate of Perceived Exertion (RPE) of MVC, then contracting the antagonist (opposing) muscle at up to 50% RPE for a further 10 seconds. This cycle is repeated two additional times in each direction for a total of 60 seconds with no rest in-between.

Although CRAC stretching studies have improved flexibility significantly (up to 37%), they found it has no reduction or improvement on performance, i.e., agility and power (Burgess et al., 2019). While that study used a 20-Meter Sprint to test power and the Illinois Agility Test to test agility, both showed no decrease in time, claiming CRAC stretching did not affect performance.

Compared to Burgess et al., This study will use the Standing Long Jump Test to test for power and the L-Run Agility Test to test for agility. A further difference between Burgess et al. and this study is that they performed one CRAC stretch on only one muscle group (the hamstring), whereas this study will perform CRAC stretches on seven body parts listed below.

Material & Methods

Study Design

Seven volunteers were selected who had no injury that could affect the study. This study was conducted over one day. Participants will be tested for flexibility, agility and power prior to and post CRAC stretching.

A break of a minimum of 40 minutes will be taken after the first set of tests to allow full recovery before the stretches and the second round of testing.

The participants will do a total of 7 Partner Assisted CRAC Stretches using the modified CRAC Protocol. One CRAC stretch was performed for each body part: chest, core, hip flexors, hamstrings, calves, and ankles – inversion & eversion.

Participants

Seven participants (20 to 37 years old) were chosen who are active at least three to five hours a week. Ethical guidelines and health screening were used to select the participants and explain their rights throughout the study.

Instrumentation

The Sit and Reach test will be utilised to assess the improvement in hamstring flexibility. After a 5-minute warmup on a stationary bike, participants were seated in front of the sit and reach measuring box and asked to reach as far forward as possible. No knee bending or bouncing was allowed, and participants had to hold the position for three seconds (ACSM, 2000).

For agility testing, the L-run required the participant to change direction laterally, takes only approximately 5 to 6 seconds to complete, and, based on observation, has a solid relationship for dynamic sports. Subjects performed two warmup run-throughs to familiarise themselves with the actions required. The participants then completed two tests, and the best time was recorded. Webb and Lander initially developed the L-Run as a test of agility for rugby union, which has similar movement patterns to those used during rugby league play (Meir et al., 2020).

A standing long jump will be performed on a wooden floor utilising a tape measure and zero-mark indicators to test power. To exclude the contribution of arm swing, arms are folded across the chest. Subjects performed three warmup jumps to familiarise themselves with the technique and then performed three maximal efforts with a 45-second recovery between each jump. Jump distance was measured to the nearest centimetre by observation from zero mark to rear-most heel on landing. The best trial was used for statistical analysis (Morriss et al., 2001).

Results

For the flexibility exercise (Sit and Reach), the participants had an average improvement of 47% (*see Figure 1*), where the distance reached had increased between 2 and 6.5 centimetres (*see Figure 2*) as all participants could reach their toes, so that became the zero baseline. The average improvement is calculated for the difference between the before and after values divided by the before value. For instance, subject 1 made a 3.70cm improvement, with a before reach of 15.3cm and an after reach of 19cm. The percent of improvement (*see Figure 1*) was calculated as centimetres improved divided by the before reach, so in this case, 3.70cm divided by 15.3cm, which results in a 24.18% improvement. Of the 7 participants, the average improvement was 3.60cm.

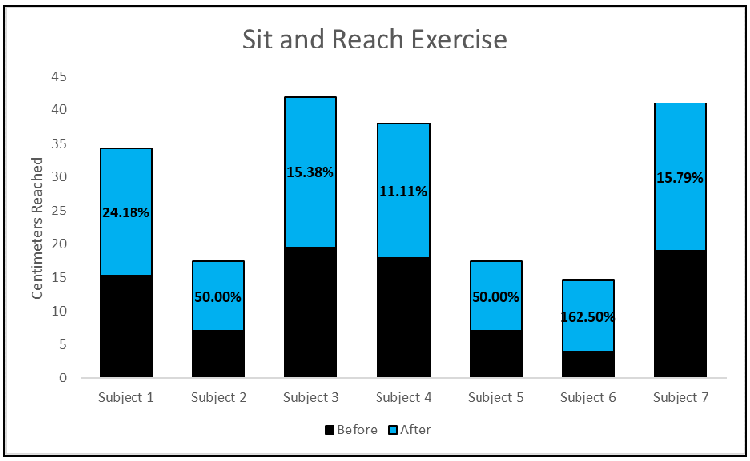

Figure 1: Sit and Reach Exercise Results

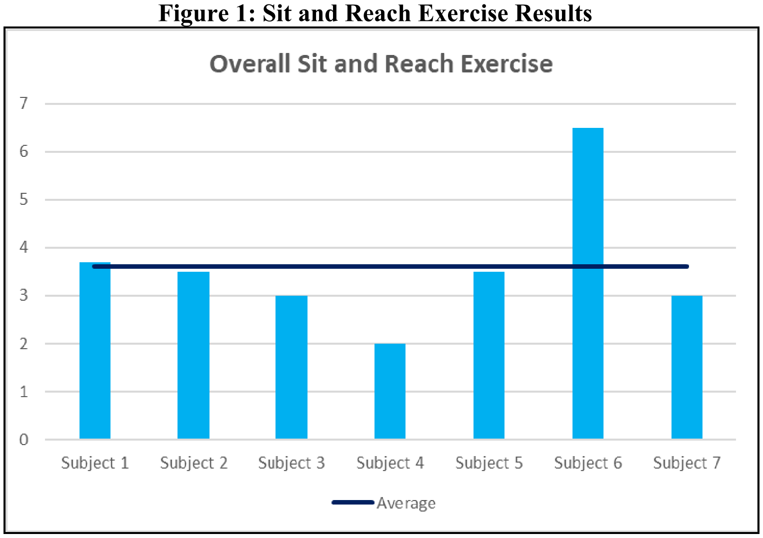

Figure 2: Overall Sit and Reach Exercise Results

For the power exercise (Standing Long Jump), the participants had an average improvement of 10% (*see Figure 3*), where the distance reached had increased between 5 and 31 centimetres (*see Figure 4*). The percent of improvement was calculated as centimetres improved divided by the before distance, so in the case of subject 1, 31cm divided by 184cm, which results in a 16.85% improvement. Of the 7 participants, the average improvement was 18.93cm.

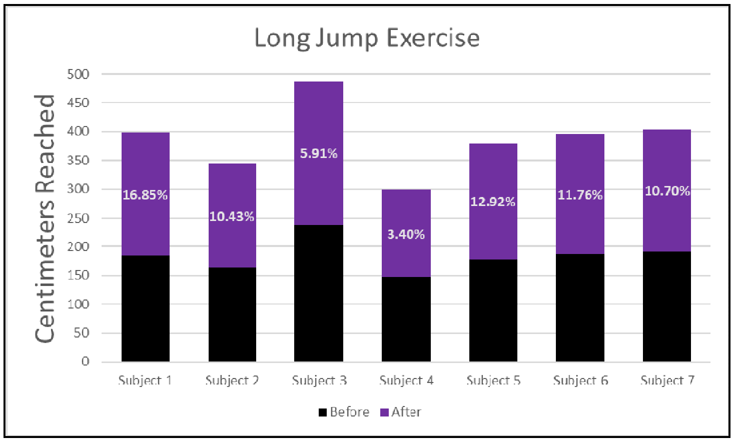

Figure 3: Long Jump Exercise Results.

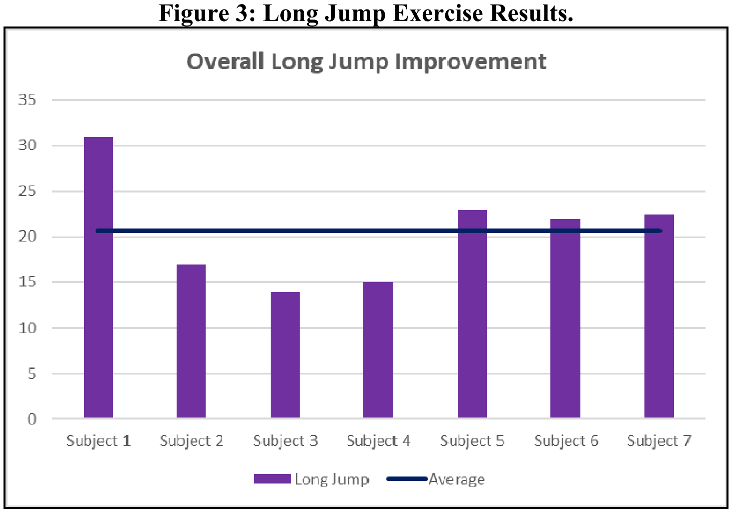

Figure 4: Long Jump Exercise Results.

For the agility exercise (L-run), the participants times had decreased by an average of 4.42% (*see Figure 5*), where agility improved between 0.08 seconds to 0.44 seconds (*see Figure 6*). The percent improvement was calculated similarly to the sit and reach and the long jump exercise. The percent of improvement was calculated as seconds improved divided by the before time, so in the case of subject 1, 0.27s divided by 5.76s, which results in a 4.69% improvement. Of the 7 participants, the average improvement was 0.27 seconds.

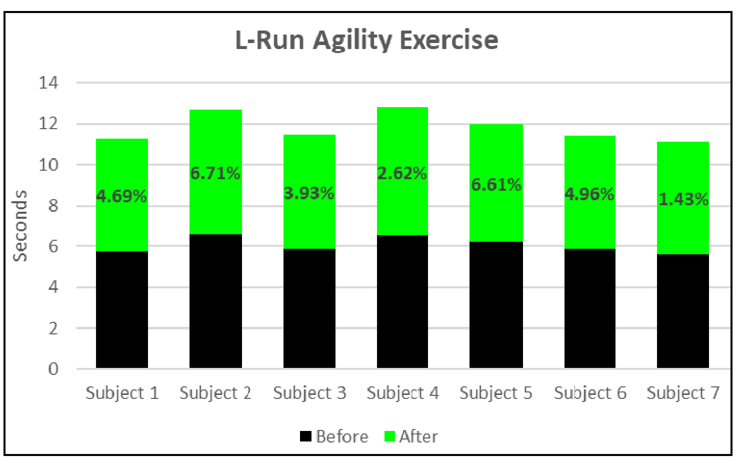

Figure 5: L-Run Agility Exercise Results.

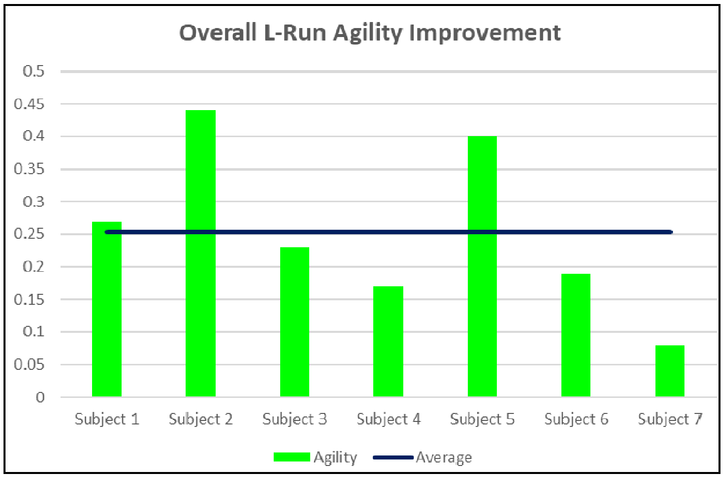

Figure 6: L-Run Agility Exercise Results.

Discussion

The CRAC stretches used in this study effectively improved flexibility, agility, and power. The increase in flexibility is consistent with previous literature (Ryan et al., 2010; Burgess et al., 2019; Feland & Marin, 2004).

The most significant finding is the improvement in agility and power, which other literature has failed to reveal significantly. While Ryan et al. found that CRAC stretching improved postural stability, Burgess et al. found that CRAC did not improve or impinge on power or agility. Several possible differences between the studies could have caused these different findings. These include the type of testing, number of stretches performed during the study (one versus seven), amount of rest during the stretch (rest versus no rest), and reduction from MVC to 15% to prevent muscle fatigue. Stretching multiple muscles involved in each exercise provided additional improvements in all three categories, flexibility, agility, and power.

Nagarwal et al. focused on the possibility of autogenic inhibition and reciprocal inhibition as the two significant mechanisms allowing for increased flexibility and range of motion. The concept of autogenic and reciprocal inhibition relies on the physiological functions of muscle spindles and Golgi tendon organs (GTOs). The GTOs are activated by muscle tension; when a muscle has too much tension, the GTOs stimulate muscle relaxation. Muscle spindles are activated by stretch; overstretching a muscle will stimulate muscle contraction. Both autogenic and reciprocal inhibition suggests a balance between GTOs and muscle spindles that can be manipulated to improve flexibility and range of motion.

It is speculated that CRAC stretching could cause these results through **autogenic inhibition** and **reciprocal inhibition** (Nagarwal et al., 2010). Autogenic inhibition is a normal physiological phenomenon that prevents a muscle from exerting more force than it can handle (Oxford University Press, 2021). "Autogenic inhibition is a reduction in the excitability of a stretched muscle that is being contracted" (Piper, 2009); in other words, autogenic inhibition can recruit additional GTOs or increase GTO activity and inhibit muscle spindle activity, which results in a deeper flex of the target muscle, and ultimately increased range of motion.

Reciprocal inhibition manipulates the same concepts as autogenic inhibition with one significant difference. Instead of causing decreased excitability in the muscle being stretched and contracted (as in autogenic inhibition), reciprocal inhibition causes decreased excitability of the stretched muscle while the opposing muscle is being contracted (Piper, 2009). In other words, "reciprocal inhibition causes inhibition of the target muscle following the contraction of the opposing muscle" (Nagarwal et al., 2010); see *Figure 7*. Reciprocal inhibition is the concept that a muscle on one side of a joint relaxes to accommodate the contraction of an opposing muscle on the other side of a joint.

The concept of reciprocal inhibition seems more likely in the case of CRAC stretching because the target muscle is first stretched to its theoretical stretch barrier, in which case the muscle spindles will signal for muscle contraction. This action is immediately followed by a 10-second contraction against resistance (phase 1). For phase 2, the opposing muscle is then contracted for 10 seconds. This action theoretically inhibits the contraction of the original target muscle, allowing for additional flexibility and range of motion for that muscle. Autogenic inhibition does not directly account for the use of the opposing muscle that is implemented in CRAC stretching.

Hidle et al. expands beyond autogenic inhibition and reciprocal inhibition and suggests two additional possible mechanisms of increased flexibility and range of motion, such as stress relaxation and gate control theory. The general concept behind stress relaxation is that eventually, "the muscle loses the ability to resist stretching over time" (Hidle et al., 2012); however, additional research into this theory needs to be undertaken it can be applied to PNF or CRAC stretching.

So far, three mechanisms have been discussed as possibilities that may account for the increase in flexibility and range of motion, but what could account for the increased agility and power found in this study?

A fourth mechanism, gate control theory, may elaborate on the mechanics behind the increased power and agility. Gate control theory is fuelled by the concept that pain and pressure both activate their respective receptors at the same time (Hidle et al., 2012). Hidle et al. suggests that during CRAC stretching, when the muscle reaches its stretch barrier and is further stretched beyond its normal ROM, "a large force and stretch is produced … when the participant resists the stretch" (Hidle et al., 2012). When this process is repeated consistently over time, it is thought that the excitability of the stretched muscle decreases as it gets used to the increased muscle and tendon length – which further increases force due to the length-tension relationship of muscles (Hidle et al., 2012). "With increased muscle length comes ability to produce greater force because of the length-tension relationship. With increased ROM and decreased GTO inhibition, the muscle may be able to increase its strength and force production" (Hidle et al., 2012). This increase in force is likely the cause of increased power that occurs with CRAC stretching, giving the muscle greater potential of increasing its contractile velocity.

Another consideration for the improvement of **agility** and **power** is the removal of inhibitors such as the stretch reflex during the muscles' contraction when it is in an extreme range due to the activity. Extending the range of the muscle or rather pushing out the stretch barrier of all the muscles involved in each movement prevents the stretch reflex from being engaged. This could explain the greater speed between movements.

The last consideration is the effects of the **static contraction**. During a contraction into areas previously unreachable, more muscle fibres are engaged. Consciously contracting the muscle in that position would improve the neuromuscular pathways into these areas, enabling greater control of more of the muscle, thus generating more force.

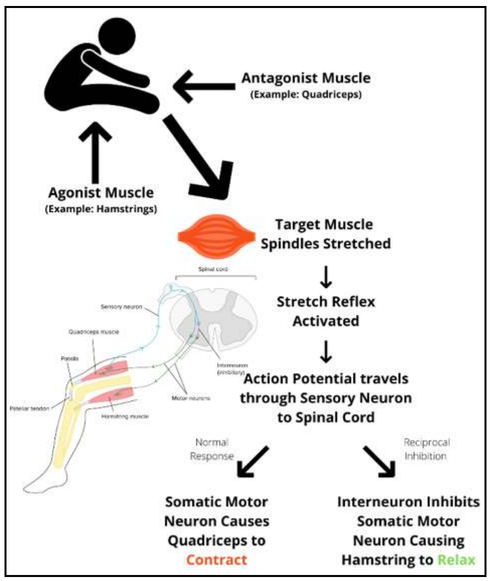

Figure 7: Reciprocal Inhibition

Limitations.

This case study experienced a few limitations. For instance, an extended agility test. It is theorised that this would be more helpful in establishing how much CRAC may improve agility with greater accuracy with a longer running time. While improvement was seen in this experiment, it is possible that the length of the test created an unfair bias in favour of the CRAC stretching technique.

While this study measured the immediate effect of CRAC stretching before an exercise, future studies ought to explore the long-term effects of consistent CRAC stretching to ascertain if there is a possibility for long-term improvement in flexibility, agility, and power.

Future Studies.

Future studies ought to be explored using a larger sample size to achieve statistical validity. Future studies ought to contain a control group that uses static or other dynamic stretching, which can be compared to the experimental group that uses the CRAC stretch method. If these changes are implemented, then a randomised-controlled trial can be administered, and statistical analysis can be investigated.

If this concept can be transformed into a randomised-controlled trial, then all of the possible bias associated with a case study would be eliminated. In this study, there is a possibility that selection and measurement biases were exhibited. In a randomised-controlled trial, the addition of a control group and a larger sample size would increase the possibility for statistical significance. Despite these limitations, the results indicate the possibility that the CRAC mechanism, which is a simple stretch that takes advantage of a normal physiological phenomenon of the human body, may provide improved flexibility, agility and power. Increased flexibility and range of motion translates into less energy burnt, which could substantially impact an athlete's endurance and can be especially beneficial in sports such as basketball, rugby, and soccer (football).

Conclusion

This study shows an improvement in flexibility, agility, and power immediately after exercises preceded by CRAC stretching. The results would hopefully inspire further research of these mechanisms. While the exact mechanisms involved for these results could be many, more research needs to be conducted to explore the exact mechanisms behind these results and establish statistical significance. These results appear to be promising and should be followed up with a randomised-controlled trial and a control group where researchers can measure data in the three exercises for flexibility, power and agility and run a statistical analysis to establish if there is genuinely a statistically significant improvement in these categories.

Currently, there is a large research gap in whether or not CRAC stretching improves agility and power. To date, there are only two actual studies that measure these variables, one of which completely rejects the concept of any improvement in agility or power after using the CRAC mechanism. In this study, the difference of targeting all or most of the muscles that would be used in the exercise compared to one muscle in the study by Burgess et al. in 2019 may explain the improved results.

Further research is recommended to explore the effects of CRAC stretching techniques on flexibility, agility, and power. Further studies could include assessing CRAC stretching for improvements in sports performance and posture and balance in the elderly.

Conflicts of interest

No funding sources were used to assist in the preparations of this review. Rod Millner developed the CRAC Protocol and stretches used for this study. He arranged for the study to occur, but to ensure no conflict of interest, Mr Millner's involvement was limited to assisting with the participants of the 7-partner assisted CRAC stretches.

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