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The Effect of Acute, Static Stretching on the Gastrocnemius' Plantarflexion Torque across Selected Knee and Ankle Combinations

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Introduction

The gastrocnemius is a bi-articular muscle of the posterior leg that crosses over both the knee and the ankle joints(Palastanga & Soames, 2012). It lies most superficial on the posterior leg, forming a large portion of the visible calf, and thus is considered one of the most distinctive features of the musculature of man, as it relates to his bipedal nature and way of traversing(Salmons, 1995). The gastrocnemius originates from two separate heads that are connected to the condyles of the femur by strong tendons. The larger, medial head attaches to the upper, posterior portion of the medial condyle while the smaller, lateral head of the gastrocnemius attaches to the lateral side of the lateral condyle of the femur(Salmons, 1995). Both heads also find some origin from the capsule of the knee joint. These attachment tendons then spread over the muscle bellies in aponeuroses from which the muscle fibers of the gastrocnemius heads arise in a bipennate fashion. The muscle bellies then descend down the leg, remaining separate, with the medial head going farther down than the lateral head, to then insert into a broad aponeurosis that connects with the tendon of the soleus muscle to form the Achilles tendon(Salmons, 1995).

The Achilles tendon thus begins at about midcalf and is typically around 15 cm long(Salmons, 1995). Although it originates where the gastrocnemius heads insert, the soleus muscle continues to insert more fibers until near the Achilles tendon’s inferior end. As it reaches the bottom of the leg, it narrows and then expands as it moves to the calcaneus, finally attaching to its’ posterior surface at the bone’s midpoint(Salmons, 1995). The tendon plays an important role in reducing energy cost of locomotion due to its ability to store energy elastically and release it at certain moments during locomotion, effectively halving the work needed to be done by the muscles(Ker, 1981; Ker, Bennett, Bibby, Kester, & Alexander, 1987). The tendon’s fibers associated with the gastrocnemius insert more laterally on the calcaneus, while those fibers associated with the soleus insert more medially(Salmons, 1995). As a result, it has been shown that the soleus muscle tends to function with slow twitch muscle fibers that help steady the leg, especially when involving standing or absorbing force during locomotion, while the gastrocnemius muscle tends to function with fast twitch muscle fibers, involving more propulsive and explosive movements such as walking, running, and jumping(Edgerton, Smith, & Simpson, 1975; Moore & Dalley, 1996). Collectively then, the gastrocnemius and soleus are the chief plantar flexors of the foot and are sometimes known as the “triceps surae”(Salmons, 1995). However, the gastrocnemius, because of its origin on the condyles of the femur, has also been shown to be a flexor of the knee(Li, Landin, Grodesky, & Myers, 2002). Overall, the gastrocnemius is typically a prominent and powerful muscle on the posterior leg.

Both heads of the gastrocnemius are innervated by the tibial nerve. Spinal nerves L4, L5, and S1 to S3 form the larger, tibial division of the sciatic nerve, which descends down the posterior thigh, and bifurcates into the tibial nerve and common peroneal nerve proximal to the knee. The tibial nerve then continues descending, crossing near the distal border of the popliteus muscle, then passing with the popliteal artery anterior to the arch of the soleus, further continuing into the leg. In addition, after crossing the popliteal fossa, the tibial nerve appears lateral and superficial to the popliteal vessels at the knee, where it is vertical and in the midline of the limb. Once in the distal portion of the fossa, the tibial nerve is overlapped by the junction of the gastrocnemius heads, where it sends motor branches to the gastrocnemius heads. It also innervates six other muscles on the posterior knee and leg: soleus, plantaris, popliteus, tibialis posterior, flexor digitorum longus, and flexor hallucis longus(Salmons, 1995).

Due to the gastrocnemius' bi-articulate nature, both joint angles of the ankle and knee contribute to the muscle's overall length-tension curve. Prior research done by Riemann et al. looked into the change in stiffness of the gastrocnemius during three different angles of the ankle (10° plantar flexed, 0°, and 10° dorsiflexed) and two angles of the knee (0° and 90° both flexed), finding that stiffness increased from plantarflexion (PF) to dorsiflexion (DF) for either knee angle, as well as 0° for the knee producing higher stiffness for any ankle angle than 90°(Riemann, DeMont, Ryu, & Lephart, 2001). This helps illustrate the importance of both joint angles on the gastrocnemius, and therefore was further investigated by Li et al and Landin et al(Landin, Thompson, & Reid, 2015; Li et al., 2002).

Li et al looked at multiple joint angle combinations for the gastrocnemius to determine the largest knee flexion moment, finding that the greatest knee flexion moment occurred at the anatomical position of the knee (0°) regardless of ankle angle, and furthermore reinforced that the gastrocnemius has a significant effect on knee joint stability until it is flexed passed 15°(Li et al., 2002). Landin et al. then further investigated the effect of similar knee-ankle joint combinations on the gastrocnemius as a plantar flexor, and found that the highest PF force of the gastrocnemius was with a straight knee (0°) and a 15° DF ankle, in addition to finding that with 105° knee flexion combined with 15° PF the gastrocnemius had its lowest force production(Landin et al., 2015). Thus they determined, in accordance with Li et al.'s findings, that the gastrocnemius finds its optimal length for both joints when in 0° knee flexion and 15° ankle DF(Landin et al., 2015; Li et al., 2002). Landin et al. further remarked that it is most likely the mechanical advantage of the lever system for both joints that determine the gastrocnemius' joint flexion forces, because of slight differences in PF force between their studies and Li et al.'s(Landin et al., 2015; Li et al., 2002). See Figure 1 for lever diagrams. The gastrocnemius functions as a third-class lever in the knee, providing little mechanical advantage, while in the ankle it functions as a second-class lever, which is much more powerful.

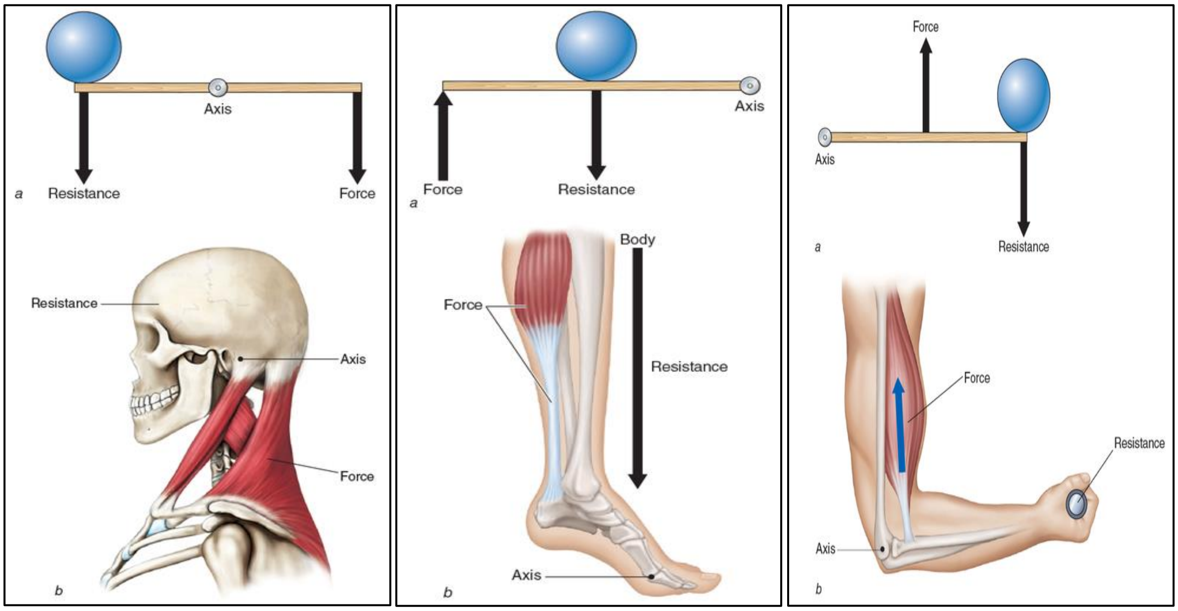

Figure 1. Lever Diagrams. Images from left to right show: a first-class lever, second-class lever, and third-class lever, respectively(Behnke, 2012).

What was most surprising is that at the greatest position of force production, the gastrocnemius is also at its greatest length, which is unlike previous findings with other bi-articular muscles, which have shown that a muscles' optimal length is not typically the greatest length(Brockett, Morgan, & Proske, 2001; Gordon, Huxley, & Julian, 1966; Jones, Allen, Talbot, Morgan, & Proske, 1997; Landin et al., 2015; Lynn, Talbot, & Morgan, 1998; Morgan, 1990; Morgan, Claflin, & Julian, 1996; Talbot & Morgan, 1998; Wood, Morgan, & Proske, 1993). Therefore, Landin et al. concluded that the full ranges of motion for the gastrocnemius at both joints do not elongate it past its optimal length for producing PF force(Landin et al., 2015). In light of this possibility, this study investigates the effect of stretching on the gastrocnemius, to see whether continuing to elongate its length could reach a more or less optimal length for producing PF force, which is heavily involved in locomotion and athletic performance.

Stretching is typically defined as a particular type of movement undergone with the purpose of reducing resistance to that movement and therefore increasing the range of motion (ROM) for that movement around the joints involved(Magnusson, 1998). There are several types of stretching that can accomplish this same purpose. These include types such as: isometric, active, passive, proprioceptive neuromuscular facilitation, ballistic, active isolated, and/or resistance, to identify some of the more common types. However, all types of stretching fall into essentially two fundamental types: static or dynamic, which will be used throughout this study. Static stretching is typically defined as moving a joint or muscle to the end of its ROM and holding that position for 15-60 seconds, and sometimes less in practice(Behm & Chaouachi, 2011; Norris, 1999; Young & Behm, 2002). Dynamic stretching is defined as controlled movement through the active ROM for a joint(Behm & Chaouachi, 2011; Fletcher, 2010). Further terms used to describe stretching are acute or chronic, wherein acute usually refers to a brief bout of stretching and/or stretching done without consistency in a person's life; and chronic refers to a longer period of stretching and/or is normally part of a person's regular habits.

The mechanisms of what actually occur during stretching to reduce resistance are still debated and under-researched, but some tend to view it in light of causing dampened motor-neural activity and therefore less muscle activation and contraction, allowing the musculotendinous unit (MTU) around a joint to move further because of the reduced contraction(J Avela, Kyröläinen, & Komi, 1999; Fletcher & Monte-Colombo, 2010; Fowles, Sale, & MacDougall, 2000). These have been demonstrated with studies showing significant decreases of electromyography paired with decreases in peak torque output after undergoing static stretching, which reinforce the idea of decreases in torque due to reduced neural activity; albeit these studies had prolonged bouts of stretching that lasted at minimum 8 minutes and the neural activity reduction could also have been due to fatigue(Joel T Cramer et al., 2004; Marek et al., 2005; Rosenbaum & Hennig, 1995). Others explain the mechanisms in a more mechanical fashion, looking at the effect of stretching causing damage to muscle cross-bridges or the MTU, and/or changes to the stiffness and elasticity of the MTU, and therefore by all effects increasing the ROM but decreasing the torque production(Janne Avela, Finni, Liikavainio, Elina, & Komi, 2004; Fletcher & Anness, 2007; Fletcher & Jones, 2004; Fletcher & Monte-Colombo, 2010).

In most cases, mechanical responses to stretching are thought to involve a direct effect on the MTU's length-tension and angle-torque relationships(Joel T Cramer et al., 2004; Fletcher & Monte-Colombo, 2010). The length-tension relationship of a MTU is how its length is related to the isometric force that it can produce(Gordon et al., 1966). More specifically this relationship involves the length between actin and myosin filaments in a muscle's sarcomere, and therefore the ability for them to connect optimally in order to contract and generate force depends on how close or far away the filaments are from each other(See Figure 2)(Brughelli & Cronin, 2007). Furthermore, the tendinous and other connective tissues' contribution to this relationship is the passive tension which helps to add force to a contraction (the active tension) when the length of the MTU is typically at its longest length, wherein it acts in parallel with the active muscle contraction(see Figure 3)(Brughelli & Cronin, 2007).

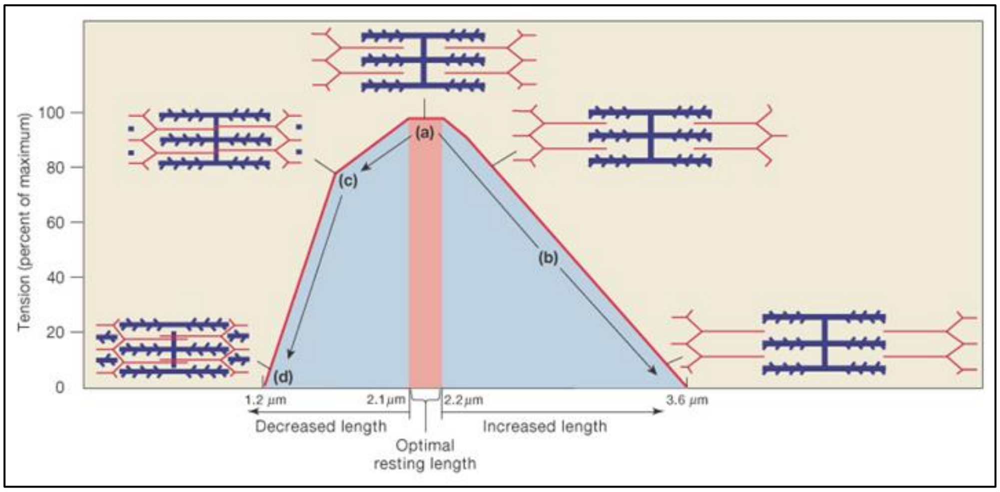

Figure 2. The length-tension relationship for actin and myosin filaments(Gallon, n.d.). Myosin filaments are blue, actin filaments are red. This figure shows how there is an optimal length for the filaments to bind and contract a muscle most efficiently and powerfully, typically somewhere in the middle of a muscle's length.

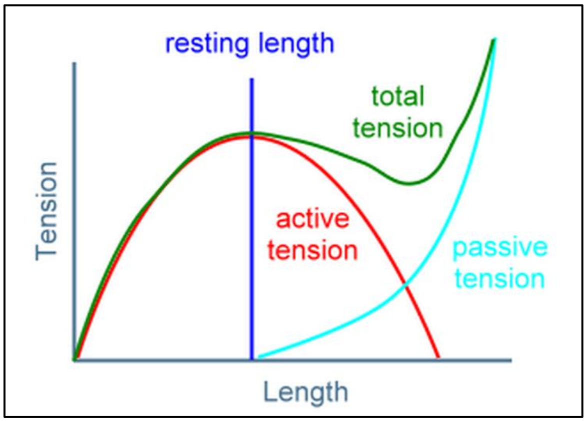

Figure 3. The length-tension curve of a general muscle(Pollen, 2015). The active tension results from the muscle tissue and tends to peak tension when the muscle is at rest, whereas the passive tension results from connective tissue that finds its peak tension typically at a muscle's longest length. Total tension combines both the active and passive tensions.

For all muscles there is a particular length when the force is maximized, and this length-tension relationship varies with each muscle and person as well as in response to the angle-torque relationship.

The angle-torque relationship is how a joint's angle relates to the torque produced by the muscle around that joint(Brughelli & Cronin, 2007). For every joint there is a particular angle where a specific muscle's torque is maximized. This, in combination with the length-tension relationship, suggests there is an optimal joint angle and muscle length where the torque is completely maximized. Although, where a muscle's length is optimal is not necessarily the optimal joint angle, and vice-versa, thus there is a need for further research to clarify not only the optimal length-tension and angle-torque relationships, but also the optimal combination of the two. As such, for each person and muscle these relationships change because of the many compounding factors such as: moment arm lengths, fiber lengths, tendon stiffness, muscle stiffness, and/or neural input.

Typically, it is difficult to measure the specific length and connectivity of subjects' muscle fiber and filament lengths, while it is much easier and simpler to measure joint angles involved with the muscles using dynamometry and goniometry. As a result, due to the correlation between the length-tension and angle-torque relationships, most researchers tend to assume the angle-torque relationship as proxy for the length-tension relationship. While it isn't the ideal way to perform research on muscle force production and factors that affect it, the practicality of the assumption helps to produce more research overall and the findings aren't significantly limited, as illustrated by the article discussed in the next paragraph(Behm & Chaouachi, 2011). This allows stretching research to rely more steadily on dynamometry and goniometry to produce findings on muscle length and force. In summary, stretching can affect the length-tension and angle-torque relationships of a muscle by increasing the effective ROM and change the length of peak force or angle of peak torque, and this can be measured easily with dynamometry and goniometry while the findings are extrapolated.

However, while stretching has been shown to reliably increase a muscle's ROM, the effect of stretching on a muscle's force and performance by most research is still very debated and inconclusive on whether it improves or hinders muscle force and performance. In a review of over 150 articles, Behm and Chaouachi focused on the most prevalent and current static and dynamic stretching research, thoroughly looking into every aspect of stretching (Behm & Chaouachi, 2011). The reviewers searched the articles for factors affecting stretching and findings such as: duration, contraction type responses, intensity, intensity mechanisms, study populations, combination of dynamic and static stretching, and finally covering dynamic stretching alone, in an effort to uncover what may be producing the non-uniformity of stretching research. They point out that while there is a greater prevalence of studies that show an impairment on performance after static stretching, there are still a number of studies that either show no effect on performance or benefit performance. Furthermore, they found that most of these studies that showed negative performance were to a minimal degree that wouldn't necessarily bother the recreational fitness enthusiast, only the elite athlete(Behm & Chaouachi, 2011). Then, when looking into the responses and mechanisms behind the stretching induced performance decrements, they found that most of the decreases in muscular force were related to mechanical properties of the MTU and how stretching affected the length-tension relationship. The authors linked this possibility to the fact that the changes in the length-tension relationship are related to changes in the angle-torque relationship, where the greatest effect of these relationships would be seen during isometric testing and research(Behm & Chaouachi, 2011). Furthermore, they found that for studies involving the gastrocnemius and other plantar flexors when stretching was applied there was a decrease in torque. Notably in Fowles et al., a study involving 13 plantar flexors, there was found that after a prolonged period of stretching for 30 minutes, there was a 28% decrease in maximum torque immediately following stretching, which had lasting deficits of 9% for the following hour(Fowles et al., 2000). According to Behm and Chaouachi, there were several other studies that demonstrated sustained bouts of static stretching produced decreases in torque and performance, and that these ranged in duration of stretching from less than 90 seconds to 30 minutes(Behm et al., 2006; Behm, Button, & Butt, 2001; Behm & Chaouachi, 2011; Behm & Kibele, 2007; Cornwell, 1998; Fowles et al., 2000; Nelson, Allen, Cornwell, & Kokkonen, 2001; Nelson, Guillory, Cornwell, & Kokkonen, 2001; Power, Behm, Cahill, Carroll, & Young, 2004). In addition, Behm and Chaouachi found that typical stretching sessions for athletes would only last for a few seconds of 18 seconds at maximum, normally, and as such, acute bouts of static stretching are reasonable to produce torque decrements for selected muscles in an average population(Behm & Chaouachi, 2011). Therefore, because of the combination of these two observations, that the gastrocnemius finds its optimum length to be its maximum length, which is unlike other bi-articulate muscles, and that stretching is found to increase a muscle's ROM while its effects on power output is uncertain, we chose to combine the effects of the muscle's angle-torque relationship with stretching in an attempt to further clarify its functions. We hypothesize that an acute bout of static stretching on the gastrocnemius will decrease PF torque across selected knee and ankle joint combinations.

Methods

Participants

Seven undergraduate male students (age: 19.7 ± 0.8 years; mass: 83.7 ± 5.9 kg; height: 178.3 ± 6.0 cm) and twenty-four undergraduate female students (age: 19.8 ± 1.5 years; mass: 62.2 ± 13.3 kg; height: 161.1 ± 6.5 cm) participated in this study. Several inclusion criteria were used. The first inclusion criterion was no history of lower extremity injury or a physical abnormality. This information was obtained by questioning each potential participant during the initial visit to the laboratory. Secondly, all responses to items on the physical activity readiness quotient had to be negative(Thomas, Reading, & Shephard, 1992). When a prospective participant met these criteria, the next step was to read and sign the informed consent document approved by the University's Institutional Review Board.

Equipment

A Biodex System III Dynamometer (Biodex Medical Systems, Shirley, NY) controlled the angle of the subject's right ankle and measured the isometric PF torque (Nm). It maintained the ankle at three positions during testing: firstly at 15° PF (recorded as +15°), secondly at 0°, the anatomical position, and thirdly at 15° DF (recorded as -15°). Regular calibration checks ensured the accuracy of its measurements. Furthermore, Biodex equipment is well established in literature as a high quality research and rehabilitation platform (Drouin, Valovich-McLeod, Shultz, Gansneder, & Perrin, 2004; Landin et al., 2015; Li et al., 2002). Contraction of the gastrocnemius was induced through surface electrodes with a Grass electrical stimulation generator (model SD9B). Electrodes (2"x4") were placed across the common belly of the medial and lateral heads of the gastrocnemius. The knee joint angle was controlled with removable casts in four positions during testing: 0° (anatomical position), 30°, 60°, and 90°, with the last three measures indicating degrees of knee flexion from the anatomical position.

Procedure

Participants made two visits to the lab one week apart. One visit involved stretching (S) the other did not (NS). The order was randomly assigned for each individual, but counterbalanced. On NS days they would be seated directly into the Biodex. For S days, the subjects would perform two stretching exercises for 3 reps of 30 seconds for 2 sets of the exercises. Rest was taken in between sets and exercises but it was minimal. Total S time was 6 minutes and was done directly on the right gastrocnemius. The first exercise involved the subject standing with a wide split stance with the right leg behind them and the left in front, the right leg remained straight throughout the exercise. They would then lean with their hands against a wall or pole in front of them so as to take the right heel off the ground a little and create tension on the right gastrocnemius. At this point they would then focus on pushing that heel down to create the stretch. This is demonstrated in Figure 4. The second exercise had the subject place the right heel as near to the base of a wall or pole as possible with the toes of the right foot running up the wall. Keeping the right leg straight, they would then move their body closer to the wall while keeping the right foot in the same position to create tension in the right gastrocnemius. This is also demonstrated in Figure 4.

Figure 4. Two positions for stretching exercises performed on S days.

Next, subjects were positioned in the Biodex with the right ankle joint parallel to the rotational axis of the dynamometer (see Figure 5).

Figure 5. Biodex Systems III Dynamometer set-up and positioning for ankle and knee joints with electrical stimulation.

Electrodes were placed on the gastrocnemius across the belly of the muscle just distal to the point where the two heads merge. The amount of electrical stimulation was standardized across the subjects using the formula and procedure first devised by Li et al., and then used in subsequent work with the gastrocnemius, biceps brachii, triceps brachii, and rectus femoris(Landin, Myers, Thompson, Castle, & Porter, 2008; Landin, Thompson, & Reid, 2014; Landin et al., 2015; Li et al., 2002). The magnitude of 15 Hz train square wave stimulation with 10 ms pulse duration was gradually increased from 0 V. The voltage that produced a PF moment equal to 1.7% of body weight, multiplied by stature, and held for 5 s, was designated as the testing voltage. This formula ensured that the voltage applied, while varied for each subject, produced the same level of stimulation in each subject. Pilot testing revealed that this level of stimulation was both effective and reasonably comfortable for the subjects.

After being positioned in the Biodex, on either S or NS days, subjects would undergo a warm-up. It involved a 105° knee cast position and the subjects were electrically stimulated via surface electrodes three times for about 8 seconds in each of the three ankle joint positions. After this, the testing order was randomized for each subject in regard to the knee positions. Four knee flexion angles (0°, 30°, 60°, and 90°) and three ankle angles (-15° DF, 0°, +15° PF) created 12 joint combinations. Knee angles were maintained with removable casts, while ankle angles were controlled by the dynamometer. The Biodex would always begin with PF, then neutral, then DF for the ankle positions. At each position the right gastrocnemius was electrically stimulated, in a counterbalanced order, three times. Across all trials, the subjects were instructed to neither assist nor resist the contraction, and remain as still as possible. The maximum PF moment, the highest PF moment during stimulation, for each joint angle combination was recorded during stimulation and tabulated as a dependent measure.

Analysis

Data for the dependent measures were compiled by averaging the maximum PF moment across the three trials at each joint combination for each subject for both occasions of S and NS. JMP® Pro (version 14.0.0) was then used to analyze the data with a mixed model, within-subject ANOVA. *Post hoc* Student t's and Tukey HSD were applied as needed. The alpha level was set at 0.05.

Results

Significant main effects were found for the ankle $F(2,60) = 13.63$, $P < 0.001$ and ankle*knee interaction $F(6,180) = 7.64$, $P < 0.001$. Significant main effects were further evaluated with Student t's and Tukey HSD *post hoc* tests as needed.

Student t's *post hoc* test revealed general effects of stretching were not significant ($P = 0.874$). Values appear in Table 1.

Tukey HSD *post hoc* tests revealed significant differences between -15° DF and 0° ankle flexion in addition to -15° DF and +15° PF ($P < 0.001$ for both). No significant differences were found between other ankle angle comparisons. The greatest torque was also found at -15° DF (27.58 ± 1.27 Nm). The lowest torque was found at +15° PF (23.92 ± 1.27 Nm). Values appear in Table 2.

Student t's *post hoc* tests revealed significant differences between 0° and 90° knee flexion when the ankle was at -15° DF, and additionally between 0° and 30° knee flexion when the ankle was at +15° PF ($P = 0.002$ for both). No significant differences were found for other interactions. The greatest torque was found with the ankle at -15° DF when the knee was flexed to 90° (29.71 ± 1.51 Nm). The lowest torque was found with the ankle at +15° PF when the knee was at 0° flexion (21.88 ± 1.51 Nm). Values appear in Table 3.

Table 1. Main Effects of Stretching (Nm)

Stretch	**Mean**	**SD**
NS	25.17	1.31
S	25.35	1.31

The difference between NS and S were insignificant ($P = 0.874$). Difference between values is 0.18 Nm.

Table 2. Main Effects across Ankle Angles (Nm)

Ankle Angle (°)	Mean	SD
-15 DF	27.58*	1.27
0	24.29	1.27
+15 PF	23.92	1.27

The difference of -15° DF between 0° and +15° PF were significant (P < 0.001, for both). Difference between 0° and +15° PF was insignificant (P = 0.633). PF: plantarflexion position, DF: dorsiflexion position. *significantly different from other values (P<0.001)

Table 3. Main Effects across Knee and Ankle Combinations (Nm)

Knee Angle (°)	Ankle Angle (°)			
	-15 DF	0	+15 PF	Mean
0	25.51*	23.53	21.88*	23.64
30	27.49	24.77	26.19*	26.15
60	27.60	24.63	24.01	25.41
90	29.71*	24.21	23.57	25.83
Mean	27.58	24.29	23.91	

Significant differences were found between 30°/+15° PF and 0°/+15° PF, and between 90°/-15° DF and 0°/-15° DF (P = 0.002 for both). All other comparisons are insignificant (P > 0.05). PF: plantarflexion position, DF: dorsiflexion position. *significantly different from values with same color

Discussion

The gastrocnemius is a well-researched muscle, recognized for its ability to flex the knee and plantarflex the foot, and for being a major component of human locomotion. There are also decades of studies devoted to stretching, many investigating the gastrocnemius. For the first time, this study sought to further investigate the gastrocnemius and the effects of stretching on it while considering the effects of different knee and ankle angles. The study put forth the hypothesis that an acute bout of static stretching on the gastrocnemius will decrease PF torque across selected knee and ankle joint combinations. The principle finding was that acute, static stretching had no significant effect on the resulting PF torque of the selected knee and ankle joint combinations as a whole, neither decreasing nor increasing the torque.

This finding goes against the majority of static stretching research reviewed by Behm and Chaouachi, which found that in most studies stretching induces performance decrements and decreases in torque/force(Behm & Chaouachi, 2011). One cause for the lack of effect found could be the stretching duration applied, however, this is something still highly varied from study to study. For instance, as previously noted, Behm and Chaouachi found that for a wide variety of stretching duration, from 90 seconds to 30 minutes, there were significant decreases in force values(Behm et al., 2006, 2001; Behm & Chaouachi, 2011; Behm & Kibele, 2007; Cornwell, 1998; Fowles et al., 2000; Nelson, Allen, et al., 2001; Nelson, Guillory, et al., 2001; Power et al., 2004). In contrast, the researchers found other studies implementing a similar range of stretching durations, from 45 seconds to 8 minutes, that resulted in either no significant effects from stretching or significant increases in force values(Beedle, Rytter, Healy, & Ward, 2008; Behm et al., 2006; Behm & Chaouachi, 2011; Joel T. Cramer et al., 2007; Egan, Cramer, Massey, & Marek, 2006; González-Ravé, Machado, Navarro-Valdivielso, & Vilas-Boas, 2009; Handrakis et al., 2010; Knudson, Bennett, Corn, Leick, & Smith, 2001; Molacek, Conley, Evetovich, &

Hinnerichs, 2010; Robbins & Scheuermann, 2008; Ryan et al., 2008; Samuel, Holcomb, Guadagnoli, Rubley, & Wallmann, 2008; Torres et al., 2008; Unick, Kieffer, Cheesman, & Feeney, 2005; Winke, Jones, Berger, & Yates, 2010). Therefore, while we implemented a more moderate duration of stretching with 6 minutes which could have affected the results of the study, it is unlikely, based on previous research, that this is a clear and adequate reason for our findings.

A second explanation for the lack of effect found could be due to stretching intensity. This study didn't record or create a set intensity for stretching with subjects, instead stretching was simply done to the point of feeling a stretch, not necessarily to the point of discomfort (POD) or maximum POD. In a study by Knudson et al., they had subjects stretch to the point just before the POD, a submaximal intensity similar to this study's, then tested vertical jump height, which resulted in no significant changes(Knudson et al., 2001). In contrast, a study by Behm and Kibele had subjects stretch to 50% POD, 75% POD, and 100% POD and found that exercise performance decreased significantly across all trials as one moved towards 100% POD(Behm & Kibele, 2007). In addition, there are other studies which used submaximal intensity that offer conflicting results of either significant or insignificant changes(Beedle et al., 2008; Bradley, Olsen, & Portas, 2007; J. T. Cramer et al., 2005; Joel T Cramer et al., 2004; Hough, Ross, & Howatson, 2009; Knudson, Noffal, Bahamonde, Bauer, & Blackwell, 2004; Manoel, Harris-Love, Danoff, & Miller, 2008; Sayers, Farley, Fuller, Jubenville, & Caputo, 2008). However, for studies that stretch to maximum POD, significant decreases in performance and force are routinely found(Behm, Bambury, Cahill, & Power, 2004; Behm et al., 2006, 2001; Cornwell, Nelson, & Sidaway, 2002; Fowles et al., 2000; Nelson, Guillory, et al., 2001; Power et al., 2004). It seems then, that typically stretching to maximum POD is a definite way to result in decreases of force, whereas when the stretching intensity is submaximal, it is not as certain what will result. In regards to this study, submaximal intensity of stretching could have led to the lack of effects on the gastrocnemius since the muscle did not experience the full effect of the stretch and failed to alter the gastrocnemius' length. For instance, just as the stretch placed on a muscle undergoing normal motion isn't enough to create a change in the muscle length or activity, so would submaximal stretching result in no effect on the muscle, especially when it was done in an acute fashion and not prolonged or routine durations. In future research, it would be advised to implement both the use and recording of stretching subjects to a maximum POD in order to ensure definite effects.

A final consideration for the lack of effects in this study could result from the mechanisms involved with stretching, such as neuromuscular or mechanical mechanisms. It is still unclear how much each mechanism contributes to the overall effect of stretching. In regards to the neuromuscular effect of stretching, it is typically seen that after stretching, there is an electromechanical delay that results in decreased torque due to a slower response for a neuron to excite a muscle(Janne Avela et al., 2004). Electromechanical delay is typically defined as the time between the onset of excitation of a muscle to the onset of force produced by the muscle(Cavanagh & Komi, 1979; Conforto et al., 2006; Costa et al., 2012; Gabriel & Boucher, 1998; Hopkins, Feland, & Hunter, 2007; Vint, McLean, & Harron, 2001). It is affected by several factors such as time needed for propagation of the action potential, the duration of the excitation and contraction processes, muscle length, gender, age, fatigue of muscle and/or neuron, muscle action, training, and muscle temperature(Janne Avela et al., 2004; Cavanagh & Komi, 1979; Costa et al., 2012; Grosset, Mora, Lambertz, & Perot, 2005; Grosset, Piscione, Lambertz, & Pérot, 2009; Hopkins et al., 2007; Vint et al., 2001; Winter & Brookes, 1991; Zhou, Carey, Snow, Lawson, & Morrison, 1998). The primary effect focused on with stretching is the change in muscle length but also potential fatigue of the muscle or neuron. While decrease in torque due to electromechanical delay and an inhibited neuromuscular activity is expected after stretching because of these effects, the impairments could have been bypassed due to the use of external stimulation for this study. The external stimulation served the purpose of keeping the subjects standardized but could have also negated neuromuscular decrements due to stretching by hiding their expression because no voluntary contraction was required of subjects; hence, no impairment of neuron fatigue or delayed propagation of the action potential time would matter if the muscle was being excited from an external source. A single study by Avela et al contradicts this however, where they had subjects undergo 1 hour of repeated, prolonged stretching and then tested both voluntary and involuntary contractions (external stimulation) afterwards for the triceps surae, resulting in 16.8% reduction in torque values for involuntary contractions (Janne Avela et al., 2004). Notable differences from this study are the much higher duration and intensity of stretching applied in Avela et al, which was previously discussed, and could offer a reason as to the difference in findings.

Secondary findings were that a DF ankle (-15°) and a 90° knee produced the greatest torque (29.71 ± 1.51 Nm), while a PF ankle (+15°) and a straight knee (0°) produced the smallest torque (21.88 ± 1.51 Nm). These findings likely resulted from the significant differences between the ankle positions alone, as seen that when ankle and knee were isolated and analyzed from one another, the ankle was found to have significant main effects, where the greatest torque was during DF, while the knee did not have significant main effects. The trend is still interesting to note that torque increased as the ankle was moved linearly from PF to DF, but decreased as the knee moved from being bent (90°) to straight (0°), albeit in a non-linear fashion. These values agree with those found by Landin et al, Li et al, and Reimann et al for the ankle, but conflict with their findings for the knee, where the studies showed that torque was maximized when the ankle was DF and the knee straight(Landin et al., 2015; Li et al., 2002; Riemann et al., 2001). These results continue to affirm the gastrocnemius as a powerful plantar flexor that has its optimum length as its maximum length in regards to the ankle angle, however, the knee confounds this notion presently. When examined on its own, the knee was found to have its maximum torque at 30° flexion (26.15 ± 1.41 Nm), which is much closer to a straight leg than 90° but still a confusing finding. This could possibly be thought to have resulted from the inclusion of stretching as compared to Landin et al. and Li et al., however, these particular findings were analyzed with the stretching effects removed(Landin et al., 2015; Li et al., 2002). Furthermore, the same trends were noted for NS when analyzing stretching and knee effects alone without the ankle effects, which is when stretching wouldn't have an influence yet. It is important to note that knee values were found to be insignificant for all analyses, and may not be a meaningful finding to consider.

Conclusions

There were no significant effects of acute, static stretching on selected knee and ankle joint combinations for the gastrocnemius' PF torque. This goes against the majority of static stretching research, which typically results in decreases of torque/force(Behm & Chaouachi, 2011). This could have several explanations such as involuntary contractions, a moderate stretching duration, and the submaximal stretching intensity used in this study. Secondarily, it was shown that a DF ankle still produces the largest PF torque for the gastrocnemius and reinforces the notion that the gastrocnemius' greatest length is also its optimal length when considering the angle-torque curve, as first seen in other studies(Landin et al., 2015; Li et al., 2002; Riemann et al., 2001). However, this study differs from this same finding because of the insignificant effect of the knee angles on PF torque, whereas normally it is seen that a straight knee significantly produces the greatest torque in conjunction with a DF ankle. It is recommended for further research to implement higher intensity, such as maximal POD, into the stretching protocol and measure neural activity while using external stimulation in order to elicit significant stretching effects on the gastrocnemius to discover if its maximum length can be pushed further to produce a new optimal length for producing PF torque or reinforce static stretching literature and how it typically decreases torque production.

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