2-2020

The Effect of Static Stretching on Proprioception, Pennation Angle, and Muscle Power Production

Lacey G. Dennis

Eva Alyss Blais

Kolyse E. Wagstaff

Li Li

Duke Biber

BioCore
Exploring Scientific Community

International Journal of Biotechnology and Bioengineering

Research Article
ISSN 2475-3432

The Effect of Static Stretching on Proprioception, Pennation Angle, and Muscle Power Production

Lacey Dennis[1], Eva Blais[1], Kolyse Wagstaff[1], Li Li1, Duke D. Biber[*2], and Daniel R. Czech[1]

[1]*Georgia Southern University, Statesboro, GA 30458, Georgia*

[2]*University of West Georgia, Carrollton, GA 30118, Georgia*

Abstract

With widespread use of pre-exercise stretching methods across sport and exercise, recent studies have questioned the effectiveness of such methods (Kay & Blazevich 2012; Cramer et al., 2005; Curry, Chengkalath, Crouch, Romance, & Manns, 2009). The purpose of this study was to examine how the relationship between pennation angle, proprioception, and muscle power are influenced by a static stretching protocol. Participants (n = 17) from a southeastern university in the United States consented to participate and were divided into an experimental group (n = 12) and control group (n = 5). The experimental group engaged in static stretched by placing the right foot on an incline board and maximally dorsiflexing the ankle joint while keeping the bottom of their foot flush with the board's surface and the knee fully extended. The control group remained seated for the same amount of time and did not engage in stretching. Both groups were measured for vertical jump using the Vertec force plate, electrical activity of the gastrocnemius via the Terason ultrasound machine, and proprioception of the ankle joint via the Biodex 2 dynamometer pre- and post- stretching and control protocols. Results indicated that static stretching resulted in a decrease in muscle power without change of proprioception or electrical-mechanical delay while accompanied by an increase in pennation angle. The increase in pennation angle may the reason why static stretch resulted in a reduction in muscle power. The results are discussed in regard to previous research and future practical application.

Keywords: Static stretching, Proprioception, Power, Output

Corresponding author: **Duke D. Biber**
University of West Georgia, Carrollton, GA 30118, Georgia.
E-mail: dbiber@westg.edu

Citation: Duke D. Biber et al. (2020), The Effect of Static Stretching on Proprioception, Pennation Angle, and Muscle Power Production. Int J Biotech & Bioeng. 6:2, 37-43

Received: October 4, 2019
Accepted: October 14, 2019
Published: February 28 , 2020

The Effect of Static Stretching on Proprioception, Pennation Angle, and Muscle Power Production Stretching before athletic events has benefits for athletes prior to and following performance by improving range of motion in joints, lessening stiffness, and helping to prevent injury (Costa et al., 2012). That being said, some studies have looked at the different effects of statically stretching muscles before athletic events based on stretch types, extent, and effectiveness, yet these studies do not explain why the loss of muscle power production occurs (Cramer et al., 2005; Curry, et al., 2009; Behm, Bambury, Farrell, & Power, 2004; Kay et al., 2013; Simic, Sarabon, & Markovic, 2013). Given the potential positive effect of pre-exercise static stretching on the reduction of incidence of muscle strains, static stretching can be incorporated into a comprehensive pre-exercise warm-up routine, when maximal muscular performance is not the focus (Simic, Sarabon & Markovic, 2013). Stretching for a duration of zero to 45 seconds could be performed after activity to facilitate an increase in range of motion and flexibility, and decrease muscle soreness (Behm & Chaouachi, 2011; Kay & Blazevich, 2012; Simic, Sarabon, & Markovic, 2013)

However, static stretching is not recommended prior to activities that are high-speed, explosive or in activities where reactive forces are necessary due to the negative impact on acute power production and muscle performance (Cramer et al., 2005; Kay & Blazevich, 2012; Simic, Sarabon, & Markovic, 2013). Activities such as vertical jump, sprint, agility, and one-repetition maximum lifts can be negatively affected by static stretching through a reduction in force production, balance, sprint times, power output, peak torque, and electromyography amplitude (Behm et al., 2004; Behm & Chaouachi, 2011; Cramer et al., 2005; Curry et al., 2009). Furthermore, static stretching can decrease the musculotendinous unit stiffness for a duration of ten minutes after static stretching (Nakamura et al., 2011). The mechanism for the decrease in the musculotendinous unit stiffness and muscle stiffness has been related to changes at the musculotendinous unit proximal to the musculotendinous junction and an increase in the flexibility and movement of the aponeurosis and the connective tissue (Nakamura et al., 2011).

Many studies have examined the effect of static stretching on muscle power production based on the duration, type, and timing of stretch (Cramer et al., 2005; Curry et al., 2009; Behm et al., 2004; Kay et al., 2013; Simic, Sarabon, & Markovic, 2013). While none of the present studies justify why the muscle power production is affected by static stretching, there are many hypotheses, such as a result of a change in pennation angle, electromechanical delay (EMD), and proprioception (Behm et al., 2004; Cramer et al., 2005; Curry et al., 2009; Kay et al., 2013; Sarabon & Markovic, 2013).

For example, passive stretching changes the stiffness of the muscle-tendon unit, which is strongly related to EMD (Grosset, Piscione, Lambertz, & Pérot, 2009). EMD, or the delay between muscle stimulation and force production, may play a role in decreasing the amount of power produced by the muscle (Esposito, Lacourpaille, Hug, & Nordez, 2013). Muscle tendon unit stiffness has been found to effect EMD while muscle neural activation did not contribute to the change (Esposito, Limonta, & Ce, 2011). Results of the study showed that peak tetanic force was reduced by 31% and remained inhibited throughout the recovery time. When compared with the EMG and force delays, data shows that the peak tetanic force reduction occurred in conjunction with a lengthened EMD (Esposito, Limonta, & Ce, 2011). Research has found that EMD is affected by a variety of factors, including electrical, chemical, and mechanical mechanisms (Costa et al, 2012; Esposito et al., 2013; Limonta, & Ce, 2011). Further research into how muscle power production may be impacted by a lengthened EMD caused by passively stretching the muscle is needed. Furthermore, proprioception, or the sense of position and the sense of velocity/movement including cutaneous receptors and the vestibular and visual senses, may impact muscle power (Hillier, Immink, Thewlis, 2015). With motor control, proprioception is crucial for feedback and feedforward operations of movement that are used along with other or instead of other sensory systems. (Hillier et al., 2015; pp. 2). The degradation of proprioception requires individuals to rely solely on visual senses for feedforward and feedback processes, inhibiting movement control (Hillier et al., 2015). Previous research on proprioception has used passive and active repositioning using a Biodex 2 isokinetic dynamometer to measure proprioception (Willems et al., 2002). Bouts of stretching held to the point of discomfort can have negative effects on balance, potentially due to the stretch causing impairments on the ability to detect and react to the changes in muscle length and force, negatively impacting muscle power production (Cornwell, Nelson, & Sidaway, 2002; Hillier et al., 2015; Willems et al., 2002). Because of the negative impact of degraded proprioception on locomotion and balance, it is important to further understand the impact of static stretching on proprioception and muscle power output.

Lastly, it is suggested that muscle power production may be affected by static stretching through a change in pennation angle. Pennation angle (PA) is defined as the angle between the insertion of the muscle fascicle and the aponeurosis of the muscle (Kawakami, Ichinose, & Fukunaga, 1998; Padhiar et al., 2008). When a muscle contracts, muscle fibers shorten and PA increases (Kawakami et al., 1998; Padhiar et al., 2008). When a muscle contracts the PA increases and reduces the force-producing capabilities of the muscle as the force of the muscle fibers being exerted on the tendon is equivalent to the value of the cosine of the PA (Finni, 2006; Kawakami et al., 1998).There is a correlation between PA and muscle power production, but no research has examined how each is affected by static stretching (Edama et al., 2015; Kawakami et al., 1998).

Currently, there is a lack of research examining how static stretching effects muscle power. Specifically, the purpose of this study was to examine the impact of static stretching on PA, proprioception, EMD, and how such changed impacted muscle power output. It was hypothesized that participants would have a prolonged EMD observed after passively stretching the gastrocnemius when compared to the control group. It was also expected that the stretching of the gastrocnemius would be effective, increasing PA and range of motion by greater than three percent, resulting in a reduction in power following a static stretching protocol. Lastly, it was hypothesized that there would be observable reduced power output of the gastrocnemius, via reduced flight time when the participant jumps on the force plate

Methods

Participants

Upon University Review Board approval, participants for this study were recruited from a southeastern university in the United States. To determine if the participants were eligible to complete the study, a Physical Activity Readiness Questionnaire (Par-Q) form was completed. If the participants answered "yes" to any of the questions on the Par-Q they were excluded from participation in the study. The Par-Q form was within the informed consent that was explained and signed before the participant were able participate in the study. Additionally, present or previous injury to the legs resulting in the inability to jump or stretch using the knee, ankle, foot, gastrocnemius, or other involved areas resulted in exclusion from the study. In total, 17 participants consented to participate in the study. However, five participants could not be used in analysis because stretching protocol was not followed.

Measures

Electromyography (EMG). Delsys Trigno System Wireless EMG electrodes were placed on the lateral and medial heads of the gastrocnemius to measure the electrical activity of the gastrocnemius. To obtain the location of the lateral and medial heads of the gastrocnemius, a tape measure was used to mark the location which was 30% proximal on the connecting line between the popliteal crease and the center of the lateral and medial malleolus on each participant's right leg (Edama et al., 2015, Abellaneda et al., 1998). To ensure that the EMG was securely attached to the skin without interference, approximately a 1.5-inch circle was required to be shaved on both the lateral and medial heads of the gastrocnemius. A 1.5-inch square of very fine sandpaper was used to exfoliate the skin, and an alcohol pad was utilized to cleanse the skin of any lotions or creams, ensuring the EMG remained firmly secured to the skin throughout the testing protocol.

Vertical Jump. Participants were asked to complete a series of six jumps, both before and after going through an effective stretching protocol. A treadmill consisting of two forceplates (one in the front and one in the back) was utilized to record forces as the participant jumped. The forceplate was zeroed before and between each participant using the auto-zero feature of the forceplates. Each participant was asked to stand still on the forceplate while 2-4 seconds of a static stance was recorded. Set up next to the forceplate was a Vertec, which was used to record participant jump height. The lowest paddle on the Vertec was adjusted to the participant's maximum fingertip height when standing flat-footed on the forceplate with one arm and fingertips fully extended. This correlated to zero on the Vertec, so when the participant jumped the highest paddle which they hit was recorded as the height in inches that they jumped from the forceplate. Participants were instructed to jump with maximum effort, using only the gastrocnemius and excluding using the thigh muscles. In an effort to isolate the gastrocnemius, participants were told not to bend or use their knees when jumping, and to keep them locked. Therefore, the jump was more of a bounce off of the toes and would be much less high than a normal vertical jump maximum, since half of the leg was not being utilized. Participants could complete practice jumps one or two times, until they felt comfortable with the jumping protocol and the researchers assessed that the participant understood the jump instructions. The two types of jumps recorded for the study included single jumps and rapid jumps. The single jump was one bounce off from the toes and ended when the participant landed back on the forceplate. The rapid jump had the same instructions as the single jump, but it required the participant to immediately "bounce" back into the air after landing on the force plate for two to four more jumps, continuing to hit the Vertec on each jump until the participant felt as though he/she had reached the maximum possible jump height without using other muscle groups. The participant alternated jumping styles for a total of six jumps pre-stretch and six jumps post-stretch.

Proprioception. Passive (PAP) and active ankle proprioception (AAP) in the gastrocnemius muscle was evaluated using the Biodex 2 dynamometer and the Biodex Advantagwe Software Package (Biomedical Systems Inc., Shirley, NY). The participants were placed in a supine position with their knees bent depending on the height and length of the individual's legs. Participants were then blindfolded to avoid visual feedback. The right ankle would be correctly aligned with the axis of dynamometer in a Dorsiflexion/ Plantarflexion attachment. The neutral position for this study was 90⁰ angle of the ankle joint measured using a goniometer. The three target angle positions from the initial 90⁰ angle are 10⁰ of plantar flexion, 10⁰ of dorsiflexion and a target of the original 90⁰ angle starting from 10⁰ plantar flexion. In AAP, the movement speed was set at 45⁰/s and in PAP the velocity was set at 5⁰/s. The participant was given a stop button used to stop the movement of the attachment when the participant believed they were at the target angle and to release the machine to begin movement during PAP. Each test for these was given in a randomized order to attempt to avoid a learning effect.

Stretch Protocol. Static stretching was performed by having each participant in the experimental group place his/her foot on one of three increasing positions on an incline/slant board. The participant was required to maximally dorsiflex the ankle joint, while keeping the bottom of their foot flush with the board's surface and the knee fully extended (Cornwell, Sidaway, & Nelson, 2002). Participants were required to stretch using one of the positions on the board for 30 seconds three times, taking a break of ten seconds between stretching periods. Participants could move up or down between increasing inclines after holding a position for the 30 seconds, if needed or desired to increase or decrease the stretch of the gastrocnemius.

Stretch Effectiveness. The range of motion for each participant in the experimental group was measured both before and after static stretching. The range of motion was determined with the use of a weight bearing lunge (WBL) (Konor, 2012). The weight bearing lunge was performed in a standing position, with the heel in contact with the ground, the right knee in line with the second toe, and the great toe 10 cm away from the wall (Konor, 2012). The distance was measured with the use of a centimeter measuring strip secured to the floor. Balance was maintained by allowing contact with the wall using two fingers from each hand (Konor, 2012). Participants were asked to lunge forward, directing their knees towards the wall until there right knee touched the wall (Konor, 2012). The foot was progressed away from the wall 1 centimeter at a time if the subject was able to touch the wall at 10 centimeters (Konor, 2012). If the subject could not reach the wall at 10 cm then the subject was progressed towards the wall 1 centimeter at a time (Konor, 2012). The subject was required to be able to touch the wall with their right knee without lifting the heel from the ground (Konor, 2012). The stretch was determined to be reliable with a 1-centimeter increase in the weight bearing lunge before and after static stretching. The increase of 1 centimeter of distance between pre- and post- measurements equals 4.1 degrees of dorsiflexion range of motion (ROM) (Konor, 2012). If the static stretching after the initial 30 seconds for a total of three times was not deemed effective for the participant, the individual was required to be stretched again for another three sets of 30 seconds, and completed the measurements again until the range of motion had increased to show effectiveness of the stretching protocol.

Procedures

Following completion of the informed consent, participants were divided into either the control group or the experimental group (i.e. stretching group). Pre-test measures of muscle power, PA, and vertical jump were conducted for both groups. Both groups were evaluated on passive (PAP) and active ankle proprioception (AAP) using the Biodex 2 dynamometer and the Biodex Advantage Software Package (Biomedical Systems Inc., Shirley, NY.) Both groups of participants were measured for electrical activity of the gastrocnemius using ultrasound via the Delsys Trigno System Wireless EMG electrodes, which were placed on the lateral and medial heads of the gastrocnemius. ROM was then measured for both groups using a weight bearing lunge technique (Konnor, 2012) which is done in a standing position with the heel remaining in contact with the ground. The final baseline measure was vertical jump, involving a series of six jumps and two types of jump (i.e. single and rapid jumps) using two forceplates (one in the front and one in the back) and a Vertec, which was used to record participant jump height. Following pre-test measures, the experimental group engage in a static stretching protocol that was performed on an incline board where participants maximally dorsiflexed their ankle joint three times for 30 seconds. Participants were required to keep their knee fully extended and the heel of their foot flush with the board's surface. (Cornwell, Sidaway, & Nelson, 2002). The control group went through the measurement of PA and vertical jump on the force plate twice in order to determine reliability of PA measurements between trials, but did not engage in static stretching. Following static stretching, both the experimental and control groups conducted post-test measures of muscle power, PA, and vertical jump,.

Data Analysis

Descriptive statistics were provided for PA, proprioception, EMD, and muscle power output through means and standard deviations. Group differences in pennation angle, proprioception, EMD, and muscle power output between experimental and control groups were examined using t-tests and Cohen's d effect size. Effect sizes around .20 were considered small, around .50 were considered moderate, and .80 and greater were considered large (Hedges & Olkin, 1985).

Results

The descriptive statistics (X + SD) for the pre-stretch and post-stretch pennation angle (PA) measurements for medial and lateral triceps surae complex for the experimental and control groups can be seen in table 1. Results showed an increase in both pre-stretch lateral PA (13.61+ 2.84°) to post-stretch lateral PA (15.61+ 2.08°) and pre-stretch medial PA (13.81+ 3.20°) to post-stretch lateral PA(16.34+ 2.29°). Between pre-stretch MPP (3020.97 N +2216.23 N) and post-stretch MPP (2369.68 N +1524.47 N), a decrease in MPP was observed. The Cohen's d effect size for pre-stretch and post-stretch PA for the lateral triceps surae was 0.69, which is medium. The Cohen's d effect size for pre-stretch and post-stretch PA for the lateral triceps surae was 0.72, which is medium. The descriptive statistics (X + SD) for the weight-bearing lunge (WBL) pre-stretch, post-stretch, PA Lateral pre-stretch, PA Lateral post-stretch, PA medial pre-stretch, and PA medial post-stretch for the experimental and control groups can also be found in **table 1.**

Values of weight-bearing lunge (WBL) at pre- and post-stretch protocol between groups

Group	Participant	WBL pre-stretch	WBL post-stretch	PA Lateral Pre-stretch	PA Lateral Post-stretch	PA Medial Pre-stretch	PA Medial Post-stretch
Experimental	1	9	11	15.04	17.1	19.02	19.74
	2	9	11	10.1	15.39	11.033	14.12
	3	7	8	10.86	13.34	9.27	13.2
	4	11	12	17.4	17.7	14.83	15.38
	6	13	14	11.17	13.51	14.36	17.8
	9	6	7	14.96	18.27	15.57	16.372
	13	11	3	15.745	14.009	12.585	17.771
	Mean, SD	9.42 + 2.44°	10.86 + 2.54°	13.61+ 2.84°	15.61 + 2.08°	13.81 + 3.20°	16.34 + 2.29°
Control	10	-	-	15.48	15.47	12.679	12.98
	14	-	-	8.48	8.56	17.257	17.19
	15	-	-	12.71	12.877	14.729	15.12
	16	-	-	6.944	6.6	11.93	11.195
	17	-	-	14.308	14.56	13.59	13.85
	Mean, SD	-	-	11.58 + 3.71°	11.61 + 3.86°	14.04 + 2.08°	14.07 + 2.26°

The values of pre-stretch muscle power production and post-stretch muscle power production, including descriptive statistics (X + SD) for muscle power production for the experimental and control group participants, can be seen in table 2. There was a decrease in power in the vertical jump from pre-stretch (M = 3020.97 ± 2216.33 N) to post-stretch (M = 2369.68 ± 1524.47 N) for the experimental group.

Muscle power production of participant vertical jump heights by group

Group	Subject	Pre-stretch Single Jump Power Production (N)	Post-stretch Single Jump Power Production (N)
Experimental Group	1	2944.29	2993.15
	2	1317.44	1324.9
	3	5041.88	4520.49
	4	3225.97	2255.92
	6	877.24	650.06
	9	1006.52	862.39
	13	6733.44	3980.86
	Mean + SD	3020.97 + 2216.13	2369.68 + 1524.47
Control Group	10	1120.57	1146.95
	14	2576.43	2310.17
	15	1127.09	1285.01
	16	1845.79	2647.6
	17	500.42	520.55
	Mean + SD	1434.06 + 796.67	1582.06 + 879.05

The results for the EMD for the medial and lateral heads of the gastrocnemius for both the experimental and control groups can be seen in table 3. Means and standard deviations are also provided for each group.

EMD delay calculated for the medial and lateral heads of the gastrocnemius by group

Group	Subject	Pre-stretch medial EMD length (s)	Post-stretch medial EMD length (s)	Pre-stretch lateral EMD length (s)	Post-stretch lateral EMD length (s)
Experimental Group	1	0.114	0.176	0.048	0.177
	2	0.2675	0.1375	0.288	0.087
	3	0.1775	0.2925	0.1735	0.2825
	4	0.1165	0.2085	0.072	0.098
	6	0.4485	0.2545z	0.326	0.2535
	9	0.1045	0.196	0.258	0.2055
	13	0.268	0.044	0.2455	0.023
	Mean + SD	0.21 + 0.13	0.19 + 0.08	0.20 + 0.11	0.16 + 0.10
Control	10	0.0715	0.108	0.051	0.08
	14	0.0465	0.0535	0.035	0.029
	15	0.275	0.1765	0.1335	0.2145
	16	0.0975	0.218	0.217	0.2195
	17	0.002	0.0015	0.0435	0.047
	Mean + SD	0.10 + 0.11	0.11 + 0.09	0.10 + 0.08	0.12 + 0.09

Results for AAP and PAP is shown in Table 4. Results for the t-test were not significant ($p>0.05$). The effect size was evaluated using Cohen's d. Four of the six effect sizes are of medium magnitude and two are small Cohen, J., 1988).

Dorsiflexion, Neutral and Plantarflexion positions for PAP and AAP by group

Position	PAP/AAP	Group	Mean (⁰)	SD (⁰)	SE (⁰)	t-test	Effect size
10⁰ Dorsiflexion	**Active**	**Stretch**	**-0.25**	**2.86**	**1.08**	**0.16**	**0.41**
		Control	**-1.90**	**5.22**	**2.34**		
	Passive	**Stretch**	**0.66**	**1.93**	**0.73**	**0.20**	**0.36**
		Control	**-0.26**	**3.24**	**1.45**		
	Active	**Stretch**	**1.61**	**5.16**	**1.95**	**0.45**	**0.05**
90⁰ Neutral		**Control**	**1.87**	**4.14**	**1.85**		
	Passive	**Stretch**	**0.18**	**3.19**	**1.20**	**0.14**	**0.45**
		Control	**-1.24**	**3.07**	**1.37**		
10⁰ Plantarflexion	**Active**	**Stretch**	-2.90	7.01	2.65	**0.11**	**0.52**
		Control	**0.26**	**4.27**	**1.91**		
	Passive	**Stretch**	**-1.88**	**5.05**	**1.91**	**0.47**	**0.03**
		Control	-2.03	6.40	2.86		

Discussion

The purpose of this study was to examine the impact of static stretching on PA, proprioception, EMD, and how potential changes impacted muscle power output. Overall, results indicate that the static stretching protocol significantly reduced muscle power production without the change of proprioception, EMD, and with an increase in PA. Following examination of proprioception, EMD, and PA, analysis indicates that increased pennation angle was the contributing factor to muscle power reduction.

It was hypothesized that participants in the experimental group would have a prolonged EMD observed after statically stretching the gastrocnemius. These results are different than the hypothesis and previous research (Herda et al., 2010). Data analysis allowed for examination of both the medial and lateral sides of the muscle (see Table 3). The mean EMD post-stretching for the medial gastrocnemius in the experimental group decreased by 0.03 seconds. In the control group of participants, this post-stretching medial EMD increased by 0.01 seconds. On the lateral side, the mean EMD post-stretching for the experimental group decreased by 0.04 seconds. The control group mean post-stretching EMD on the lateral side increased 0.02 seconds. This data is opposite of the hypothesis and previous research showing that EMD lengthened after static stretching of the muscle, as the EMD for the experimental group decreased following effective static stretching of the gastrocnemius (Waugh, Korff, Fath & Blazewich, 2013, 2014).

It was also hypothesized that PA would increase following a static stretching protocol. Based on the results from the study, it can be concluded that our hypothesis was valid (see Table 1). PA measurement when compared before and after static stretching was increased on both the medial and lateral gastrocnemius (Héroux, Stubbs, & Herbert, 2016). On average the pre-stretch lateral PA was measured as 13.34 + 2.48°, with the post-stretch lateral PA was 15.21 + 2.14°. On average the pre-stretch medial PA was measured as 14.26 + 2.99°, with the post-stretch lateral PA was 16.57 + 3.06°. Table 1 shows the mean increase of 1.44 centimeter after stretching for the experimental group participants, above the necessary 1-centimeter increase required. This correlates to a joint ROM increase of 4.1 degrees, equating to an effective stretch (Konor, 2012). Previous research has not found an increase in ROM from PA following static stretching (Konrad & Tilp, 2014). The hypothesis is further confirmed through analysis of the control group PA. The trial 1 and trial 2 mean pennation angle measurements for medial and lateral triceps surae were within less than 0.1° of each other. For muscle power production pre-stretch single jump and post-stretch single jump in control subjects showed an increase in muscle power production. This increase could be due to the subjects becoming more familiar with how to jump without using their knees between the two trials. However, even though this learning curve could have been present the fact that the muscle production decreased with static stretching and increased without static stretch shows that the muscle power production was affected by the static stretching. Overall, it is well known that when a muscle is contracted the PA will increase, which will reduce the force-producing capabilities of the muscle (Kawakami, et al., 1998). This research contributes to previous research that PA may reduce muscle power output.

Lastly, it was hypothesized that there would be observable reduced power output of the gastrocnemius, showing that muscle power production was decreased via reduced flight time when the participant jumps on the force plate. When considering the decreased power production, table 2 shows the mean decrease of 651.29 N in the experimental group after stretching effectively, which is a significant decrease in power production after stretching the gastrocnemius. This is consistent with previous research indicating a reduction in vertical jump following static stretching (Fletcher & Monte-Colombo, 2010; Hough, Ross, & Howatson, 2009). In the control group, who completed a second series of jumps after a similar break time without stretching, the power production increased by an average of 148 N, demonstrating again that static stretching correlates with decreased muscle power production. Research supports a reduction in muscle power output following static stretching (Kay & Blazevich, 2012).

As with all research, there were certain limitations to this study, including the use of a 2D ultrasound rather than 3D measurement for PA. However, if there is a change in measuring PA with a 2D ultrasound then measuring PA with a 3D will demonstrate a change in PA. This limitation does not affect our results. There is also the potential of competence when using an ultrasound probe for measuring. When performing ultrasound measurement the ultrasound user has to be competent in the measuring technique with the ultrasound probe. If the user is not competent then the data could be unreliable (Ihnatsenka, 2010). In this study the user competency was verified with the use of control subjects. From the data is can been seen that the ultrasound user measured PA in two trials with the results being within less than 1° of each other. A final limitation was that participants did not follow protocol for the rapid jumps, and the data was not useable for analysis in this study.

Overall, this study showed that the decrease in muscle power production after static stretch could be due to the increase in PA. This factor could be one of many that causes a decrease in muscle power production, however results indicate that PA, when compared to EMG and proprioception, decreases muscle power production in high intensity activities. This study provides evidence for the increase in PA and reduction in muscle power output following a static stretching protocol.

References

1. Abellaneda, S., Guissard, N., & Duchateau, J. (2009). The relative lengthening of the myotendinous structures in the medial gastrocnemius during passive stretching differs among individuals. Journal of Applied Physiology, 106(1), 169-177.

2. Behm, D. G., Bambury, A., Cahill, F., & Power, K. (2004). Effect of acute static stretching on force, balance, reaction time, and movement time. Medicine & Science in Sports & Exercise, 36(8), 1397-1402.

3. Behm, D. G., & Chaouachi, A. (2011). A review of the acute effects of static and dynamic stretching on performance. European Journal of Applied Physiology, 111(11), 2633-2651. doi: 10.1007/s00421-011-1879-2

4. Cornwell, A., Sidaway, B., Nelson, A. (2002). Acute effects of stretching on the neuromechanical properties of the tricep surae complex. European Journal of Applied Physiology.86 (5), 428-434.

5. Costa, P. B., Ryan, E. D., Herda, T. J., Walter, A. A., Hoge, K. M., & Cramer, J. T. (2012). Acute effects of passive stretching on the electromechanical delay and evoked twitch properties: A gender comparison. Journal of Applied Biomechanics, 28, 645-654. doi:10.1007/s00421-009-1214-3

6. Cramer, J. T., Housh, T. J., Weir, J. P., Johnson, G. O., Coburn, J. W., & Beck, T. W. (2005). The acute effects of static stretching on peak torque, mean power output, electromyography, and mechanomyography. European Journal of Applied Physiology, 93(5-6), 530-539.

7. Curry, B. S., Chengkalath, D., Crouch, G. J., Romance, M., & Manns, P. J. (2009). Acute effects of dynamic stretching, static stretching, and light aerobic activity on muscular performance in women. Journal of Strength and Conditioning Research, 6, 1811.

8. Edama, M., Onishi, H., Kumaki, K., Kageyama, I., Watanabe, H., & Nashimoto, S. (2015). Effective and selective stretching of the medial

head of the gastrocnemius. Scandinavian Journal of Medicine & Science in Sports, 25(2), 242-250. doi:10.1111/sms.12203

9. Esposito, F., Limonta, E., & Ce, E. (2011). Passive stretching effects on electromechanical delay and time course of recovery in human skeletal muscle: New insights from an electromyographic and mechanomyographic combined approach. European Journal of Applied Physiology, 111, 485-495. doi:10.1007/s00421-010-1659-4

10.Finni, T. (2006). Structural and functional features of human muscle–tendon unit. Scandinavian Journal of Medicine & Science in Sports, 16(3), 147-158.

11.Fletcher, I. M., & Monte-Colombo, M. M. (2010). An investigation into the possible physiological mechanisms associated with changes in performance related to acute responses to different preactivity stretch modalities. Applied physiology, nutrition, and metabolism, 35(1), 27-34.

12. Grosset, J. F., Piscione, J., Lambertz, D., & Pérot, C. (2009). Paired changes in electromechanical delay and musculo-tendinous stiffness after endurance or plyometric training. European Journal of Applied Physiology, 105(1), 131.

13. Herda, T. J., Ryan, E. D., Costa, P. B., Walter, A. A., Hoge, K. M., Uribe, B. P., ... & Cramer, J. T. (2010). 4 Acute effects of passive stretching and vibration on the electromechanical delay and musculotendinous stiffness of the plantar flexors. Electromyography & Clinical Neurophysiology, 50(6), 277.

14. Héroux, M. E., Stubbs, P. W., & Herbert, R. D. (2016). Behavior of human gastrocnemius muscle fascicles during ramped submaximal isometric contractions. Physiological Reports, 4(17), 1-10.

15. Hough, P. A., Ross, E. Z., & Howatson, G. (2009). Effects of dynamic and static stretching on vertical jump performance and electromyographic activity. The Journal of Strength & Conditioning Research, 23(2), 507-512.

16. Ihnatsenka, B., Boezaart, A.P. (2012). Ultrasound: basic understanding and learning the language. International Journal of Shoulder Surgery. 4(3), 55-62.

17. Kay, A. D., & Blazevich, A. J. (2012). Effect of acute static stretch on maximal muscle performance: A systematic review. Medicine & Science in Sports & Exercise, 44(1), 154-164.

18. Kawakami, Y., Ichinose, Y., & Fukunaga, T. (1998). Architectural and functional features of human triceps surae muscles during contraction. Journal of Applied Physiology, 85(2), 398-404.\

19. Konor, M. M., Morton, S., Eckerson, J. M., & Grindstaff, T. L. (2012). Reliability of three measures of ankle dorsiflexion range of motion. International Journal of Sports Physical Therapy, 7(3), 279-287.

20. Konrad, A., & Tilp, M. (2014). Increased range of motion after static stretching is not due to changes in muscle and tendon structures. Clinical Biomechanics, 29(6), 636-642.

21. Nakamura, M., Ikezoe, T., Takeno, Y., & Ichihashi, N. (2011). Acute and prolonged effect of static stretching on the passive stiffness of the human gastrocnemius muscle tendon unit in vivo. Journal of Orthopaedic Research: Official Publication of the Orthopaedic Research Society, 29(11), 1759-1763. doi:10.1002/jor.21445

22. Padhiar, N., Al-Sayeagh, H., Chan, O., King, J., & Maffulli, N. (2008). Pennation angle of the soleus in patients with unilateral Achilles tendinopathy. Disability & Rehabilitation, 30(20-22), 1640-1645.

23.Simic, L., Sarabon, N., & Markovic, G. (2013). Does pre-exercise static stretching inhibit maximal muscular performance? A meta-analytical review. Scandinavian Journal of Medicine & Science in Sports, 23(2), 131-148.

24. Waugh, C. M., Korff, T., Fath, F., & Blazevich, A. J. (2013). Rapid force production in children and adults: Mechanical and neural contributions. Medicine & Science in Sports & Exercise, 45(4), 762-771.

25. Waugh, C. M., Korff, T., Fath, F., & Blazevich, A. J. (2014). Effects of resistance training on tendon mechanical properties and rapid force production in prepubertal children. Journal of Applied Physiology, 117(3), 257-266.

Citation: Duke D. Biber et al. (2020), The Effect of Static Stretching on Proprioception, Pennation Angle, and Muscle Power Production. Int J Biotech & Bioeng. 6:2, 37-43