Physiological Effects of Static Stretching on Muscle Force Output

Riley Aicher, Rachel Greenberg, Grace Holzem, Sam Palmer, Morgan Pooler, Regan Truttschel

University of Wisconsin-Madison, Department of Physiology

Physiology 435

Lab 601, Group 7

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Word Count: 4109

Abstract

Static stretching is a common part of modern pre-exercise warm-up routines, usually as a method to reduce cramping and prevent injury. Static stretching involves the sustained stretching of a muscle, and by extension its muscle fibers and their sarcomeres, for a set period of time. This has the effect of temporarily increasing the muscle's length. In this study, we explored the possibility that static stretching would affect muscular activity via the length-tension relationship. Thirty participants were instructed to clench a hand dynamometer while their maximum clench force, electromyography, and blood pressure (before and after the clench) were recorded. Participants first performed the maximum clench test without stretching beforehand, and then, after a waiting period of 7 minutes, they performed the clench force test again after static stretching. It was hypothesized that if static stretching was performed prior to muscle exertion, a change in the three physiological variables could be detected in reference to the participant's baseline trial. A paired two-tailed T-Test was used to determine whether there was a statistically significant difference between the pre- and post-static stretching conditions for each of the three physiological variables tested where $p<0.05$ was significant. The maximum clench force data and the change in systolic blood pressure data were both found to vary significantly between pre-stretching and post-stretching trials. The electromyography data did not show a significant difference between the pre- and post-stretching conditions. Based on these results, the null hypothesis can be accepted for the electromyography data, while the null hypothesis cannot be accepted for the clench force and the change in blood pressure. This research along with future studies can be utilized to further understand the effects of static stretching on muscle activity and performance.

Introduction

There is ongoing controversy regarding the effects of various types of stretching, particularly over which has the most advantageous, or perhaps the least detrimental, effects on muscle strength and power output. Stretching is most commonly done prior to exercise performance as a way to reduce stiffness and increase range of movement. By using stretching as a warm-up, an individual may additionally increase their performance by increasing body core temperature, faster action potential transmission, and metabolic activity (Kendall, 2017). The three main types of stretching, including static, dynamic, and pre-contraction, all have been shown to increase flexibility and muscle extensibility (Page, 2012), yet the effectiveness varies across age groups, activity levels, and muscle groups. Dynamic stretching involves moving the limb from its neutral position to the end of its range of motion, and moving the limb back to its original position. Dynamic stretches are done in a smooth, controlled manner and are repeated several times (Murphy 1994). This is in contrast to static stretching, wherein the target muscle is placed at its greatest possible length before pain is experienced and held in this position for a defined amount of time (Anderson 1991).

Skeletal muscles are made up of muscle fibers, which are organized into functional units called sarcomeres, which are themselves made up of thick and thin filaments (Cooper 2000). Thick filaments are made up of myosin, and thin filaments are made up of actin. The filaments are bound by cross-bridges protruding from the thick filaments, which contain specialized sites with high affinity for binding to the actin of the thin filaments (Widmaier 2008). When muscles contract, the cross-bridges are activated in order to allow binding to actin. In binding, thick filaments generate a force on the thin filaments, leading to the sliding filament mechanism, wherein the thick filaments pull on the thin filaments, causing a sliding motion as the sarcomere shortens (Cooper 2000).

Stretching is thought to decrease muscle strength by lengthening the fibers that make up the muscles, that is, increasing the length between the origin and insertion of the muscle (Page 2012). Different muscles of the body have different optimal lengths to deliver the greatest torque, or rotational force, as described by McHugh & Nesse (2008). Linearly, muscles tend to exhibit a length-tension relationship, where tension decreases as length increases, decreasing the ability of the muscle to perform explosive contractions (Herda *et al.,* 2008). This relationship is especially fragile in shorter muscle. Stretching, therefore, can decrease muscle force by increasing the muscle length, subsequently decreasing the tension and the ability to create a force upon contraction.

Static stretching provides the most benefits for athletes who require more flexibility, such as gymnasts or dancers, where dynamic stretching provides the most direct benefits to athletes who engage in running or jumping, such as basketball players (Page, 2012). It has been demonstrated that static stretching in particular has negative effects of varying significance on muscle strength and force output across numerous muscle groups (Simic, 2013; Kay 2012). Additionally, a literature review done by researchers Blazevich and Kay reported that there were significant reductions in handgrip strength after static stretching (2012). For this reason, static stretching has increasingly fallen out of favor as a warm-up for athletic activity. In light of the ongoing uncertainty around static stretching, it is critical to establish the practice's detrimental effects, if any exist.

The three physiological variables measured in this study were clench force, electrical muscle activity, and systolic blood pressure. Clench force can be an important indicator of overall health and fitness levels, and dynamometers are often used to measure force accurately and precisely (Poitras 2011). Static stretching also led to a decrease in electromyography (EMG) data pre- to post- stretching (Cramer *et al.,* 2004). It is expected that clench force as a measure of muscle strength will decrease, along with the electromyography measurement due to decreased sensitivity of muscle spindles to activation from the central nervous system (Ye, 2016). In a study performed by Kruse *et al,* mean arterial pressure decreased after moderate-intensity stretching, so it is expected that systolic blood pressure readings will decrease following static stretching (2016). Additionally, McNeil *et al.* found that a muscle actively participating in maximum voluntary contraction experiences decreased blood flow due to occlusion of local arteries (2015). This would be indicative of decreased systolic blood pressure immediately post-exertion and leads to the reasonable prediction that if strength of contraction is diminished after static stretching, systolic blood pressure would decrease less when stretching is done prior to exertion than if no stretching is performed.

We hypothesized that static stretching prior to muscle exertion will cause a decrease in the maximal force applied to a hand dynamometer relative to the baseline force. In order to quantify the effects of static stretching on muscle strength, data regarding clench force, systolic blood pressure, and muscle activity (EMG) of the primary muscles involved in clenching will be recorded and analyzed. Recording maximum clench force output, maximum electrical muscle activity, and change in systolic blood pressure could potentially lead to more knowledge and resolution to the controversy regarding the effects of static stretching.

Materials

Electrical muscle activity, systolic blood pressure and clench force were the three physiological variables tested in this experiment. EMG activity was tested using electromyogram electrode leads (Model: SS2LB, SN: 1006B0928, Biopac Systems, Inc. Goleta CA) and Biopac Disposable Electrodes (Biopac Systems, Inc. Goleta CA) with Electrode Gel (Signa Gel 250g tube Ref # 15-25). Maximum EMG value in millivolts (mV) during the clench pulse with the maximum clench force was used as a proxy for overall EMG activity. Systolic blood pressure was measured using an Omron 10 Series+ Blood Pressure Monitor (Model: BP791IT, Omron Healthcare Co, Ltd. Lake Forest, IL). Clench force was tested using a hand dynamometer (Model: SS25LA, SN: 1501004240, Biopac Systems, Inc. Goleta CA), with maximum clench data in Newtons used as a measure of clench force. Biopac Student Lab System (BSL 4 software, MP36) was used to record and analyze the quantitative data, along with the Biopac Systems, Inc. Student Manual (Biopac Systems Inc. ISO 9001:2008).

Methods

Screening and Consent

Participants were gathered from the University of Wisconsin's Physiology 435 course in the Spring of 2018 and given a consent form with detailed information about their potential role in the experiment, followed by a survey to gather lifestyle information before measurements were taken. The survey consisted of questions to screen for pre-existing health concerns to ensure the safety of all participants involved in the study. Survey questions included age, the type of exercise each participant regularly engaged in and how often they engaged in physical activity. Participants who signed the consent form and successfully passed the health screening were allowed to continue with the experiment.

Baseline Trial

The dominant arm of each participant was cleaned with an alcohol swab and allowed to dry. Three electrodes with electrode gel were placed on the inside of the forearm- one slightly distal to the elbow on the radial side, one roughly two inches above the wrist on the radial side, and one roughly one inch from the wrist on the ulnar side of the forearm, and attached to the white, black, and red EMG leads respectively. The leads were then inserted into the Biopac MP36 Data Acquisition Unit**.**

The blood pressure cuff was placed snugly on the bicep of the dominant arm in order to measure the blood pressure in the arm producing the muscle strength output. Participants were seated and asked to keep their feet flat on the floor and their arm relaxed on the table as the preliminary blood pressure reading was taken. Immediately following the reading, the cuff was removed and the participant was asked to hold the dynamometer in their dominant hand with their forearm facing up, so that the thumb wrapped around the shorter end of the device. They were then asked to squeeze the device using their full strength five times for a duration of two seconds each squeeze, with a two second pause in between. Data regarding the EMG activity and clench force was recorded by the Biopac System, Inc. software during the duration of the five clenches on the hand dynamometer. Immediately following the final squeeze, participants were asked to place dynamometer on the table. The blood pressure cuff was applied on the dominant arm so that blood pressure could be measured again, making sure the participant's feet were flat on the floor and arm rested on the table. This data served as a baseline for each participant. A stopwatch was then started for seven minutes, during which the participant was instructed to rest.

Experimental Trial

At the end of the resting period, participants were asked to perform static stretching on their dominant forearm and bicep. Participants completed three sets of wrist extension stretches. With their dominant arm held out in front of them they were asked to use their non-dominant hand to pull back the fingers of their dominant hand so that the palm faces away from the body, holding for 10 seconds for each set. Participants then completed three sets of wrist flexion stretches, performed like the wrist extension stretch described above, but the non-dominant hand pulls the fingers down, holding for 10 seconds each set. They then performed a bicep wall stretch. The hand of their dominant arm is placed flat against a wall at shoulder height with the arm parallel to the floor. The body is pivoted away from the arm until slight tension in the bicep could be felt. These stretches were chosen to target the wrist flexor muscles which include the flexor pollicis longus and the flexor digitorum profundus. These are the primary muscles used for clenching (Tops & De Jong, 2006)**.** Again, this stretch was held for ten seconds repeating three sets. Once the stretching was completed, blood pressure was taken again as described before, and the participant was asked to clench the dynamometer five times for a duration of two seconds each squeeze, with a two second pause in between. Upon completion of the dynamometer reading, blood pressure was taken for a final time. The maximum clench force, maximum EMG peak, and systolic blood pressure were recorded from each reading.

Data Analysis

Clench force was recorded for each participant during the series of clenches on the hand dynamometer and was analyzed to find the maximum force applied in Newtons in both the pre- and post-static stretching conditions. Participants were prohibited from seeing the computer screen to try and alleviate effects of competition. The absolute change in clench force was then calculated for each participant. The absolute change in clench force after static stretching was also calculated for all participants.

Similarly, for each participant the maximum EMG value in millivolts was recorded for each series of clenches in both pre- and post-static stretching. The absolute change in maximum EMG was calculated for each participant, and the absolute change in maximum EMG was also calculated for the entire sample.

Blood pressure was measured both before and after the clench test in order to calculate the change in systolic blood pressure after muscle exertion. This was done in both the baseline and experimental trials for each participant. The change in systolic blood pressure post-stretching was then subtracted from the change in systolic blood pressure pre-stretching in order to determine how static stretching affected the way that systolic blood pressure changed after exertion for each participant.

Positive Control

A change in maximum clench force and maximum EMG due to static stretching were detected by Biopac Systems, Inc. devices as seen in Figures 1 and 2, and a change in blood pressure was also detected using the Omron 10 Series+ Blood Pressure Monitor. Table 1 displays the data as the experiment was performed on a group member. These changes are evident as the maximum clench force and maximum EMG values both decreased after static stretching was performed prior to muscle exertion. In both cases, a change in systolic blood pressure was also detected after muscle exertion.

Measurement	**Without Stretching**	**With Stretching**
Maximum Clench Force (N)	52.52	36.61
Maximum EMG (mV)	1.84	1.59
Initial Blood Pressure	116/76	107/76
Final Blood Pressure	113/75	107/71

Table 1. Positive Control data demonstrating a measurable effect of static stretching on clench force, maximum EMG, and blood pressure.

Negative Control

Negative control data were collected from one of the group members. The maximum clench force and maximum EMG were detected by Biopac Systems, Inc. devices, and systolic blood pressure was also detected using the Omron 10 Series+ Blood Pressure Monitor. The participant followed the aforementioned experimental methods, but instead of repeating the experiment with stretching, the participant did not stretch. This test, in which the participant did not stretch before repeating the experiment, presented results similar to the baseline data that were recorded. These results demonstrated that the baseline measurements recorded for every participant served as a suitable standard of comparison between experimental conditions.

Another control trial was performed to determine a suitable rest period that would minimize the effect of fatigue. When the participant waited 5 minutes between trials, the data demonstrated significant influence from fatigue. In a repeated trial, this effect was no longer seen when the resting period was increased to 7 minutes as seen in Table 2.

Measurement	Without Stretching (Trial 1)	Without Stretching (Trial 2)
Maximum Clench Force (N)	42.76	49.79
Maximum EMG (mV)	1.92	2.27
Initial Blood Pressure	109/68	110/70
Final Blood Pressure	105/71	108/69

Table 2. Negative Control data demonstrating no effect due to fatigue, indicating that 7 minutes is a sufficient rest period.

Results

Subject Characteristics

A total of 30 participants underwent testing, and results from all 30 participants were used in this study. The population consisted of 19 females and 11 males ranging in age from 20 to 25 years old. All of the participants were enrolled in Physiology 435 at the University of Wisconsin-Madison at the time of testing. Prior to their participation, test subjects were asked to read and sign a consent form, which outlined the details and informed them of any benefits and/or risks of the study.

Survey Results

Prior to completion of the experiment, participants filled out a short survey that asked about a range of information regarding their physical activity and stretching patterns. Participants were asked how many hours per week they exercise, how they would rank their general physical activity (on a scale of 1-5), how often they stretch, their age, and if they had any pre-existing medical conditions that would interfere with the short-duration clench testing.

All participants reported on the survey that they did not have any pre-existing medical conditions that would affect their short-duration clench testing. On average, 53.3% of participants reported that they exercised around 3-4 hours per week, whereas 13.3% reported that they exercised around 10+ hours per week. On a scale of 1-5, with 1 being the lowest general physical activity level and 5 being the highest, 46.7% of participants ranked themselves as being a 3 for physical activity level. Additionally, 30% of participants ranked themselves as being a 4 for physical activity level. When asked about the amount of stretching that participants do, 53.5% reported that they stretch once every few days, whereas 26.7% reported that they stretch once a week and 13.3% reported that they stretch daily (Figure 4).

Physiological Results

A paired two-tailed T-Test with significance level of 0.05 was used to determine whether there was a statistically significant difference between the pre- and post-static stretching conditions for each of the three physiological variables measured.

Maximum clench force was found to vary significantly between pre-stretching and post-stretching trials (p-value: 0.02). The mean maximum clench force without static stretching was 229.61±98.33 N. After static stretching, the mean maximum clench force decreased to 217.93±97.00 N (Figure 5). From pre-stretching to post-stretching trials, participant demonstrated a mean decrease of 11.68 Newtons. Out of the total number of participants, 70% showed a decrease in maximum clench force after static stretching whereas 30% showed an increase in maximum clench force (Figure 6).

Systolic blood pressure change was also found to vary significantly between pre- and post-stretching trials (p-value: 0.03). The results showed that prior to static stretching, the mean change in systolic blood pressure was -3.73±8.30 mmHg. After participants completed static stretching, the mean change in systolic blood pressure was 1.4±9.64 mmHg (Figure 7).

EMG failed to demonstrate a significant variation between the pre- and post-stretching conditions (p-value: 0.36). The mean maximum EMG pre-static stretching was 2.08±0.71 mV and the mean maximum EMG post-static stretching was 2.17±0.86 mV (Figure 8). The EMG results showed no consistent pattern with 57% of participants displaying a decrease in EMG activity after static stretching and 43% presenting an increase in EMG activity after stretching.

Discussion

Despite an abundance of research on the topic of static stretching and exercise, the relationship between static stretching and muscle activity remains an open question. Some recent studies have suggested that static stretching may correlate with decreased muscle force output, reduced decrease in blood pressure and reduced EMG activity.

Our finding of statistically significant differences in muscle force generation and systolic blood pressure change for pre- and post-stretching conditions suggests that there is an inverse relationship between static stretching and muscle force, and a direct relationship between static stretching and change in blood pressure. Systolic blood pressure generally decreased after the clench test prior to static stretching while there was an increase in systolic blood pressure seen after the clench test when static stretching was performed.

The lack of a demonstrably significant difference between EMG activity for pre- and post-stretching conditions suggests that there may not be a relationship between muscle electrical activity and static stretching. While there is limited evidence to suggest that static stretching is related to a decrease in EMG activity (Cramer *et al.,*2005), this experimental evidence comes not only from leg extensors, a much larger muscle group, but from an experiment that involved stretching for a much longer period of time of multiple minutes. It is possible that the effect

Cramer *et al.* describes is not observed in our study because our experimental conditions were inherently smaller and thus were not able to expose the level of granularity in the data that Cramer *et al.* was able to generate. In a study done by Hough *et. al*, results showed that even though a decrease in EMG activity after static stretching was not significant, which is similar to this experiment, the observed decrease could be potentially attributed to neurological impairment, resulting in decreased muscle activation (2009). Various factors that could cause a decrease in muscle activation include the Golgi tendon reflex, the mechanoreceptor, and the nociceptive pain feedback responses (Hough *et. al,* 2009), although none of these measurements were performed in this experiment. Given the existence of several studies that show results contrary to our own data, we cannot draw any definitive conclusions and can only suggest that further research is needed to elucidate the relationship between static stretching and EMG activity, if one exists.

There are several factors that could have influenced the likelihood of a decrease in maximum clench force, which was observed in this experiment. It has been found that competition can improve muscular performance through both psychological and physiological changes (Cooke *et al*., 2011). Despite the fact that participants were not shown results, many participants expressed a desire to improve their maximum clench force during the second post-stretching trial. This could have led to increased effort by the participant and thus an inaccurate representation of their true maximum clench abilities. It is possible that if this variable had been controlled, a more pronounced difference between pre- and post-stretching trial groups may have been observed.

As was self-reported, participants ranged from very active to sedentary, possibly introducing confounding effects due to differences in lifestyle and physical ability. Participants also self-reported their stretching routine, with some claiming to stretch daily, and others reporting never stretching. This could influence a participant's susceptibility to the effects of stretching in the experiment. Previous muscle fatigue from recent workouts or other muscularly repetitive tasks could have also affected the results of the clench force data. Fatigue has been found to affect muscle performance through both physical and neuronal means, suggesting that previous fatigue could have had confounding effects on the participants ability to produce a maximum muscular performance during the clench force test (Enoka and Stuart 1992). Finally, although data were collected about activity level, exercise frequency, and stretching frequency, the small number of participants indicates that any sub-groups would have been extremely small. Therefore, efforts to subdivide participants in order to control for physiological variables ran the relatively large risk of giving skewed or unreliable data.

In future studies, self-report data on caffeine consumption and physical activity within 24 hours of the study should be taken in order to control for the effects of stimulants on the physiological variables being tested. For example, it is possible that variable caffeine intake among participants may have confounded blood pressure measurements; Hartley *et al*. concluded that caffeine intake could significantly increase systolic blood pressure in both healthy and hypertensive individuals (2000). Questions regarding a participant's overall feelings of fatigue or tiredness could be added to the survey in order to get an overall sense of performance. It may be beneficial to include a post-study survey, including questions asking whether participants felt more fatigued during the second clench, as time to recovery may be different among individuals with different physical activity levels. In order to see more drastic effects, the muscle force generation and EMG data can be tested from larger muscle groups, such as the quadriceps.

Upon finding a significant decrease in muscle force generation after static stretching, the results have a variety of implications for athletes looking to maximize athletic performance. It may be advisable for athletes to refrain from static stretching prior to activities that require large force outputs, as this has the potential to decrease performance.

Conclusion

Based on these results, the null hypothesis of no relationship between static stretching and the experimental variable can be accepted for electromyography, while the null hypothesis cannot be accepted for clench force and the change in systolic blood pressure. Statistical analysis shows that after static stretching, the maximum clench force generally decreased while the systolic blood pressure increased, both to a statistically significant degree. There were no significant trends in the EMG data that supported the hypothesis. In conclusion, this study along with further research can be utilized to better understand the relationship between static stretching and muscle activity and performance.

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References

Anderson B.A., Burke E.R. (1991). Scientific, Medical, and Practical Aspects of Stretching. *Clinics in Sports Medicine*. 10:63–86.

Cooke A, Kavussanu M, McIntyre D, Ring C. Effects of competition on endurance performance and the underlying psychological and physiological mechanisms. *Biol Psychol*. 2011;86(3):370-378. doi:10.1016/j.biopsycho.2011.01.009

Cooper G. Actin, Myosin, and Cell Movement. In: *The Cell: A Molecular Approach*. ; 2000:1-7.

Cramer JT, Housh TJ, Weir JP, Johnson GO, Coburn JW, Beck TW. The acute effects of static stretching on peak torque, mean power output, electromyography, and mechanomyography. *Eur J Appl Physiol*. 2005;93(5-6):530-539. doi:10.1007/s00421004-1199-x

Enoka RM, Stuart DG. Neurobiology of muscle fatigue. *J Appl Physiol*. 1992;72(5):1631-1648. doi:0161-7567/92

Hartley TR, Sung BH, Pincomb G a, Whitsett TL, Wilson MF, Lovallo WR. Hypertension risk status and effect of caffeine on blood pressure. *Hypertension*. 2000;36(1):137-141. doi:10.1161/01.HYP.36.1.137

Herda TJ, Cramer JT, Ryan ED, Mchugh MP, Stout JR. Acute effects of static versus dynamic stretching on isometric peak torque, electromyography, and mechanomyography of the biceps femoris muscle. *J Strength Cond Res*. 2008;22(3):809-817. doi:10.1519/JSC.0b013e31816a82ec

Hough, P., Howatson, G., Ross, E. (2009). Effects of Dynamic and Static Stretching on Vertical Jump Performance and Electromyographic Activity. *Journal of strength and conditioning research / National Strength & Conditioning Association*. 23. 507-12. 10.1519/JSC.0b013e31818cc65d.

Kay AD, Blazevich AJ. Effect of acute static stretch on maximal muscle performance: A systematic review. *Med Sci Sports Exerc*. 2012;44(1):154-164. doi:10.1249/MSS.0b013e318225cb27

Kendall, B. J. (2017). The Acute Effects of Static Stretching Compared to Dynamic Stretching with and without an Active Warm up on Anaerobic Performance. *International Journal of Exercise Science*, *10*(1), 53–61.

Kruse NT, Silette CR, Scheuermann BW. Influence of passive stretch on muscle blood flow, oxygenation and central cardiovascular responses in healthy young males. *Am J Physiol -*

Hear Circ Physiol. 2016;310(9):H1210-H1221. doi:10.1152/ajpheart.00732.2015

McHugh MP, Nesse M. Effect of stretching on strength loss and pain after eccentric exercise. *Med Sci Sports Exerc*. 2008;40(3):566-573. doi:10.1249/MSS.0b013e31815d2f8c

McNeil, C. J., Allen, M. D., Olympico, E., Shoemaker, J. K., & Rice, C. L. (2015). Blood flow and muscle oxygenation during low, moderate, and maximal sustained isometric contractions. *American Journal of Physiology - Regulatory, Integrative and Comparative Physiology*, *309*(5), R475–R481.

Murphy D.R. (1994). Dynamic Range of Motion Training: An Alternative to Static Stretching. *Chiropractic Sports Medicine*. 8:59–66.

Page, P. (2012). Current Concepts In Muscle Stretching For Exercise And Rehabilitation. *International Journal of Sports Physical Therapy*, *7*(1), 109–119.

Poitras, C. (2011). Grip Strength Is Good Indicator of Overall Health. *UConn Today.*

Simic L, Sarabon N, Markovic G. Does pre-exercise static stretching inhibit maximal muscular performance? A meta-analytical review. *Scand J Med Sci Sport*. 2013;23(2):131-148. doi:10.1111/j.1600-0838.2012.01444.x

Tops M, De Jong R. Posing for success: Clenching a fist facilitates approach. *Psychon Bull Rev*. 2006;13(2):229-234. doi:10.3758/BF03193835.

Widmaier, E. P., Raff, H., Strang, K. T., & Vander, A. J. (2008). *Vander's human physiology: The mechanisms of body function*. Boston: McGraw-Hill Higher Education.

Ye X, Beck TW, Wages NP. Influence of prolonged static stretching on motor unit firing properties. *Muscle and Nerve*. 2016;53(5):808-817. doi:10.1002/mus.24913

Appendix

Figures 1-2: Proof that instruments used were sufficient for desired measurements

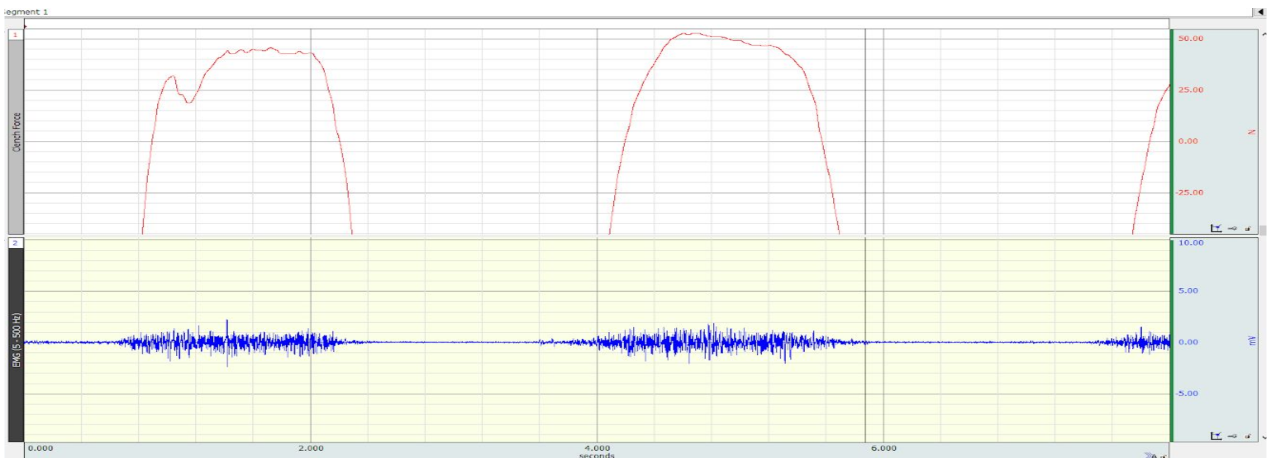

Figure 1. Max Clench force (top) and EMG data (bottom) of person pre-stretch

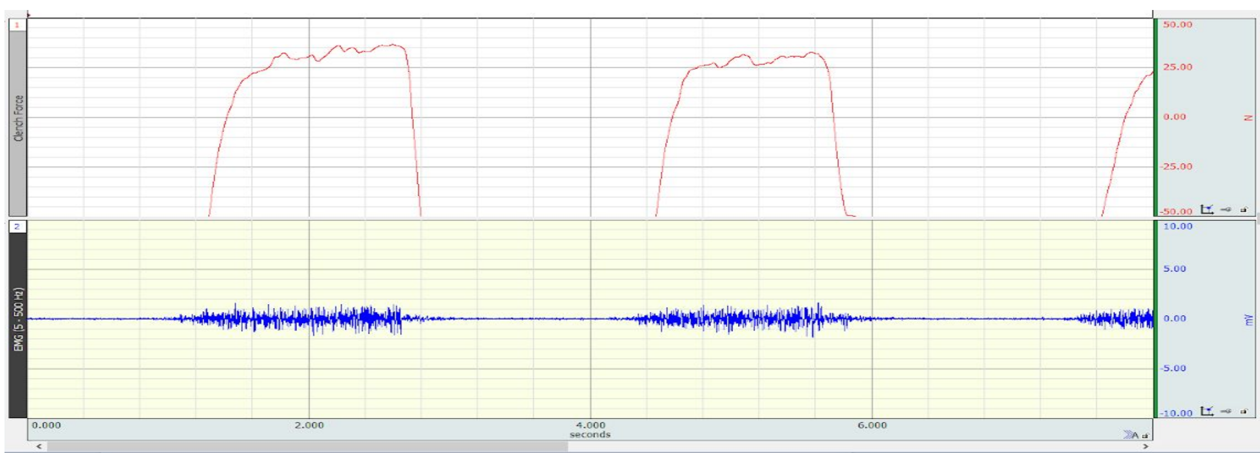

Figure 2. Max Clench force (top) and EMG data (bottom) of person post-stretch

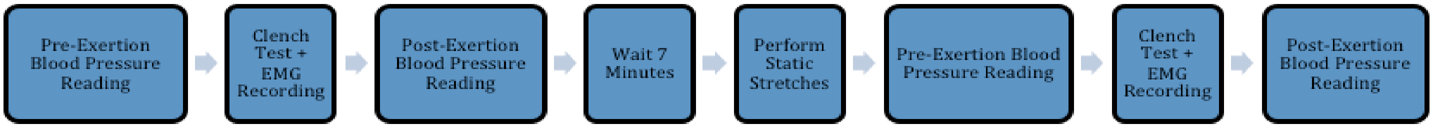

Figure 3. Baseline measurements for each participant were recorded by completing an initial blood pressure reading, followed by five successive maximum strength clenches on the hand dynamometer using the dominant hand in order to collect maximum clench force and EMG data, and another blood pressure reading post-exertion was taken immediately after the clench test. After waiting 7 minutes, the participant performed static stretching on their dominant arm. A pre-exertion blood pressure reading was taken before performing a second clench test which was again followed by a post-exertion blood pressure reading.

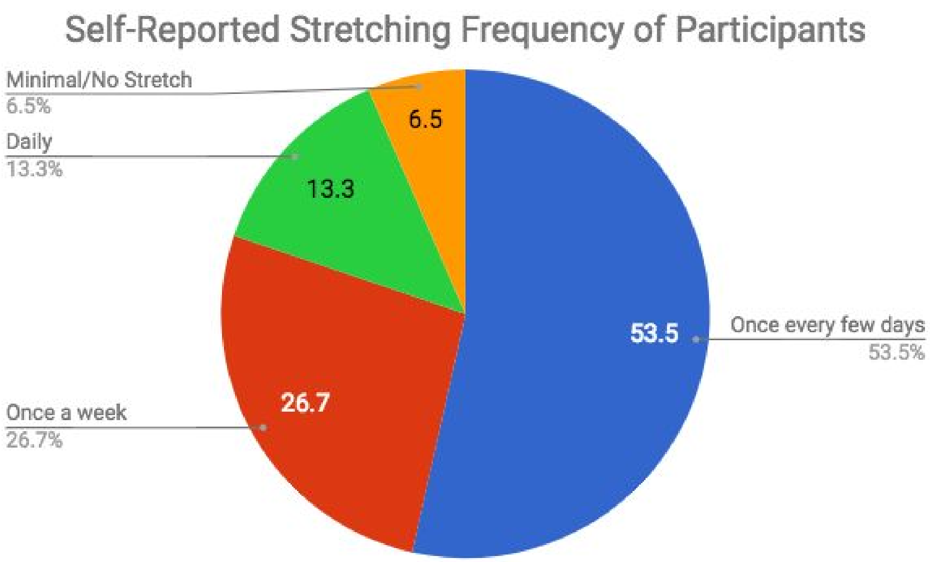

Figure 4. Participants self-reported how frequently they perform stretching (n=30).

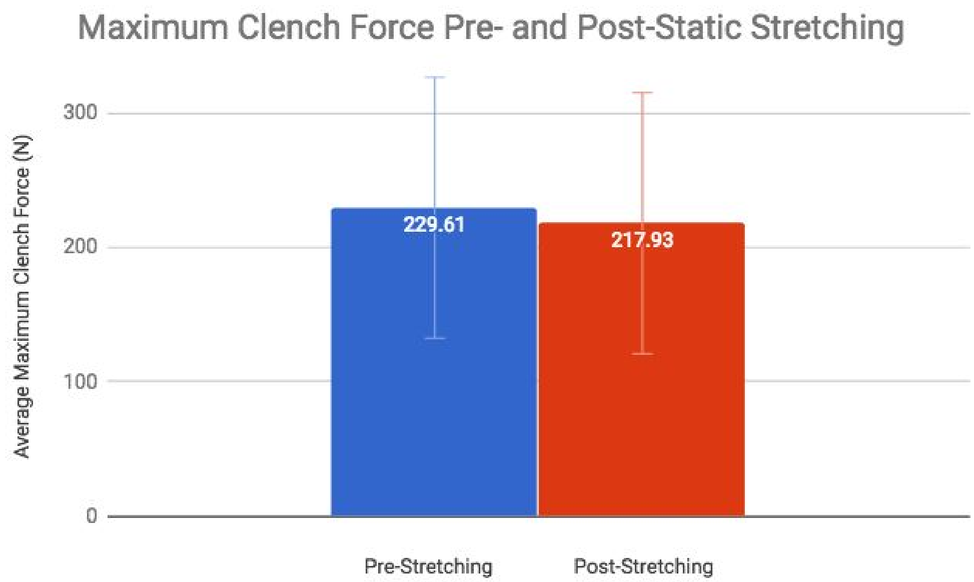

Figure 5. A decrease in the mean maximum clench force was seen between the pre- and post- static stretching conditions. This difference was found to be statistically significant ($p<0.05$).

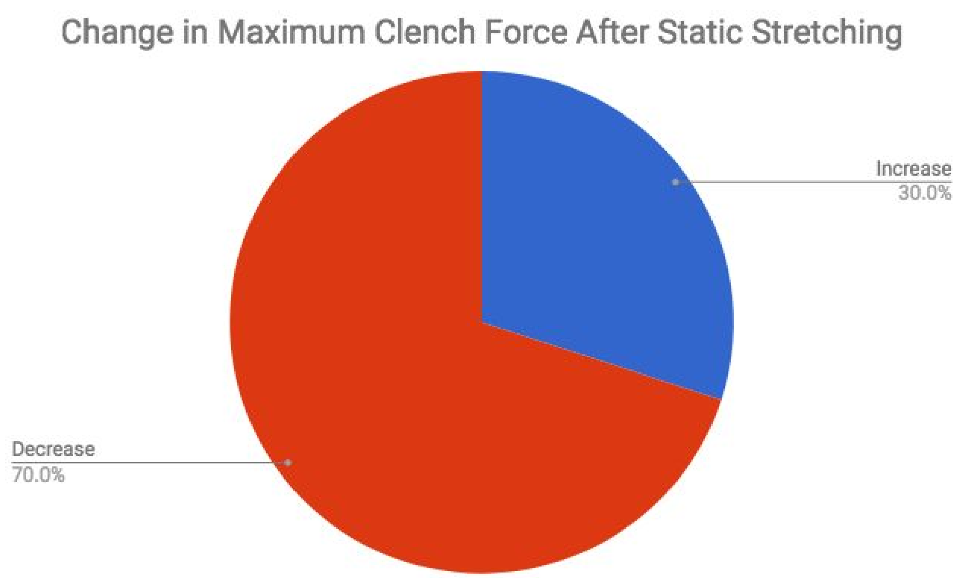

Figure 6. Percentage of participants who showed either a decrease in maximum clench force or an increase in maximum clench force. The majority of participants showed a decrease in maximum clench force after static stretching.

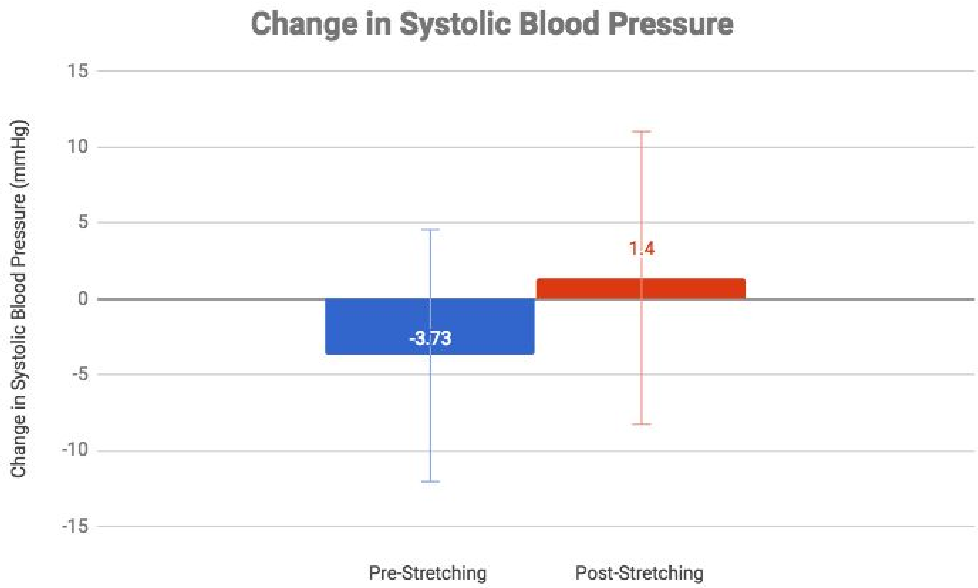

Figure 7. The pre-static stretching condition showed a mean decrease in systolic blood pressure after performing the clench test. The post-stretching condition showed a mean increase in systolic blood pressure. The difference between the two trials was found to be statistically significant (p<0.05).

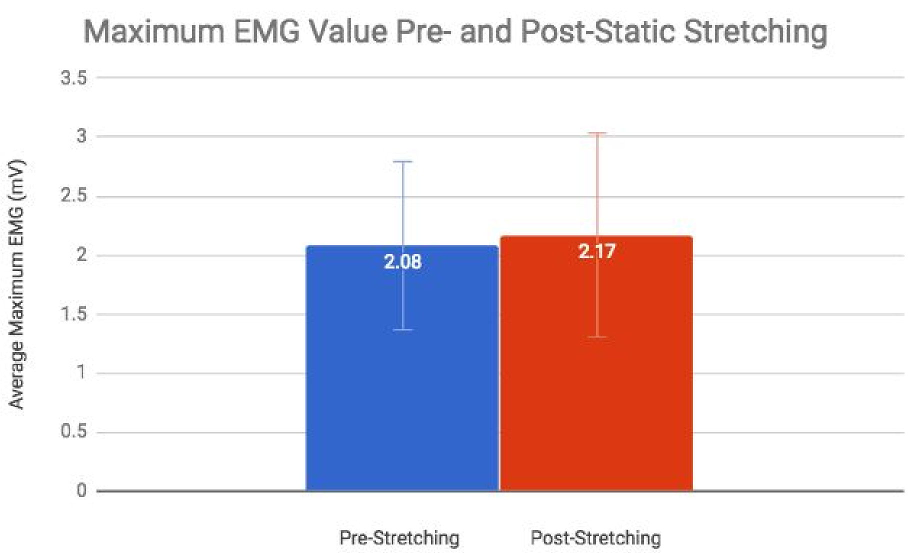

Figure 8. A slight increase in mean maximum EMG activity was observed in the post-static stretching condition compared to the pre-stretching condition. This difference was not statistically significant (p>0.05).