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Acute response of a lower extremity mobility routine on AROM, sprint time, and vertical jump height in flexible and nonflexible adults.

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Abstract

Although previous studies have shown that stretching can increase range of motion and affect performance, the comparison of the effects on flexible and nonflexible adults is not clear. Therefore, the purpose of this study was to determine how flexible and nonflexible adults responded to a lower extremity mobility routine focusing on the hip and ankle joints. A randomized treatment experimental design was used in which subjects had their hip and ankle ranges of motion, lower body flexibility, countermovement vertical jump, and sprint performance assessed. They were then randomly assigned to one of two treatment orders for hip (n=9) or ankle (n=6) stretching before the same measurement outcomes were assessed again immediately after completing the treatment. The second treatment was completed at least 2 days later. The percent change of pretest to posttest range of motion, flexibility, and performance measurements were not significantly different between flexible and nonflexible adults after both a hip and an ankle stretching/mobility session.

Keywords: mobility; dynamic stretch; static stretch; myofascial release; flexibility; sprint; vertical jump; ROM

Introduction

Muscle tightness and limited joint range of motion are not ideal when training or competing in sports; therefore, it is a common practice to stretch and warm-up prior to exercising. Most warmups typically begin with exercises that warm the core body temperature before conducting static stretching to elongate the muscles and increase range of motion; this is usually followed by dynamic movements that mimic the event being performed (3,10,19). Research has examined multiple different types of stretching techniques on range of motion, flexibility, and performance outcomes. Static stretching has been shown to have contrasting results on performance outcomes; while it seems to increase range of motion in joints, it may also decrease strength and power performance (13,19). The dose-response relationship for static stretching shows that holding a stretch for shorter durations (e.g., less than 45 seconds) has less negative impact on performance outcomes while holding a stretch for longer durations (e.g., greater than 45 seconds) is more likely to impair strength and power output (2,11).

Dynamic stretching is typically defined as motions that move the joints through a full range of motion repeatedly (14); when used during a warm-up, the movements often mimic the sport or event that is going to be performed. Multiple studies have shown that dynamic stretching, unlike static stretching, does not impair strength and power performance, and may improve those outputs along with increasing range of motion (6,14). Hough et al., found that dynamic stretching significantly improved a concentric vertical jump compared to static stretching which reduced performance of that movement (10). Cetin et.al., studied the effects of a dynamic warm-up on sprint time, vertical jump, and agility performance; when paired with specific hip mobility exercises, dynamic stretching increased sprint performance but had no effect on vertical jump height (9). In a study by Kruse et. al., the dose-response relationship

showed that 1 and 5 minutes after dynamic stretching occurred, countermovement vertical jump performance improved compared to static stretching and no stretching in a study conducted with NCAA Division I collegiate volleyball players (13).

Self-myofascial release, in which muscles are rolled over a foam cylinder to release tension in the fascia, has quickly grown in favor among the recreationally active population (14,15). Although the timeframe for how long the effects last has not been reported, studies show evidence of self-myofascial release improving range of motion (14). Smith et. al., examined the combination of dynamic stretching and foam rolling on vertical jump performance; vertical jump height improved significantly after the combination session which lasted for 15 minutes after the stretching treatment (14). They also conducted a separate study on foam rolling combined with static stretching on the range of motion in dorsiflexion; combining foam rolling with static stretching did not further increase ankle range of motion when compared to a static stretching only group and a foam rolling only group (15). Konrad et al., completed a systematic review and meta-analysis focused on the combination of foam rolling and stretching on range of motion and performance outcomes (11). This study recommended foam rolling prior to stretching over stretching only even though the combination of static stretching with foam rolling did not show any greater benefits in joint range of motion (11). The combination of dynamic stretching with foam rolling showed improvements in vertical jump height (11).

Previous research has examined the effects of different stretching techniques on movements such as jumping and sprinting, but there has not been much research on how varying levels of flexibility play a role in the response to stretching prior to exercise performance. The purpose of this study was to determine how college students who regularly exercise respond to an acute bout of stretching based on their initial level of flexibility. The goal was to see if those

with tighter joints would show greater improvements in active range of motion, flexibility, vertical jump performance, and sprint time after a stretching/mobility session than those with looser joints.

Materials and Methods

Subjects:

Fifteen college students (10 female and 5 male) who regularly exercised completed this study (mean ± SD; age, 20.60 ± 1.64 years; height, 175.93 ± 9.38 cm; and body mass, 77.93 ± 13.86 kg found in Table 1). Regular exercise was defined as subjects performing moderate intensity exercise for 30 minutes a day at least 3 days per week for the last 3 months (1). The physically active population being studied included student varsity athletes, club athletes, runners, gym-goers, etc. All subjects were asked to refrain from exercising the day of and the day prior to each study session. Before their first session, subjects filled out an informed consent, COVID informed consent, PAR-Q+, and demographic questionnaire. The University of Lynchburg Institutional Review Board for Human Subjects Research approved this study; the approval number for this study was LHS2122061.

Procedures:

A total of two testing sessions per subject were used to complete the study. Age, sex, and typical mode of exercise were self-reported and recorded. Height was recorded in centimeters using a stadiometer (Seca 213 Portable Stadiometers, Chino, California, USA) and weight was recorded in kilograms using an electric scale (Tanita BWB-800AS, Arlington Heights, IL, USA) at the beginning of the first session. Following the demographic data collection, each subject then had both ankle and hip active ranges of motion assessed using a 12-inch plastic goniometer (Model 12-1000, Baseline Fabrication Enterprises, White Plains, NY, USA) (see Appendix A).

Ankle plantarflexion and dorsiflexion, as well as hip flexion and extension were assessed. Subjects then had their lower body flexibility tested using modified sit and reach box (Acuflex I Flexibility Tester, Novel Products, USA) and a weight-bearing lunge test (see Appendix A). The final pretest measurements were vertical jump performance using a vertical tester (Vertec, JUMPUSA.com, Sunnyvale, CA, USA) and a 30-meter sprint timed using a touchpad timing system (Brower TCi Timing System, Brower, Utah, USA). After the pretests were completed, subjects were randomized into treatment order, with treatment A focusing on hip mobility and stretching and treatment B focusing on ankle mobility and stretching. Whichever treatment subjects were assigned first was completed during session 1, with the other treatment completed during session 2. Both treatments started with 5-minutes of a self-foam rolling session, using a 36-in foam roller (AMFit, Vancouver, WA, USA) on the specific joint and its surrounding muscles. Subjects then completed a series of exercises that were completed under the direction of the student researcher. Demonstrations and feedback were provided if movements and exercises were unknown to the subjects. After each mobility/stretching session, subjects' active ranges of motion were retested along with lower body flexibility, vertical jump height, and 30-meter sprint time. At the end of session 1, subjects were scheduled for their second session which took place at least two days after the first. During the second session, subjects completed treatment of the other joint with the same procedures used in session 1, starting with the pretreatment range of motion measurements.

Ankle Plantarflexion

Subjects removed their socks and shoes before sitting on a padded table with their legs extended straight in front of them and their feet hanging off the edge. Measurements using the goniometer were taken with the axis placed at the lateral malleolus. The stationary arm was

aligned with the fibular head and the moving arm aligned with the 5th metatarsal, following it as the foot moved. The subject pushed their foot down as far as it would go, as if they were pressing on the gas pedal in their car. As the subject's ankle reached its limit for range of motion, the goniometer was removed from the limb and the angle was recorded (Appendix A). This measurement was completed on both ankles for each subject.

Ankle Dorsiflexion

With their socks and shoes removed, subjects sat on a padded table with their legs extended straight in front of them and their feet hanging off the edge. The goniometer was placed in the same position as during plantarflexion, but the subject pulled their toes back toward their body as far as possible. As the subject's ankle reached its limit for range of motion, the goniometer was removed from the limb and the angle was recorded (Appendix A). This measurement was completed on both ankles for each subject.

Hip Flexion

Subjects lay down in the supine position on the padded table with their legs fully extended. The greater trochanter of the femur was palpated so the axis of the goniometer was placed at the hip joint. The stationary arm was aligned with the midline of the pelvis and the moving arm was aligned with the femur, toward the lateral epicondyle of the knee. The subject lifted the leg being measured off the table with their knee flexed as much as possible and raised it up as far as possible without lifting the other hip off the table. The moving arm followed along the femur until the hip reached its limit for range of motion, at which point the goniometer was removed and the angle degree was recorded (Appendix A).

Hip Extension

The subjects lay in the prone position on the padded table with their legs fully extended. The goniometer was placed in the same position as when hip flexion was tested, but the subject moved their leg up toward the ceiling, away from their body. Subjects kept their other hip on the table and held the lifted position for approximately 2 seconds so an accurate measurement could be taken. Once the hip's limit for range of motion was reached, the goniometer was removed, and the angle was recorded (Appendix A).

Sit-and-Reach

To test hamstring and lower trunk flexibility, the sit-and-reach test was performed using the sit-and-reach box which was placed against a wall to prevent it from moving away from the subjects during the test. The subjects removed their socks and shoes before sitting on the floor with their feet slightly apart and pressed flat against the sit-and-reach box. The subject's leg extension status was monitored throughout the test to ensure it was maintained for an accurate reading. The subjects extended their arms with their palms facing down and one hand on top of the other, to ensure both arms were at the same length during the test. They then bent forward and moved their hands along the top of the box where the measuring scale was placed. The subject held their farthest position for 2 seconds before relaxing; the distance the subject was able to push the measurement marker was noted and the test repeated twice more per subject before the highest measurement was recorded (Appendix A).

Weight-Bearing Lunge Test

Subjects removed their socks and shoes before facing a designated wall. They aligned one of their feet directly beside a tape measure extended outward from the wall. The subjects then lunged forward on the foot being tested until their knee touched the wall while their heel

remained in alignment over their toes; their position was monitored to ensure their lunging foot did not invert, causing the knee to internally rotate (4). The subjects continued moving the foot being tested further back until they could no longer maintain contact with their knee against the wall and keep their heel on the floor (4). The distance from the tip of the big toe to the wall was measured and recorded in centimeters (4). The other foot was then tested.

Vertical Jump Performance

Performance was tested using the VERTEC vertical tester. The movement tested was a countermovement jump where the subjects performed a quarter squat and then used their arms to propel themselves up during the test. A demonstration was made prior to each subject's first attempt. Subjects' reaches were measured prior to conducting the jump test; the subjects reached with their dominant hand as high as they could with their backs straight through the VERTEC device. The subjects then stood underneath the device and performed the countermovement jump. They were told to gently tap the vanes they could reach during their jump to avoid swatting at them. The subjects attempted the jump as many times as they could reach and touch new vanes; once the subject failed to move any additional vanes, the test was completed, and the height reached was recorded.

30-Meter Sprint

Subjects performed this sprint test indoors. The timing system used a handheld remote device and photogates to record sprint time. The subjects repeated this test twice with a 60-90 second break and their fastest time was recorded.

Hip Mobility Exercises.

Stretch	Description	Repetitions
90/90 Hip Flexor Stretch	The subject sat on the floor with their right leg in front of them and bent at a 90° angle. Their other leg was at their side with the knee also bent at a 90° angle. Once the subject was in position, they leaned slightly forward to where they felt a stretch before rotating both hips, one internally and the other externally, while keeping their feet in contact with the floor. The final position looked the same as the starting position, but with the opposite leg in front.	10x10 seconds each side
Frog Stretch	The subject got on their hands and knees on a mat. They turned their feet out to the side and pushed their butt down and back. They then began moving their knees further apart while continuing to push their butt down until they felt a deep stretch in their hips. The timer was then started.	2x30 seconds
World's Greatest Stretch	The subject started in a planking position on their hands and feet. The subject brought one of their feet directly beside the hand of the same side so they were in a deep lunge position. The other leg remained straightened. They then released the hand on the same side as the lunging foot to touch their elbow to the floor before raising it above their head while twisting their torso toward their lunging leg. They then sat back on their opposite leg while straightening the lunging leg in order to feel a stretch in their hamstring. They then returned to the starting position and completed the movement on the other side.	x 10 each side
Banded Hamstring Stretch	The subject sat on a mat and placed a provided resistance band around their back before wrapping the other end around the foot of the leg being stretched. They then lied back with the non-banded leg extended on the floor and the stretching leg raised in the air. The subject then pulled the band toward them and flexed their toes to increase the stretch. The timer was started. After 30 seconds, the subject brought their banded leg's knee toward their chest and kicked it back up into the original position 10 times. They then performed this stretch on the other leg.	2x30 seconds with 10 kicks each leg

Banded Hip Stretch	Starting in the same position as the previous stretch, the subject then moved their leg across their body while keeping their shoulders on the ground. The timer was started and after 30 seconds, the subject bent their stretching leg's knee and brought it toward their body before kicking it back out 10 times. They then performed this stretch on the other leg.	2x30 seconds with 10 kicks each leg
Backward Lunges	The subject began by standing straight with their feet shoulder width apart. They then stepped back with one leg into a lunge and reached back with their arms over their heads. The subject then stood back up and repeated the movement on the other side.	x 10 each side
Butterfly	The subject began sitting on the floor with their knees bent and the soles of their feet touching. The subject then pressed down on one knee with their hand while leaning back on their other hand. This position was held for 10 seconds before the subject switched sides.	10x10 seconds
Pigeon Stretch	The subject sat on a mat with one knee bent at a 90° angle and the other leg extended behind them. They then pulled their chest up and kept their back straight. Their shoulders and chest faced forward toward the bent leg. This position was held for 10 seconds before the subject switched their legs.	10x10 seconds

Ankle Mobility Exercises.

Stretch	Description	Repetitions
Ankle Pumps	The subject sat on the edge of a padded table with their legs off the side. They moved their foot in an up and down motion as fully as possible to obtain their full range of the dorsiflexion and plantarflexion motions.	x 10 each side
Ankle Circles	The subject sat on the edge of a padded table with their legs off the side. They moved their ankle in a clockwise motion, making sure to move it as completely as possible. After this movement was completed 10 times on each foot,	x 10 each side

	they moved their ankle in a counterclockwise motion 10 times.	
Heel Drops on step	Standing on a step with their heels off of the edge, subjects lowered their heels as far as they could toward the floor before raising them back up to the starting position.	10x10 second hold at bottom
Ankle Flexions w/Band	The subject sat on the edge of a padded table with their legs off of the side. With a provided band wrapped around the anterior side of one of the subject's feet, the researcher held the other end of the band in their hands. The subject then pulled their toes back toward their body as far as they could. The researcher then moved the band to be wrapped around the posterior side of one of the subject's feet. The subject held the other end of the band and pushed their toes away from their body as far as they could.	x 10 each ankle
Forward Lunge	The subject started standing with their feet shoulder width apart. They then stepped forward with one of their feet into a lunge position with their knee over their ankle and passing the toes.	10x10 seconds
Plantarflexion Stretch	The subject stood facing a wall with their feet shoulder width apart. Using the wall for support, they brought one leg back and pressed the top of their foot into the ground.	10x10 seconds
Calf Stretch	The subject stood facing a wall with their feet shoulder width apart. Using the wall for support, the subject pressed the toes of one of their feet into the wall with their heel pressed into the floor.	10x10 seconds
Scoops	The subject stood with their feet shoulder width apart. They then moved on foot forward and pressed their heel into the ground with their toes pointed up. The subject then bent at the hips and brushed their arms from behind them to in front of them before standing back up.	x 10 each side
Squat with Overhead Reach	The subject stood with their feet slightly wider than shoulder width apart and their toes pointed forward or slightly out to the side. They hinged at the hips and grabbed their feet before lowering their hips into a squat position. Subjects were told to get as low as possible while keeping their heels on the ground. They then raised each arm	x 10

	one at a time before standing back up and repeating the movement.	

Statistical Analyses

Post-hoc, subjects were divided into either a flexible or non-flexible group, based on a median split from their range of motion and flexibility scores. Data analyses were performed using IBM SPSS Statistics for Windows, version 28.0 (Armonk, NY: IBM Corp.). A paired samples t-test comparing pretest measurements across the two visits was run to determine the equality between groups for the pretest measurements. These measurements included all ranges of motion tested (ankle plantarflexion, ankle dorsiflexion, hip flexion, hip extension), flexibility test scores (sit-and-reach and weight-bearing lunge), and performance outcomes (countermovement vertical jump displacement and 30-meter sprint time). Two dependent paired-sample t-tests were run to determine if there were any significant differences from pre to post outcomes after the hip treatment and ankle treatment. Ankle plantarflexion, ankle dorsiflexion, hip flexion, and hip extension ranges of motion were combined and labeled as cumulative ROM for use in the following test. An independent t-test was run to determine if there were any significant differences in the percent change of the measurement outcomes (hip & ankle ranges of motion, sit-and-reach scores, weight-bearing lunge test scores, vertical jump displacement, and 30-meter sprint time) between the flexible and nonflexible groups after both ankle and hip stretching. This analysis determined if there was a significant difference in the percent change of measurements before and after treatment between the flexible and nonflexible groups. The level of significance for all tests was set at 0.05, *a priori*.

Results

Subject Demographics

There were 10 female and 5 male college students who completed this study. Their ages ranged from 18-23 years, their heights ranged from 159.50-191.50 cm, and their body masses ranged from 63.50 to 107.70 kg (Table 1).

Pretest Measurement Condition Equality

There was a significant difference between the pre-test measurements across visits for right hip flexion ($t(14) = 2.81$, $p < 0.05$). Right hip flexion (mean ± SD) was significantly higher during the ankle pretest session (115.73 ± 7.44 degrees) than the hip pretest session (109.07 ± 9.35 degrees) (Table 2). There was no significant difference between the pretest measurements across visits for left hip flexion ($t(14) = 1.30$, $p > 0.05$). There were also no significant differences between the pretest measurements across visits for any of the other variables tested (Table 2).

Range of Motion Pre vs Post Treatment

Right Hip Flexion**:** During the hip visit, there was a significant difference from pretest to posttest ($t(14) = -2.51$, $p < 0.05$). The pretest right hip flexion range of motion (mean ± SD) was 109.07 ± 9.35 degrees, and the posttest range of motion was 114.93 ± 6.41 degrees (Table 3). During the ankle visit, there was no significant difference from pretest to posttest ($t(14) = 0.05$, $p > 0.05$). The pretest right hip flexion range of motion (mean ± SD) was 115.73 ± 7.44 degrees, and the posttest range of motion was 115.67 ± 8.93 degrees (Table 4).

Left Hip Flexion**:** During the hip visit, there was significant difference from pretest to posttest ($t(14) = -2.44$, $p < 0.05$). The pretest left hip flexion range of motion (mean ± SD) was 113.60 ± 9.34 degrees and the posttest range of motion was 118.27 ± 7.25 degrees (Table 3). During the

ankle visit, there was no significant difference from pretest to posttest ($t(14) = -0.12$, $p > 0.05$). The pretest left hip flexion range of motion (mean ± SD) was 116.53 ± 6.50 degrees and the posttest range of motion was 116.73 ± 6.51 degrees (Table 4).

Right Hip Extension: During the hip visit, there was no significant difference from pretest to posttest ($t(14) = -0.30$, $p > 0.05$). The pretest right hip extension range of motion (mean ± SD) was 22.47 ± 11.65 degrees, and the posttest range of motion was 22.87 ± 9.97 degrees (Table 3). During the ankle visit, there was no significant difference from pretest to posttest ($t(14) = 1.92$, $p > 0.05$). The pretest right hip extension range of motion (mean ± SD) was 20.40 ± 8.33 degrees, and the posttest range of motion was 17.47 ± 8.85 degrees (Table 4).

Left Hip Extension**:** During the ankle visit, there was no significant difference from pretest to posttest ($t(14) = -0.34$, $p > 0.05$). The pretest left hip extension range of motion (mean ± SD) was 18.47 ± 9.15 degrees and the posttest range of motion was 19.07 ± 7.81 degrees (Table 3). During the ankle visit, there was a significant difference from pretest to posttest ($t(14) = -0.12$, $p < 0.05$). The pretest left hip extension range of motion (mean ± SD) was 20.33 ± 9.11 degrees and the posttest range of motion was 16.13 ± 5.78 degrees (Table 4).

Right Ankle Plantarflexion**:** During the hip visit, there was a significant difference from pretest to posttest ($t(14) = -2.25$, $p < 0.05$). The pretest right ankle plantar flexion range of motion (mean ± SD) was 66.93 ± 10.46 degrees, and the posttest range of motion was 69.53 ± 10.35 degrees (Table 3). During the ankle visit, there was no significant difference from pretest to posttest ($t(14)= -0.50$, $p > 0.05$). The pretest right ankle plantar flexion range of motion (mean ± SD) was 67.33 ± 10.59 degrees, and the posttest range of motion was 67.87 ± 11.10 degrees (Table 4).

Left Ankle Plantarflexion**:** During the hip visit, there was a significant difference from pretest to posttest ($t(14) = -2.22$, $p < 0.05$). The pretest left ankle plantarflexion range of motion (mean ±

SD) was 67.67 ± 10.92 degrees and the posttest range of motion was 69.93 ± 10.34 degrees (Table 3). During the ankle visit, there was no significant difference from pretest to posttest ($t(14) = 0.73$, $p > 0.05$). The pretest left ankle plantar flexion range of motion (mean ± SD) was 69.53 ± 10.62 degrees and the posttest range of motion was 68.73 ± 9.86 degrees (Table 4).

Right Ankle Dorsiflexion: During the hip visit, there was not a significant difference from pretest to posttest ($t(14) = -0.96$, $p > 0.05$). The pretest right ankle dorsiflexion range of motion (mean ± SD) was 5.80 ± 4.28 degrees, and the posttest range of motion was 7.00 ± 4.42 degrees (Table 3). During the ankle visit, there was no significant difference from pretest to posttest ($t(14) = -1.07$, $p > 0.05$). The pretest right ankle dorsiflexion range of motion (mean ± SD) was 5.07 ± 4.35 degrees, and the posttest range of motion was 6.20 ± 4.69 degrees (Table 4).

Left Ankle Dorsiflexion: During the hip visit, there was not a significant difference from pretest to posttest ($t(14) = -1.15$, $p > 0.05$). The pretest left ankle dorsiflexion range of motion (mean ± SD) was 2.67 ± 13.71 degrees and the posttest range of motion was 6.33 ± 5.27 degrees (Table 3). During the ankle visit, there was no significant difference from pretest to posttest ($t(14) = 0.27$, $p > 0.05$). The pretest left ankle dorsiflexion range of motion (mean ± SD) was 6.47 ± 3.16 degrees and the posttest range of motion was 6.27 ± 4.03 degrees (Table 4).

Cumulative Joint Ranges of Motion: During the hip visit, there was a significant difference from pretest to posttest ($t(14) = 3.83$, $p < 0.05$). The pretest cumulative joint score (mean ± SD) was 406.67 ± 46.43 degrees, and the posttest score was 427.93 ± 34.10 degrees (Table 3). During the ankle visit, there was no significant difference between the pretest and posttest ($t(14) = 1.45$, $p > 0.05$). The pretest cumulative joint score (mean ± SD) was 421.40 ± 37.72 degrees, and the posttest score was 415.07 ± 33.01 degrees (Table 4).

Weight-Bearing Lunge Test Pre vs Post Treatment

Right Lunge: During the hip visit, there was no significant difference from pretest to posttest for the right foot weight-bearing lunge test scores ($t(14) = -0.99$, $p > 0.05$). The pretest right foot lunge score (mean ± SD) was 12.97 ± 4.14 cm, and the posttest score was 13.42 ± 4.00 cm (Table 5). During the ankle visit, there was a significant difference from pretest to posttest for the right foot weight-bearing lunge test scores ($t(14) = -2.88$, $p < 0.05$). The pretest right foot lunge score (mean ± SD) was 12.84 ± 3.87 cm, and the posttest score was 13.77 ± 4.13 cm (Table 5).

Left Lunge: During the hip visit, there was no significant difference from pretest to posttest for the left foot weight-bearing lunge test scores ($t(14) = -0.69$, $p > 0.05$). The pretest left foot lunge score (mean ± SD) was 12.75 ± 4.22 cm and the posttest score was 12.99 ± 4.44 cm (Table 5). During the ankle visit, there was no significant difference from pretest to posttest for the left foot weight-bearing lunge test scores ($t(14) = -1.10$, $p > 0.05$). The pretest left foot lunge score (mean ± SD) was 12.61 ± 4.02 cm and the posttest score was 13.09 ± 3.40 cm (Table 5).

Cumulative Lunge: During the hip visit, there was no significant difference from pretest to posttest for the cumulative weight-bearing lunge test scores ($t(14) = -1.05$, $p > 0.05$). The pretest cumulative lunge score (mean ± SD) was 25.72 ± 8.29 cm, and the posttest score was 26.41 ± 8.26 cm (Table 5). During the ankle visit, there was a significant difference from pretest to posttest for the cumulative weight-bearing lunge test scores ($t(14) = -2.35$, $p < 0.05$). The pretest cumulative lunge score (mean ± SD) was 25.45 ± 7.72 cm, and the posttest score was 26.85 ± 7.47 cm (Table 5).

Sit-and-Reach Pre vs Post Treatment

During the hip visit, there was a significant difference from pretest to posttest ($t(14) = -4.59$, $p < 0.05$). The pretest sit-and-reach score (mean ± SD) was 24.43 ± 8.19 cm, and the posttest

sit-and-reach score was 27.47 ± 8.29 cm (Table 6). During the ankle visit, there was also a significant difference from pretest to posttest ($t(14) = -3.56$, $p < 0.05$). The pretest sit-and-reach score (mean ± SD) was 25.97 ± 8.89 cm, and the posttest score was 27.90 ± 8.26 cm (Table 6).

Vertical Jump Performance Pre vs Post Treatment

During the hip visit, there was no significant difference in vertical jump performance from pretest to posttest ($t(14) = -0.64$, $p > 0.05$). The pretest vertical jump displacement (mean ± SD) was 51.16 ± 12.27 cm, and the posttest displacement was 51.41 ± 12.63 cm (Table 7). During the ankle visit, there was no significant difference in vertical jump performance from pretest to posttest ($t(14) = -0.94$, $p > 0.05$). The pretest vertical jump displacement (mean ± SD) was 51.60 ± 11.19 cm, and the posttest displacement was 52.09 ± 11.90 cm (Table 7).

30-Meter Sprint Pre vs Post Treatment

During the hip visit, there was no significant difference in sprint times from pretest to posttest ($t(14) = 0.51$, $p > 0.05$). The pretest 30-meter sprint time (mean ± SD) was 5.08 ± 0.45 seconds, and the posttest time was 5.05 ± 0.50 seconds (Table 8). During the ankle visit, there was no significant difference in sprint times from pretest to posttest ($t(14) = 0.18$, $p > 0.05$). The pretest 30-meter sprint time (mean ± SD) was 4.96 ± 0.50 seconds, and the posttest time was 4.95 ± 0.51 seconds (Table 8).

Percent Change for All Variables Tested

<u>Cumulative Ranges of Motion</u>

There was no significant difference in the percent change of cumulative ranges of motion between the flexible and nonflexible groups after the ankle treatment session ($t(14) = 0.72$, $p >$

0.05). The percent change of ranges of motion (mean ± SD) of the flexible group (-2.16 ± 3.49) were not significantly different from the ranges of motion of the non-flexible group (-0.66 ± 4.46) (Table 9 and Figure 1). There was no significant difference in the percent change for combined hip and ankle ranges of motion between the flexible and nonflexible groups after the hip treatment session ($t(14) = 1.28$, $p > 0.05$). The percent change for combined ranges of motion (mean ± SD) of the flexible group (2.86 ± 7.17) were not significantly different from the ranges of motion of the non-flexible group (8.46 ± 9.39) (Table 9 and Figure 2).

Weight-Bearing Lunge Test

There was no significant difference in the percent change of the weight-bearing lunge test scores after the ankle treatment session ($t(14) = -0.48$, $p > 0.05$). The percent change of weight-bearing lunge test scores (mean ± SD) of the flexible group (9.21 ± 13.86) were not significantly different from the scores of the non-flexible group (5.94 ± 12.76) (Table 9 and Figure 1). There was also no significant difference in the percent change of weight-bearing lunge test scores after the hip treatment session ($t(14) = 1.47$, $p > 0.05$). The percent change of lunge test scores (mean ± SD) of the flexible group (-0.21 ± 10.68) were not significantly different from the scores of the non-flexible group (7.56 ± 9.85) (Table 9 and Figure 2).

FMS Sit-and-Reach

There was no significant difference in the percent change of FMS sit-and-reach scores after the ankle treatment session ($t(14) = 1.56$, $p > 0.05$). The percent change of sit-and-reach scores (mean ± SD) of the flexible group (3.97 ± 4.84) were not significantly different from the percent change sit-and-reach scores of the non-flexible group (17.99 ± 23.30) (Table 9 and Figure 1). There was also no significant difference in the percent change of FMS sit-and-reach scores after the hip treatment session ($t(14) = -1.35$, $p > 0.05$). The percent change of sit-and-reach scores

(mean ± SD) of the flexible group (18.66 ± 14.70) were not significantly different from the percent change sit-and-reach scores of the non-flexible group (9.77 ± 10.80) (Table 9 and Figure 2).

Vertical Jump Performance

There was no significant difference in the percent change of vertical jump performance after the ankle treatment session ($t(14) = 0.89$, $p > 0.05$). The percent change of jump displacements (mean ± SD) of the flexible group (-0.18 ± 3.17) were not significantly different from the percent change jump displacements of the non-flexible group (1.79 ± 5.06) (Table 9 and Figure 1). There was no significant difference in the percent change of vertical jump performance after the hip treatment session ($t(14) = 0.68$, $p > 0.05$). The percent change of jump displacements (mean ± SD) of the flexible group (-0.89± 3.43) were not significantly different from the percent change displacements of the non-flexible group (0.95 ± 2.49) (Table 9 and Figure 2).

30-Meter Sprint

There was no significant difference in the percent change of sprint times after the ankle treatment session ($t(14) = -0.67$, $p > 0.05$). The percent change of sprint times (mean ± SD) of the flexible group (0.34 ± 1.59) were not significantly different from the percent change of sprint times of the non-flexible group (-0.51 ± 2.96) (Table 9 and Figure 1). There was no significant difference in the percent change of sprint times after the hip treatment session ($t(14) = 0.26$, $p > 0.05$). The percent change of sprint times (mean ± SD) of the flexible group (-0.90 ± 4.98) were not significantly different from the percent change of sprint times of the non-flexible group (-0.28 ± 4.17) (Table 9 and Figure 2).

Discussion

The purpose of this study was to determine how college students who regularly exercise responded to a bout of stretching based on their level of flexibility. It was hypothesized that those with shorter ranges of motion would show greater improvements in range of motion, flexibility scores, vertical jump performance, and sprint time after stretching than those with greater ranges of motion. However, no significant differences were found in any of the outcomes measured between the flexible and non-flexible groups after both ankle and hip treatments. Therefore, subjects categorized as non-flexible did not show greater improvements in range of motion, flexibility, vertical jump performance, or sprint time after stretching their ankles and hips than those categorized as flexible. The hypothesis was not supported by the results of this study. However, there were significant findings discovered when comparing pre-treatment measurements to post-treatment measurements for both hip and ankle treatments. During the hip visit, right and left hip flexion, right and left ankle plantarflexion, and sit-and-reach score measurements improved significantly from pre to post treatment. During the ankle visit, left hip extension range of motion decreased significantly and sit-and-reach scores improved significantly from pre to post treatment.

While there is not much current research to compare the effect of stretching on people with varying levels of flexibility, previous research has shown dynamic and static stretching along with foam rolling tend to improve range of motion (5,13,19). Like these other studies, this current research found significant improvements in range of motion measurements including hip flexion, ankle plantarflexion, and sit-and-reach scores after stretching. In contrast to research by Hough et al. which found that dynamic stretching can improve vertical jump performance, this current study found no significant difference in pre vs post treatment vertical jump displacement (9). Similarly, Cetin et al.'s study that saw dynamic stretching increase sprint performance

differed from this research because results showed no improvement in pre vs post treatment sprint times (6). However, these differences between studies on vertical jump and sprint performance may have been due to this study using a combination of static and dynamic stretching prior to testing. The study by Hough et al. had subjects perform static and dynamic stretches separately while Cetin et al. only used dynamic stretches (9,6).

This study showed no significant differences between the flexible and non-flexible groups in any of the measurement outcomes. The combination of dynamic stretching with self-myofascial release through foam-rolling has shown to improve range of motion and in research by Smith et al., improve vertical jump performance (14). However, based on this research, a combination of static and dynamic stretching with joint specific movements paired with foam rolling did not improve or significantly affect vertical jump or sprint performance which differed from previous research. This difference in results between studies is possibly due to this research using a combination of static and dynamic stretching, and static stretching has been shown to decrease power outcomes like the vertical jump (9,19).

Limitations

This study had a small sample size due to the subject recruitment process and experimental timeframe. Subjects were divided into flexible and non-flexible groups by a median split due to the small sample size. The inability to recruit subjects specifically for their flexible or nonflexible status was a major limitation for this study. The American College of Sports Medicine listed normal ranges of motion for hip flexion (90°-135°), hip extension (10°-30°), ankle plantarflexion (15°-20°), and ankle dorsiflexion (30°-50°) (1). Most subjects had ranges of motion within normal limits or greater than normal limits for hip and ankle flexibility. The only measurement in which all subjects had ranges of motion less than the normal limits was ankle

dorsiflexion. Therefore, subjects were flexible in their hips and during ankle plantarflexion but nonflexible during ankle dorsiflexion based on normative values. Without a larger sample size, the flexible and non-flexible groups did not accurately depict true flexibility levels that were within or not within normal limits. Additionally, for most subjects there were only 48 hours between sessions; however, a few subjects' sessions were separated by a week. The short time between sessions may have affected the pretest and posttest measurements of the second session due to a crossover effect from session 1's treatment. An independent t-test was run to determine if this was the case and found that the only measured outcome affected was right hip flexion. Another limitation to this study was the stretching protocol being a mixture of static and dynamic stretches. This may have impacted the results because while dynamic stretching has been shown to have positive effects on performance outcomes, static stretching has been shown to have negative effects on vertical jump and sprint performance (9,19).

Conclusion

Range of motion, flexibility, and performance measurements were not significantly different between flexible and non-flexible college students after both a hip and an ankle stretching/mobility session. Although this study's hypothesis was rejected, if this study could be repeated with some modifications, the results may be different. It might give insight into how stretching and mobility may affect range of motion and performance based on an individual's level of flexibility. With more targeted recruitment of subjects who are truly flexible and non-flexible based on normative data, future studies may show differing results.

Table 1: Subject demographics (n=15) including sex, age, height, and body mass.

Variables	*n*	*%*	*Cumulative %*
Sex			
Male	5	33.3	66.7
Female	10	66.7	100
	Mean	*SD*	*Range*
Age (yrs)	20.60	1.64	18-23
Height (cm)	175.93	9.38	159.50-191.50
Body mass (kg)	77.93	13.86	63.50-107.70

Table 2: Paired-sample t-test results comparing pre-test measurements across hip & ankle visits.

	Ankle Pre-test		Hip Pre-test			
	Mean	*SD*	*Mean*	*SD*	t	Sig. (two-sided p)
R Hip Flex (deg)	115.73	7.44	109.07	9.35	2.81	0.014*
L Hip Flex (deg)	116.53	6.50	113.60	9.34	1.30	0.22
R Hip Ext (deg)	20.40	8.33	22.47	11.65	-1.13	0.28
L Hip Ext (deg)	20.33	9.11	18.47	9.15	0.85	0.41
R Ankle PF (deg)	67.33	10.59	66.93	10.46	0.30	0.77
L Ankle PF (deg)	69.53	10.62	67.67	10.92	2.02	0.06
R Ankle DF (deg)	5.07	4.35	5.80	4.28	-0.88	0.39
L Ankle DF (deg)	6.47	3.16	2.67	13.71	1.06	0.31
Cumulative ROM (deg)	421.40	37.72	406.67	46.43	1.51	0.15
Sit-and-Reach (cm)	25.97	8.89	24.43	8.19	1.68	0.12
R Lunge (cm)	12.84	3.87	12.97	4.14	-0.30	0.77
L Lunge (cm)	12.61	4.02	12.99	4.44	-0.76	0.46
Cumulative Lunge (cm)	25.45	7.72	25.72	8.29	-0.34	0.74
Jump Displacement (cm)	51.60	11.19	51.16	12.27	0.84	0.42
Sprint Time (sec)	4.96	0.50	5.08	0.45	-1.81	0.09

Table 3: Paired-sample dependent t-test results for ranges of motion (deg) pre vs post hip treatment.

	Pre-test		Post-test			
	Mean	*SD*	*Mean*	*SD*	t	Sig. (two-sided p)
R Hip Flex	109.07	9.35	114.93	6.41	-2.51	0.025*
L Hip Flex	113.60	9.34	118.27	7.25	-2.44	0.029*
Hip R Hip Ext	22.47	11.65	22.87	9.97	-0.30	0.77
Hip L Hip Ext	18.47	9.15	19.07	7.81	-0.34	0.74
Hip R Ankle PF	66.93	10.46	69.53	10.35	-2.25	0.041*
Hip L Ankle PF	67.67	10.92	69.93	10.34	-2.22	0.043*
Hip R Ankle DF	5.80	4.28	7.00	4.42	-0.96	0.35
Hip L Ankle DF	2.67	13.71	6.33	5.27	-1.15	0.27
Cum ROM	406.67	46.43	427.93	34.10	3.83	0.006*

Table 4: Paired-sample dependent t-test results for ranges of motion (deg) pre vs post ankle treatment.

	Pre-test		Post-test			
	Mean	*SD*	*Mean*	*SD*	t	Sig. (two-sided p)
R Hip Flex	115.73	7.44	115.67	8.93	0.05	0.96
L Hip Flex	116.53	6.50	116.73	6.51	-0.12	0.90
Hip R Hip Ext	20.40	8.33	17.47	8.85	1.92	0.08
Hip L Hip Ext	20.33	9.11	16.13	5.78	2.56	0.023*
Hip R Ankle PF	67.33	10.59	67.87	11.10	-0.50	0.63
Hip L Ankle PF	69.53	10.62	68.73	9.86	0.73	0.48
Hip R Ankle DF	5.07	4.35	6.20	4.69	-1.07	0.31
Hip L Ankle DF	6.47	3.16	6.27	4.03	0.27	0.79
Cum ROM	421.40	37.72	415.07	33.01	1.45	0.17

Table 5: Paired-sample dependent t-test results for weight-bearing lunge test scores (cm) pre vs post hip & ankle treatments.

	Pre-test		Post-test			
	Mean	*SD*	*Mean*	*SD*	t	Sig. (two-sided p)
Hip R Lunge	12.97	4.14	13.42	4.00	-0.99	0.34
Hip L Lunge	12.75	4.22	12.99	4.44	-0.69	0.50
Hip Cumulative Lunge	25.72	8.29	26.41	8.26	-1.05	0.31
Ankle R Lunge	12.84	3.87	13.77	4.13	-2.88	0.012*
Ankle L Lunge	12.61	4.02	13.09	3.40	-1.10	0.29
Ankle Cumulative Lunge	25.45	7.72	26.85	7.47	-2.35	0.034*

Table 6: Paired-sample dependent t-test results for FMS sit-and-reach test scores (cm) pre vs post hip & ankle treatments.

	Pre-test		Post-test			
	Mean	*SD*	*Mean*	*SD*	t	Sig. (two-sided p)
Hip Treatment	24.43	8.19	27.47	8.29	-4.59	<0.001*
Ankle Treatment	25.97	8.89	27.90	8.26	-3.56	0.003*

Table 7: Paired-sample dependent t-test results for vertical jump displacement (cm) pre vs post hip & ankle treatments.

	Pre-test		Post-test			
	Mean	*SD*	*Mean*	*SD*	t	Sig. (two-sided p)
Hip Treatment	51.16	12.27	51.41	12.63	-0.64	0.53
Ankle Treatment	51.60	11.19	52.09	11.90	-0.94	0.36

Table 8: Paired-sample dependent t-test results for 30-meter sprint times (sec) pre vs post hip & ankle treatments.

	Pre-test		Post-test			
	Mean	*SD*	*Mean*	*SD*	t	Sig. (two-sided p)
Hip Treatment	5.08	0.45	5.05	0.50	0.51	0.62
Ankle Treatment	4.96	0.50	4.95	0.51	0.18	0.86

Table 9: Paired-sample independent t-test results of the percent (%) change of measurements pre to post treatment between flexible and nonflexible groups.

	Flexible		Nonflexible			
	M	SD	M	SD	t	Sig. (one-sided p)
Ankle Cumulative ROM	-2.16	3.49	-0.66	4.46	0.72	0.24
Hip Cumulative ROM	2.86	7.17	8.46	9.39	1.28	0.11
Ankle Sit-and-Reach	3.97	4.84	17.99	23.30	1.56	0.07
Hip Sit-and-Reach	18.66	14.70	9.77	10.80	-1.35	0.10
Ankle Cumulative Lunge	9.20	13.86	5.94	12.76	-0.48	0.32
Hip Cumulative Lunge	-0.21	10.68	7.56	9.85	1.47	0.08
Ankle VJ	-0.18	3.17	1.79	5.06	0.89	0.20
Hip VJ	-0.89	3.43	0.95	2.49	0.68	0.26
Ankle Sprint Time	0.34	1.59	-0.51	2.96	-0.67	0.26
Hip Sprint Time	-0.90	4.98	-0.28	4.17	0.26	0.40

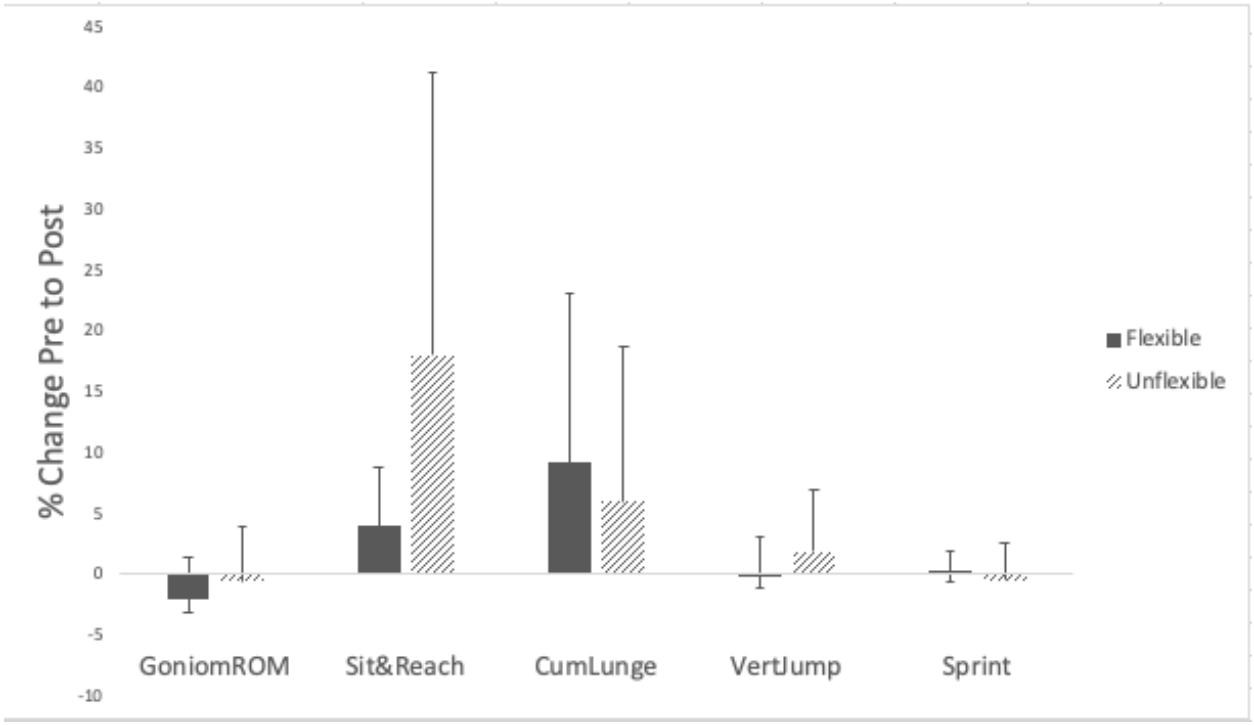


Figure 1: Percent change of ROM, sit-and-reach, cumulative lunge, vertical jump displacement, and sprint time between flexible and nonflexible groups after ankle treatment. There was no significant difference in the percent change of cumulative ROM, sit-and-reach scores, cumulative lunge scores, vertical jump displacement, or sprint times after the ankle treatment session.

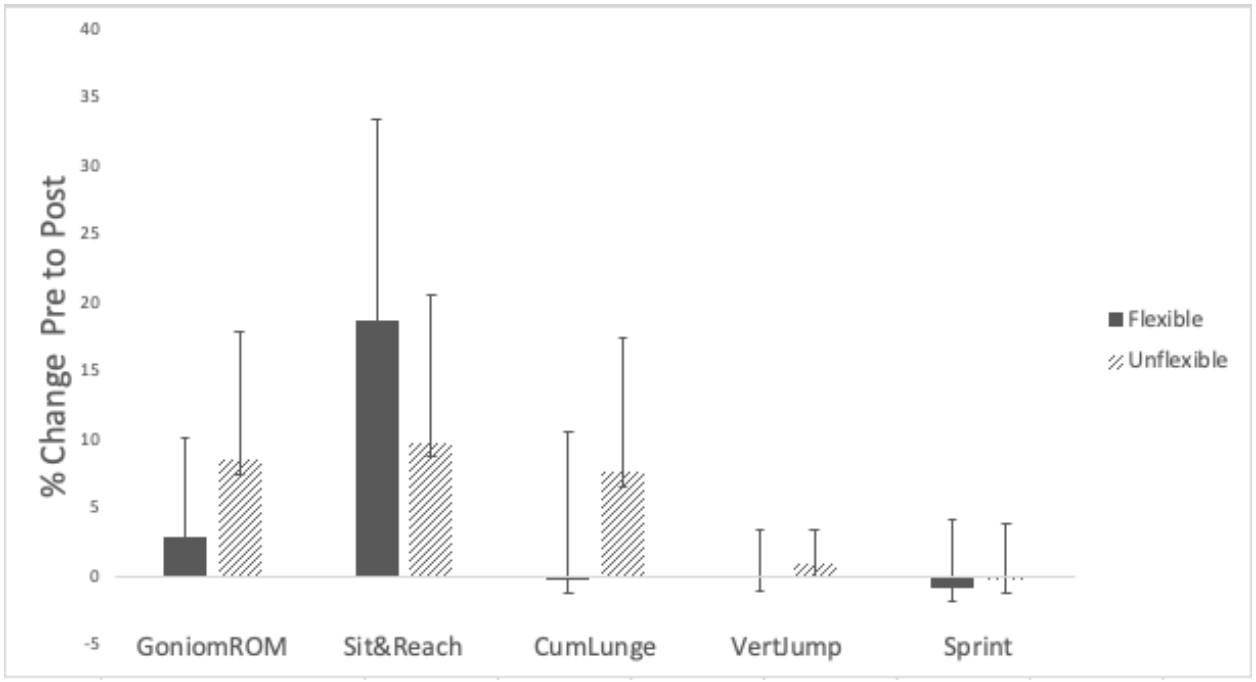
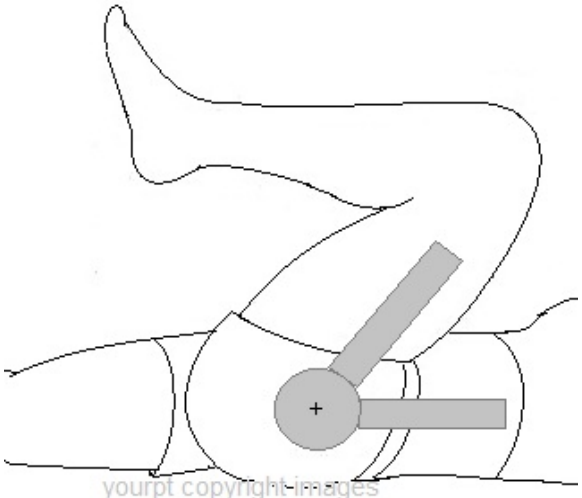
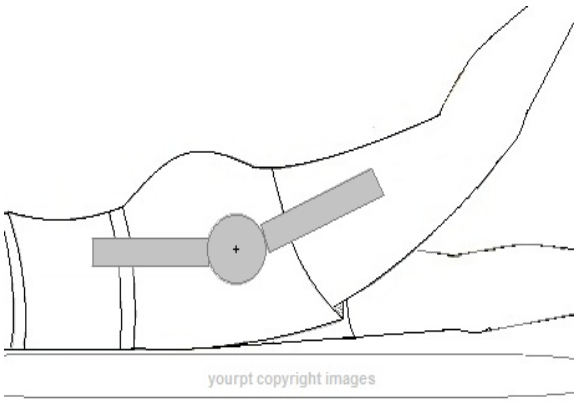


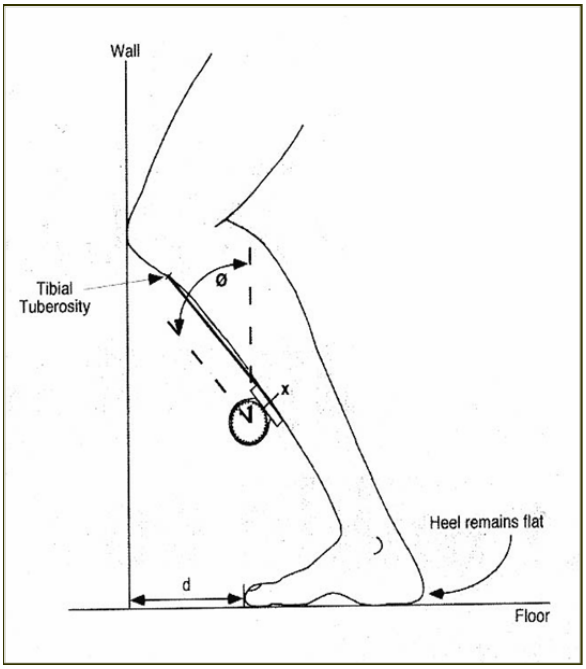
Figure 2: Percent change of ROM, sit-and-reach, cumulative lunge, vertical jump displacement, and sprint time between flexible and nonflexible groups after hip treatment. There was no significant difference in the percent change of cumulative ROM, sit-and-reach scores, cumulative lunge scores, vertical jump displacement, or sprint times after the hip treatment session.

Range of Motion Testing Examples

Ankle Plantarflexion	 (8)
Ankle Dorsiflexion	 (16)
Hip Flexion	 (18)

Hip Extension	 (17)

Flexibility Testing Examples

FMS Sit-and-Reach Flexibility Test	 (7)
Weight-bearing Lunge Test	 (4)

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