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Effect of Stretch Frequency and Sex on the Rate of Gain and Rate of Loss in Muscle Flexibility During a Hamstring-Stretching Program: A Randomized Single-Blind Longitudinal Study

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Title Page

Effect of stretch frequency and sex on rate of gain and rate of loss in muscle flexibility during a hamstring stretching program: a randomized single-blind longitudinal study.

Running Head: Effects of weekly stretching frequency

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Effect of stretch frequency and sex on rate of gain and rate of loss in hip range of motion: a randomized single-blind longitudinal study.

Abstract (263/275 words):

This study evaluated the effects of four different weekly stretching protocols on the rate of gain and decline in hamstring flexibility over an eight week period, across sex. Using a randomized single- blind design, 53 healthy subjects ages 18-46, were assigned to one of four stretching protocols or a control group. The stretching protocols consisted of either daily or three times/week stretching and performed once or twice each day. These protocols differed in terms of frequency and total weekly stretching time. All subjects stretched their hamstring muscles for four weeks and were measured weekly for hip range of motion (ROM). Stretching ceased the final four weeks as the weekly measurements continued. Results revealed no significant differences in the rate of gain or the rate of loss between the different stretching protocols (2-way ANOVA, $F = 2.60$, $p > 0.05$). All stretching groups gained in hip ROM from pre to week four ($F = 269.24$, $p<.001$). Following cessation, the rate of loss was similar for all four stretching groups ($F = 102.86$, $P <.001$); all groups retained significant gains at the end of the study ($p < 0.001$). The control group did not change over time. Those who stretched at least six times/week gained more than those who stretched three times/week (24% and 16.8% respectively, $F = 5.20$, $p < 0.05$). Subject sex did not influence ROM changes ($p > 0.05$). Stretching appears to be equally effective, whether performed daily or three times/week, provided individuals stretch at least two times each day. Moreover, while females are more flexible than males, there was no sex difference in terms of stretching response.

Key words: stretching, flexibility, hamstrings

INTRODUCTION

Muscle stretching is a common form of exercise. Athletes, recreational enthusiasts, and clinicians are among those who utilize stretching exercises. The advantage of stretching is primarily associated with increased joint range of motion (ROM). Current evidence supports that stretching increases motion in a healthy joint as well as restores movement to an injured or restricted body segment (4,5,21,33). And while the acute effect of stretching on sport performance has been called into question (28,30,31,35), sufficient evidence supports the long term use of stretching to improve flexibility and athletic performance, contribute to injury prevention, and reduce post activity muscle soreness (3,5,12,20,27,32,33,42,45,47,48,50). Improvements in joint ROM have been reported following a single stretching bout as well as after long- term stretching interventions (4,12,17,19,20,21,27,38,42,43,46,47,50). The potential physiological adaptations that allow for ROM changes include modifications in musculotendinous length, increased stretch tolerance, and viscoelastic stress relaxation (27,32,33).

Various stretching protocols have been studied in prior research, with the emphasis on optimal stretch duration and frequency per day (4,5,12,24,42). There appears to be consensus that the total stretching time per day is more important than the duration of a stretch hold position. Cipriani et al (13) found that the total daily stretching time was the key factor related to ROM gains, more so than the number of repetitions or the duration of a single stretching bout. Specifically, six repetitions of ten seconds performed twice daily produced a similar increase in ROM when compared with two repetitions of 30 seconds, performed twice daily. Thus, the main factor for either group was one minute of stretching, repeated two times each day. These findings support the work of others who also found that total time, regardless of the daily dosing, was the main factor influencing the effectiveness of stretching. Roberts and Wilson (37) found that nine repetitions of five seconds a day produced similar gains in ROM when compared with 3 repetitions of 15seconds a day. Doebler et al. (21) found that a static stretch time of two minutes per day yielded greater gains in ROM at the hip joint than durations less than two minutes.

Despite this determination, there remain many aspects of stretching that deserve attention. One area in particular is the effect of ROM when a stretching regimen is discontinued. This is a practical topic in both rehabilitation and athletics. For instance, it has been shown that adherence to exercise programs decreases following discharge from rehabilitation or physical therapy (40). Research suggests that the cessation of a stretching program will result in an eventual loss of joint ROM (27,36,38,43,47,50). If ROM is not sufficiently retained following a stretching program then patients and athletes may be more susceptible to re-injury, and may never achieve optimal flexibility for performance. Willy et al (47) found that within four weeks of cessation of a regular stretching program, joint ROM returned to baseline. These findings however, are in conflict with the finding of Guissard et al (27) who found that a stretching protocol consisting of ten minutes of passive static stretching per day, performed five times a week, for six weeks resulted in approximately 74% retention in motion up to four weeks following the cessation of the program. The stretching protocol was much more involved than that of Willy. Hence, the more frequent stretching may have contributed to the better retention. In addition, Rancour et al (36) demonstrated that intermittent stretching can attenuate the decline in hip ROM, following the cessation of a daily stretching program. Subjects in this study were able to attenuate or even maintain hip ROM gains, while stretching only two days per week.

All three of these studies examined the effects of cessation of stretching with some evidence that the gains made during stretching can be retained for up to four weeks. And the

Rancour (36) study demonstrated that stretching as infrequently as two days per week could maintain some level of flexibility.

Most studies that examine the influence of regular stretching only look at intermittent time points, such as, the beginning, middle, and end of the study. Therefore, it is not possible to determine if the gain and decline in ROM occurred immediately prior to start/cessation of stretching or if the changes occurred incrementally over the course of total time period. Further, it is unknown how much the frequency (i.e., days/week and repetitions/day) influences the rate of gain or the rate of decline in ROM. Finally, the influence of the individual's sex, which has been demonstrated to influence flexibility, has not been studied in terms of varying stretching protocols. Males have been shown to adapt quicker to fitness protocols than females, while females have been shown to demonstrate greater flexibility than males (1,2,7,8,9,11,14,15,22,23,25,26,39,43,49). It is not clear whether males or females respond differently to stretching frequency.

The purpose of this study was to document the rate of gain and rate of decline in hamstring flexibility over the course of an eight-week stretching and cessation program, and to examine whether males and females respond differently to stretching. We intended to determine if less frequent stretching each week (i.e., three days per week) would yield similar changes in flexibility as high frequent stretching each week (i.e., daily stretching). Because Rancour (36) found that as little as two days per week could maintain or possibly improve flexibility, we did expected that differences in weekly stretch frequency, (i.e., daily or three times each week) would result in similar gains over time. We chose four different stretching prescriptions that would provide a variety of stretch frequency over the course of each week, ranging from highly frequent (daily, two times/day) to least frequent (three times/week, once/day). From practical experience, we are aware of athletes who stretch highly frequently, while others struggle to find the time each week. Because athletes and individuals involved in fitness must find the most efficient means to address their fitness, flexibility, and performance training, we wished to determine if less frequent stretching could yield similar gains as more frequent stretching; this could be helpful to the individual in terms of time management. We also did not expect that sex would influence the rate of change. Research is inconclusive as to whether males or females gain at a different rate in response to stretching. Finally, we intended to document the actual rate of change over time, on a weekly basis, to provide information that is currently missing from the literature. Current research has examined changes over intermediate time points, but not on a weekly basis. Particularly from an injury and recovery standpoint, it is important to know the rate of change in flexibility that might be expected on a weekly basis.

This study examined four different stretching frequency programs ranging from 14 times each week (daily, twice each day) to three times each week (three times each week, once each day). In addition, this study followed the rate of gain and rate of loss over the course of four weeks of stretching and four weeks of cessation from stretching. It was hypothesized that hamstring ROM would increase at a similar rate for all four stretching programs, during the four week stretching phase. It was further hypothesized that the rate of decline would be comparable for all groups, regardless of the stretching program. Sex as a factor was not expected to contribute to differences between groups over time. Males and females differ in flexibility and in response to fitness/conditioning programs, however, we did not expect that these two groups would respond differently to stretching programs.

METHODS

Experimental Approach to the Problem: This study used a randomized, single-blind, longitudinal, quasi-experimental design with repeated measures. The dependent variable was hip ROM as measured with a goniometer for hip flexion. Hip ROM was measured as an indication of changes in flexibility of the hamstring muscle during the course of the study. The three independent variables were time (nine time points over eight weeks), group assignment (four different stretching protocol groups and one control group), and sex (male or female). Subjects were randomly assigned to one of the five groups. Hence, this was a multifactorial design which included time, stretching protocol, and sex as the three factors.

Subjects: This study was approved by the Institutional Review Board (IRB) for Research Ethics at XXXX (name of institution deleted for review), protocol approval number 23009. Furthermore, all subjects signed an informed consent form approved by the Institutional Review Board at XXXX (name of institution deleted for review), prior to being enrolled in this study. Seventy-three healthy adults between the ages of 18 and 50 were initially screened for the study. All subjects came from the University campus population (students, faculty, and staff); subjects were not part of any formal athletic program (i.e., all subjects were non-athletes). Following initial screening, eleven subjects were excluded based on the following exclusion criteria: all subjects must be free of lower back pain, hip, or knee pain at the time of the study (n = 2); subjects could not be currently involved in a hamstring stretching program (n = 6); subjects could not be pregnant (by self-report) (n = 0). In addition, subjects were excluded if they presented with excessive hamstring ROM (i.e., greater than 100 degrees of hip flexion in the straight-leg-raise test) (n = 5). Based on these criteria, a total of sixty-two subjects (30 male, 33 female) mean age = 24.91 years, SD = 6.40, range = 18 - 46 years were initially enrolled in the study. Subjects enrolled in the study refrained from any hamstring stretching, during the course of eight weeks, except for the stretching protocol imposed by the study itself. There were no other restrictions placed on the subjects' activities of daily living or any other recreational activities. The data from each of the variables were evaluated and met the criteria for skewness and the assumption of a normal distribution. Descriptive statistics for the sixty-two initial subjects are presented in Table 1.

[TABLE 1 about here]

Procedures: The total duration of this study was eight weeks. During the first four weeks of this period subjects participated in a static hamstring stretching program, or were assigned to a control group of no intervention. The four stretching programs varied in terms of weekly frequency. This study chose to use static stretching because it has been shown to provide similar gains in motion, over an extended period of time with dynamic stretching (50). Static stretching is defined as a sustained tension applied to a muscle group in a slow and controlled manner (3,5,20,47). In addition, static stretching is commonly used by the general public, based on its simplicity (17). In this study, subjects assigned to a stretching protocol performed static stretching for the initial four weeks of the study. Stretching was then discontinued for the final four weeks (cessation period). All stretching was performed independent of any active exercise or possible recreational programs. Subjects were instructed to avoid stretching two- hours prior to an active exercise regime or performance, as well as within one- hour following the exercise program.

Stretching Protocol and Control: This study tested four different stretching protocols (S14, S7, S6, and S3) and a control group (C). Subjects were randomly assigned to one of these five groups. The protocols differed in terms of frequency and total weekly stretching time:

1) Daily stretching, twice each day (14 minutes/week): S14

2) Daily stretching, once each day (seven minutes/week): S7

3) Three-four days/week stretching, twice each day (six-eight minutes/week): S6

4) Three-four day/week stretching, once each day (three-four minutes/week): S3

5) A control group refrained from any hamstring stretching (zero minutes/week): C

Following the pre-screening process to assure eligibility, subjects were randomly assigned to one of the five groups (i.e., S14, S7, S6, S3, and C), as illustrated in Figure 1. Only the subject and one investigator knew the subject's group assignment. All remaining investigators involved in the measuring process remained blind, including the data processor/analyzer.

Stretching Procedure: A standing one-legged hamstring stretch was used for the purpose of this study, as described by Cipriani et al. (12). The leg to be stretched was placed on an elevated surface, approximately the height of the mid-thigh, with the knee near full extension (i.e., not locked). While maintaining a neutral spine (i.e., slight lordosis), the subject flexed at the hip, drawing the anterior abdominal area toward the anterior thigh, until an uncomfortable stretching sensation was experienced in the posterior thigh of the elevated leg. Subjects maintained this position of discomfort throughout the duration of the stretch, increasing forward flexion as needed in order to sustain the sensation of discomfort for the duration of the stretch time.

The stretch position was held for a total of 30 seconds, using a standard count-down stop watch. All subjects were issued a standard count-down stop watch. Following a ten-second rest, the stretch was repeated for an additional 30 seconds. The total stretch time for a session was one-minute. The same procedure was repeated for the contralateral leg. Depending on the group assignment, stretching was performed either one or two times each day and the designated number of days per week.

Cessation Period: Subjects refrained from all hip ROM stretching for the final four weeks of the study. During this time, subjects could continue with their normal activities (i.e., those activities that they were presently engaged in).

Measurement Protocol: A standard 12-inch, double arm plastic goniometer was used to take weekly ROM measurements of hip joint flexion. Goniometric assessments have been shown to yield reliable data in measuring lower extremity joint ROM, and are considered appropriate when measurements are taken by the same tester (10,13). Using the procedures described by Cipriani et al (12) and Norkin and White (34), all subjects were measured on a weekly basis for the entire duration of this study (eight weeks). Including the pre-intervention measure, all subjects were measured nine times over the course of the study . The day of the week for each measurement period (pre-intervention, week one, week two, etc.) was the same for all subjects, as was the time of day. Three investigators measured the subjects. One investigator positioned the subject in the straight-leg-raise position, securing the leg to be measured. The second investigator measured the hip flexion angle with the goniometer, and recorded this value on a card. The card was then given to a third investigator who entered the data in to a data spreadsheet. All three individuals involved in the acquisition of data were blind to the group assignment of the subjects. Subject data were recorded using a coding system that did not reveal group assignment. Finally, all subjects were asked to self-report their average stretching time for each week. The self-reported times are provided in Table 2.

[TABLE 2 about here]

Statistical Analysis: The independent variables (factors) in this study were time (nine time points), the stretching protocol (five levels) as well as sex (male and female). The dependent variable was hip flexion range of motion (ROM) measured at the angle formed by the hip and the pelvis, with the knee extended. Intrarater reliability of the data, with a single measurer was evaluated prior to the study with an $ICC_{1,3}$ of 0.92 (0.88 – 0.96). The initial power analysis of having at least 11 subjects in each group was met (Effect size d = 1.5, alpha = 0.05, 1-beta = 0.95). A factorial (three-way) analysis of variance was used to analyze the interaction between group x sex x time. Two-way ANOVA's were performed in an absence of a three way interaction and investigated the time x sex and group x time interactions, during the stretching time period and also during the cessation time period. These analyses were followed by a simple repeated measures ANOVA for time, in the absence of a two-way interaction. Univariate approaches for main effects and t-tests for simple main effects were also used as required depending on the presence or absence of any interaction effects. A p-value < 0.05 was established as the criteria for statistical significance.

RESULTS

Fifty-three subjects completed the entire nine weeks of the study. Nine subjects were lost to follow-up at the mid-point measure of four weeks. Table 1 includes the descriptive data of those lost to follow-up along with those who remained in the study. There were no differences in terms of initial hip ROM or age between those who completed the study and those who dropped from the study. The subjects lost to follow-up did not differ from the remaining subjects in terms of age, gender, or initial hip ROM values. Loss to follow-up was attributed to lack of interest ($n = 2$), school obligations ($n = 5$), and too much time commitment ($n = 2$). At baseline, the average age and hip ROM were not different across the five groups ($p > 0.05$). The average self-reported stretching time for each week can be found in Table 2. All group self-report times are significantly different ($F = 58.2$, $p < 0.05$) from each other except the S7 and S6 groups, which were not different.

[FIGURE 1 about here]

Stretching Period: The three-way ANOVA was significant for an interaction, when including the control group ($F = 2.89$, $p < 0.05$). However, once the control group was removed from the analyses, the three-way ANOVA was no longer significant for the interaction effects ($F = 0.46$, $p > 0.05$). The subsequent two-way ANOVA for time x sex was not significant for an interaction ($F = 2.53$, $p > 0.05$). The two-way ANOVA for group x time was also not significant for an interaction ($F = 1.59$, $p > 0.05$). Hence it was determined that neither sex nor stretching group influenced the changes over time. The main effect for time was significant ($F = 266.64$, $p < 0.001$). All four stretching groups demonstrated significant gains in hip ROM from the pre-measure to week four (mean gain = 18.1 $\pm$ 6.3 degrees, $p < .05$, $eta^2 = 0.88$). In addition, all four groups demonstrated significant gains in ROM when compared to the control group ($p <.05$); the control group did not demonstrate any change in hip motion at any point in the first four weeks ($p > 0.05$). When comparing the four stretching groups to each other, the change in ROM did not differ statistically between any of the four groups ($p >.05$) at any time point during these four weeks. Finally, the change from week to week was not significant. However, when comparing the initial hip ROM with hip ROM at weeks two, three and four, these time points were all significantly greater ($p < 0.05$) from the initial. Thus, while week-to-week changes were not significant, subjects had achieved significant gains from pre-testing by week two. Finally, when collapsing groups based on stretching frequency, a significant interaction was detected. Individuals who stretched at least six times per week (S14, S7, and S6) gained greater hip ROM than those who stretched three times per week (S3), a relative difference of 24.9% vs. 16.8% ($F = 5.20$, $p < 0.05$, $eta^2 = 0.11$). Table 3 provides the average range of hip motion values for the five groups, during the first four weeks of the study. The Table contains weekly ROM values for each group as well as the relative changes between the initial measure and week four.

Cessation Period: Table 4 provides the mean ROM values across the five groups during the cessation period. The three-way ANOVA was significant for an interaction, when including the control group ($F = 2.91$, $p < 0.05$). However, once the control group was removed from the analyses, the three-way ANOVA was no longer significant for the interaction effects ($F = 1.76$, $p > 0.05$). As during the stretching period, the control group did not change over time during the cessation period. The subsequent two-way ANOVA for time x sex was not significant for an interaction ($F = 3.63$, $p > 0.05$). The two-way ANOVA for group x time was also not significant for an interaction ($F = 1.72$, $p > 0.05$). Hence it was determined that neither sex nor stretching group influenced the changes over time during the last four weeks. The main effect for time was significant ($F = 115.58$, $p < 0.001$, $eta^2 = 0.76$). The four stretching groups all demonstrated a decrease in hip ROM over time, from week four to week eight (mean loss = 9.2 ± 3.1 degrees, $p < 0.05$). There were no differences in the change in motion between any of the four groups ($p > .05$) at any time point. Just as with the stretching period, when looking only at the factor of time, week-to-week changes were not significant. The decline in motion did not approach a significant level until week eight, when compared to week four. Finally, the final hip ROM values at week eight were significantly greater than the hip ROM values at the onset of the study. All stretching group subjects retained approximately 11.2% of the gain in ROM following the four week cessation period($F = 82.78$, $p < 0.05$, $eta^2 = 0.70$). Table 4 provides the average ROM values for the five groups, during the final four weeks of the study (the cessation period). The Table contains weekly ROM values for each group as well as the relative changes between week four and week eight.

[TABLES 3 and 4 about here]

Gender Influence A 2- factor ANOVA showed no interaction between sex and time ($p>.05$). A significant main effect for sex existed throughout the study, with females demonstrating greater hip ROM than males at each time point ($p < 0.05$) . The rate of change over time however was not significant (Table 5). Figure 4 illustrates the rate of gain and loss in ROM between male and female subjects over the eight week period.

[TABLE 5 about here]

DISCUSSION

The intent of this study was to determine if weekly stretching frequency would influence the rate of gain and the rate of loss in hamstring flexibility. As expected, the control group did not demonstrate any change in hip ROM over the course of eight weeks. However, each of the stretching groups did demonstrate a change in hip ROM; each group gained hip ROM during the stretching period of the study (Figure 2) and each group lost hip ROM during the cessation period (Figure 3). The gains in our study (18.1 degrees) are similar to those reported in previous studies and perhaps slightly greater than some (6,12,18,36,39). For example, Sainz de Baranda and Ayala (39), in their investigation of different stretching routines on hamstring flexibility reported a mean gain of 15.14 degrees on the straight leg test (SLR). However, Bandy et.al (6), reported less gain for each of their stretching groups (i.e., mean gain of 10.50, 10.05, 10.45, and 11.50 degrees) respectively in their study of different stretching frequencies on hamstring flexibility. The intensity of the stretching in our study might have contributed to these gains. Subjects in our study were encouraged to continue leaning into the stretch to maintain a constant feeling of discomfort.

[FIGURES 2 and 3 about here]

In terms of weekly frequency, which was our primary interest, we found that all four groups gained at similar rates, whether stretching twice each day, every day or only three times each week. The group that only stretched once each day, three times each week demonstrated the smallest change between the four stretching groups. Thus, even those who stretched only three days/week, provided they stretched twice each day, gained at a similar rate as those who stretched every day and those who stretched every day, twice each day (Figure 4). It appears that stretching three times each week can yield ROM gains similar to a daily stretching program, provided the stretching is performed at least twice/day. These results are somewhat in support of those found by Rancour et al (36), in that even two days per week of stretching, twice per day, was able to maintain the flexibility gained following a typical stretching program. It is likely that even the occasional attention to ROM on the part of the subjects was able to provide sufficient physical stress to promote ROM gains. We cannot determine if these gains are a result of reduced sensitivity to being stretched or if the gains are a direct result of increased connective tissue length.

[FIGURE 4 about here]

Finally, we observed that the gains in ROM, during the stretching period, occurred incrementally over time (Figures 2). There was not any one single week in which gains were greater than any adjacent week. Individuals should expect gains in flexibility to occur gradually over time. We cannot determine however at what point gains would eventually plateau because we only followed stretching for four weeks. Previous research suggests that ROM gains may plateau at around six weeks of stretching (12).

In terms of loss of ROM when a stretching program is discontinued, all subjects lost ROM at the same relative rate, once stretching ceased, regardless of their prior stretching protocol. Hence, independent of the stretching frequency (i.e., whether a subject stretched every day, twice a day, or only once a day, three days/week), once a stretching program was discontinued , the rate of decline was similar for all subjects. The findings from this study provide evidence that the decline in ROM does occur incrementally over the course of 4-weeks (Figure 3). Even with this gradual loss, our subjects retained a significant improvement in hip ROM at the end of four weeks. We are not able to determine how long before subjects would return to their baseline values, but we can speculate that individuals can expect to retain some flexibility even after four weeks of cessation of a stretching program.

In regards to our findings between the sexes, as expected the female subjects in our study demonstrated higher hamstring ROM at pre, week four and week eight. These findings support previous studies which show that females are more flexible than males for most body regions (1,2,7,25). However, the relative rate of change over time did not differ between men and women (Figure 5). These findings contradict Starring et al (43) who found that male subjects are not expected to gain or maintain as much ROM as female subjects. We attribute the inconsistencies to the difference in the methodologies of these two investigations. Starring et al examined individuals with tight hamstring muscles and utilized a mechanical stretching devise however, our study recruited subjects with normal hamstring flexibility and had subjects perform a one legged hamstring stretch without the use of additional equipment. It is possible that individuals with tight muscles may respond differently to stretching compared to individuals with less tight muscles. The effect of a mechanical stretching device can also potentially influence stretching gains as subjects are no longer in control of the stretching force. Also, while there is evidence suggesting that males tend to respond faster to exercise programs compared to females, this difference was not exhibited in our stretching study (16,29,41,44).

[FIGURE 5 about here]

Our inability to find a significant difference in the stretching protocols may be attributed to a small sample size in each of the four groups. We had sufficient sizes in each group, based on our a priori power analysis; drop-outs from each group adversely affected our group sizes. Larger groups might have provided sufficient power to detect significant differences, particularly in relation to the cessation period. However, the actual differences between groups, at any time point, were so small (i.e., less than 3 degrees) that we do not believe these differences are practically significant.

An additional limitation of this study was that outside behaviors of the subjects were not controlled. Subjects could continue with their normal activities, regardless of their impact on hip motion. We are hopeful that our randomization and screening process controlled for this outside factor, however we are uncertain (i.e., the subject's behavior was not closely monitored) . Finally, this study used a sample of convenience. In this sample all of our subjects were between the ages of 18-50, the subjects were healthy and free from injury. Future studies should attempt to recruit a more diverse sample including those with musculoskeletal injuries; this will allow the findings to be generalized to other populations. Moreover, different muscles should be studied to see if similar findings are present in different muscle groups.

PRACTICAL APPLICATION

When prescribing a stretching program for patients, clients, or athletes, it is important to identify the optimal frequency and hold duration of a stretch. Thirty second hold time appears to be effective, based on this study and previous studies. We now have evidence that stretching as infrequently as three days each week can be as equally beneficial as stretching every day, in terms of hip ROM. Our data support at least six times/week of stretching, in any one week period, which can be accomplished either once each day, on a daily basis, or twice each day and only three days each week. Less frequent stretching (i.e., three days/week rather than daily) might appeal to individuals who struggle to fit stretching into their already busy schedule of training and conditioning. Athletes can consider devoting only a few days each week to stretching, while continuing with other forms of conditioning and training. Fewer days each week might also appeal to individuals who do not enjoy the process of stretching, yet require the benefits of this activity. Hence, a reduced frequency protocol might provide greater compliance for these patients, clients and or athletes. Coaches, trainers and therapists should also expect to see fairly consistent changes over time, with a stretching program. We did not find that the weekly gains were significantly different from one week to the next. Based on our data, we recommend that individuals strive to stretch two times per day, to optimize the ability of stretching to create ROM gains. Further, as observed by others, it is possible to maintain gains in ROM by continuing with stretching only two or three days each week. Individuals should be aware though that the gains achieved with a stretching program will decline gradually over time if all stretching ceases.

Table 1 Subject physical characteristics

Characteristic	Completed Study (n =53)	Dropped Out of Study (n =9)
Gender M/F	25/28	5/4
Age, years (sd)	24.0 (5.5)	25.6 (3.2)
Height, cm (sd)	171.2 (9.1)	176.5 (6.6)
Weight, kg (sd)	69.6 (15.0)	69.7 (12.2)
Initial Hip ROM (sd)	79.2 (13.1)	70.5 (12.2)

Note: groups similar at baseline

Table 2. Self- reported average stretching time for each week

Group	[a]Self-Report Minutes (sd)	Self-Report Minimum	Self-Report Maximum
Control	0.0	0.0	0.0
S14	12.5 (1.6)	10.0	14.0
S7	6.0 (0.9)	4.0	7.0
S6	5.9 (0.7)	5.0	7.0
S3	3.3 (0.7)	2.0	4.0

[a]All group self-report times are significantly different ($p < 0.05$) from each other except the S7 and S6 groups, which were not different.

Table 3. Mean Hip ROM (sd) from week one to week four, and % change pre to week 4

Group	Pre	Week 1	Week 2	Week 3	Week 4	% Change Pre to Week 4
Control	**81.0 (14.1)**	80.0 (10.4)	[a]79.6 (10.0)	[a]80.4 (11.6)	**[a]79.4 (10.8)**	**-2.0**
S14	**77.1 (13.1)**	86.5 (13.8)	[b]91.2 (13.0)	[b]93.0 (10.9)	**[b]97.6 (10.0)**	**26.5**
S7	**78.8 (14.3)**	85.5 (16.9)	[b]90.7 (16.5)	[b]93.6 (16.5)	**[b]97.7 (16.7)**	**23.9**
S6	**78.5 (13.2)**	87.3 (13.8)	[b]91.7 (12.6)	[b]94.0 (12.8)	**[b]97.7 (11.0)**	**24.5**
S3	**81.1 (12.6)**	85.7 (11.9)	[b]92.7 (11.1)	[b]93.8 (11.3)	**[b]94.7 (11.1)**	**16.8[c]**

[a]Control group significantly less than all stretching groups ($p< 0.05$)
[b]Values significantly greater than the Pre values ($p < 0.05$)
[c]Relative change significantly less than the relative change of groups S6, S7, and S14 ($p < 0.05$)

Table 4. Mean Hip ROM (sd) from week five to week eight, as well as relative % change week 4 to week 8 and pre to week 8.

Group	Week 5	Week 6	Week 7	Week 8	% Change Week4 to Week8	% Change Pre to Week 8
Control	[a]84.9(8.0)	[a]86.3 (10.1)	[a]83.2 (7.8))	**[a]83.9 (5.9)**	**5.6**	**3.5**
S14	93.0 (13.3)	91.2(11.3)	90.7 (12.2)	**[b,c]88.2 (11.8)**	**-9.6**	**14.4**
S7	91.8 (17.3)	89.9 (17.2)	86.9(15.1)	**[b,c]86.2 (16.4)**	**-11.8**	**9.4**
S6	94.7 (12.0)	90.1 (11.9)	90.6 (10.9)	**[b,c]89.4 (11.7)**	**-8.5**	**13.8**
S3	91.5 (11.2)	89.2 (9.1)	89.0 (8.5)	**[b,c]87.0 (8.7)**	**-8.1**	**7.3**

[a]Control group significantly less than all stretching groups ($p < 0.05$)
[b]Values significantly less than Week four values ($p < 0.05$)
[c]Values significantly greater than Pre values ($p < 0.05$)

Table 5: Comparison of Mean ROM Values (sd) by Gender and Week.

Gender	Male	Female	P-value
ROM, degrees, pre	75.7 (12.2)	82.3 (13.2)	<.05
ROM, degrees, week 4	90.0 (13.3)	97.6 (13.2)	<.05
ROM, degrees, week 8	83.0 (9.1)	90.6 (12.2)	<.05

REFERENCES

1. Allander, E, Bjornsson, OJ, Olafsson, O, Sigfusson N, Thorsteinsson, J. Normal range of joint movements in shoulder, hip, wrist and thumb with special reference to side: a comparison between two populations. *Int J Epedemiol*. 3: 253-261, 1974.
2. Alter, MJ. Science of Flexibility 3rd ed. Champaigen, IL: Human Kinetics: 2003.
3. Anderson, B and Burke, ER. Scientific, medical, and practical aspects of stretching. *Clin Sports Med*. 10: 63-86, 1991.
4. Bandy, WD, and Irion JM. The effects of time on static stretch on the flexibility of the hamstring muscles. *Phys Ther*. 74: 845-850, 1994.
5. Bandy, WD, Irion JM, and Briggler M. The effect of static stretch and dynamic range of motion training on the flexibility of the hamstring muscles. *J Orthop Sports Phys Ther.* 27 (4): 295- 300, 1998.
6. Bandy, W, Irion, J and Briggler, M . The effect of time and frequency of static stretch on Flexibility of the hamstring muscles.*Phys. Ther*. 77:1090-1096, 1997.
7. Bell, D. Relationship of age and sex with range of motion of seventeen joints actions in humans. *Canad J. Applied Sport Sci* 6(4): 202-206,1981
8. Blackburn, JT, Bell , DR, Norcross, MF, Hudson, JD and Kimsey, MH. Sex comparison of hamstring structural and material properties. *Clin Biomech*. 24(1):65-70, 2009.
9. Blackburn, JT, Riemann, BL, Padua, DA and Guskiewicz, KM. Sex comparison of

active extensibility, and active and passive stiffness of the knee flexors. *Clin Biomech*. 19:36–43, 2004.

10. Boone, DC , Azen S.P, and Lin, CM et al. Reliability of goniometric measurements. *Phys Ther.* 58: 1355-1360, 1978.

11. Chow, RS, Medri, MK, Leekam, RN, Agur, AM and McKee, NH. Sonographic studies of human soleus and gastrocnemius muscle architecture: Gender variability. *Eur J Appl Physiol*. 82: 236-44,2000.

12. Cipriani, D, Abel, B, and Pirrwitz, D. A comparison of two stretching protocols on hip range of motion: implications for total daily stretch duration. *J Strength Cond Res*. 17 (2): 274-278, 2003.

13. Clapper, MP and Wolf SL. Comparison of the reliability of the orthoranger and the standard goniometer for assessing active lower extremity range of motion. *Phys Ther*. 64: 214-219, 1987.

14. Clendaniel, RA, Grossman, MR, Katholic, CR, et al: hamstring muscle length in Men and women: Normative data. Abstract. *Phys Ther.* 64: 716-717, 1984.

15. Cornbleet, SL. and Woolsey, NB. Assessment of hamstring muscle length in school-aged children using the sit-and-reach test and the inclinometer measure of hip joint angle. *Phys Ther.*76: 850-855, 1996.

16. Cureton, K, Bishop, P, Hutchinson, P, Newland, H, Vickery, S. and Zwiren, L. Sex difference in maximal oxygen uptake. *Eur J Appl Physiol and Occup Physiol*. 54, 656-660, 1986

17. Decoster, L, et al. The effects of hamstring stretching on range of motion: A systematic literature review. *J Orthop Sports Phys*. 35 (6): 377-387, 2005.

18. Decoster, LC, Scanlon, RL, Horn, KD and Cleland, J. Standing and supine hamstring stretching are equally effective. *J Athl Train*. 39(4): 330-334, 2001.

19. DePino, GM, Webright, WG, and Arnold, BL. Duration of maintained hamstring flexibility after cessation of an acute static stretching protocol. *J of Athletic Training*. 35 (1): 56-59, 2000.

20. DeWeijer, VC, Gorniak, GC, and Shamus, E. The effect of static stretch and warm-up exercise on hamstring length over the course of 24 hours. *J Orthop Sports Phys Ther*. 33 (12): 727-733, 2003.

21. Doebler, M. et al. The effect of different static stretch hold times on hamstring muscle flexibility in active college students [abstract]. *Phys Ther*.80(5): 68, 2000.

22. Etnyre, BR and Lee, EJ. Chronic and acute flexibility of men and women using three different stretching techniques. *Res Q Exerc Sport*. 59:222-228, 1988.

23. Feland, JB, Hawks, M, Hopkins, JT, Hunter, I and Johnson, AW, Eggett DL. Whole body vibration as an adjunct to static Stretching. *Int J Sports Med*. 2010.

24. Feland, JB, Myrer, JM, Schulthies, SS , Fellingham, GW and. Measom GW. The effect of duration of stretching of the hamstring muscle group of increasing range of motion in people aged 65 years or older. *Phys Ther*. 81(5):1100-1117, 2001.

25. Gabbard, C and Tandy, R. Body composition and flexibility among prepubescent males and females. *Journal of Human Movement Studies*.14 (4):153-159. 1988.

26. Granata, KP, Padua, DA and Wilson, SE. Gender differences in active musculoskeletal stiffness. Part II. Quantification of leg stiffness during functional hopping tasks. *J Electromyogr Kinesiol*.12:127–135, 2002.

27. Guissard, N and Duchateau, J. Effect of static stretch training on neural and mechanical properties of the human plantar-flexor muscles. *Muscle and Nerve*. 29 (2): 248-255, 2004.

28. Gleim, GW and. McHugh, MP. Flexibility and its effect on sports injury and performance. *Sports Med*. 24:289-299, 1997.

29. Harms, C, Rosenkranz, S. Sex differences in pulmonary function during exercise. *Med Sci Sports & Exerc*. 40 (4): 664-668, 2008.

30. Handel, M, Horstmann, T, Dickhuth, H and Gulch, RW. Effects of contract-relax stretching training on muscle performance in athletes. *Eur J Appl Physiol*.76:400-408, 1997.

31. Johansson, PH, Lindstrom L, Sundelin, L and Lindstrom B. The effects of pre exercise stretching on muscular soreness, tenderness and force loss following heavy eccentric phase. *Scand J Med Sci Sports*. 9 (4):219-25, 1999.

32. Magnusson, P, et al. Biomechanical responses to repeated stretches in human hamstring muscle in vivo. *Am J Sports Med*. 24 (5): 622-627, 1996.

33. Malliaropoulos, N, et al. The role of stretching in rehabilitation of hamstring injuries: 80 Athletes follow up. *Med Sci Sports Exerc* .36 (5): 756-759, 2004.

34. Norkin, C and Joyce, D. Measurement Joint Motion: A Guide to Goniometry. (2nd ed.). Philadelphia: F.A. Davis Company, 1995

35. Orchard, J, Marsden, J, Lord, S, and Garlick D. Preseason hamstring muscle weakness associated with hamstring muscle injury in Australian footballers. *Am J Sports Med.* 29:124-128, 2001.

36. Rancour J, Holmes C, and Cipriani, D. Effects of intermittent stretching on hip range of motion following cessation of a daily four-week stretching program . *J Str Condit Res*. 23 (8): 2217-2222, 2009.

37. Roberts, JM and Wilson, K. Effect of stretching duration on active and passive range of motion in the lower extremity. *Br. J. Sports Med.* 33:259–263, 1999.

38. Rubley, MD, et al. Flexibility retention 3 weeks after a 5-day training regime. *J Sport Rehabil*. 10 (2): 105-112, 2001.

39. Sainz de Baranda, P and Ayala, F. Chronic flexibility improvement after 12 week of stretching program utilizing the ACSM recommendations: hamstring flexibility. Int. *J. Sport Med.* 31 (6): 389-96, 2002.

40. Sluijs, EM, Kok, GJ, and Zee, J. Correlates of exercise compliance in physical therapy. *Phys Ther*. 73:771-786, 1993.

41. Sparling, PB, Cureton, KJ. Biological determinants of the sex difference in 12-min run performance. *Med Sci Sports Exerc* . 15 (3): 218-23, 1983.

42. Spernoga, SG, et al. Duration of maintained hamstring flexibility after a one-time, modified hold-relax stretching protocol. *J Athl Train*. 36 (1): 44-48, 2001.

43. Starring, DT, Gossman, MR, Nicholson, GG, Lemons, J. Comparison of cyclic and sustained passive stretching using a mechanical device to increase resting length of hamstring muscles. ***Phys Ther.*** 68(3):314–320, 1988.

44. Tarnopolsky, A. Sex Differences in Exercise metabolism and the role of 17-beta estradoil. *Med Sci Sports & Exerc*. 40 (4) :648-654 , 2008

45. Tomberlin, J and Saunders, H. Evaluation, Treatment, and Prevention of Musculoskeletal Disorders Vol. 2 Extremities. The Saunders Group. Chasks, MN. 1994. p. 393.

46. Wallin, D, Ekblom, B, Grahn, R, and Nordenborg , T. Improvement of muscle flexibility. A comparison between two techniques. *Am J Sports Med*. 13:363-268, 1985.

47. Willy, RW, et al. Effect of cessation and resumption of static hamstring muscle stretching on joint range of motion. *J Orthop and Sports Phys Ther*. 31 (3): 138-144, 2001.

48. Worrell, TW, Smith, TL, Winegardner, J. Effect of Hamstring Stretching on Hamstring Muscle Performance. *J Orthop and Sports Phys Ther.* 20 (3): 154-159, 1994.

49. Youdas, JW, Krause, DA, Hollman, JH, Harmsen, WS and Laskowski E. The influence of gender and age on hamstring muscle length in healthy adults. *J Orthop Sports Phys Ther*. 35:246-252, 2005.

50. Zebas, CJ and Rivera ML. Retention of flexibility in selected joints after cessation of a stretching exercise program. *Exer Phys:* Current Selected Research 1: 181-191, 1985.

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Figures Legend

Figure 1. Group randomization process and retention

Figure 2. First 4 weeks of stretching (scaling intentionally restricted for illustrative purposes)

Figure. 3 Last four weeks (cessation) period (scaling intentionally restricted for illustrative purposes)

Figure 4. Collapsing groups into six times/week (s6+) vs three times/week (s3), scaling intentionally restricted for illustrative purposes.

Figure 5. Changes in Hip ROM over time comparing males and females.