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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.

1 Abstract (263/275 words):

2

3

4 This study evaluated the effects of four different weekly stretching protocols on the rate
5 of gain and decline in hamstring flexibility over an eight week period, across sex. Using a
6 randomized single- blind design, 53 healthy subjects ages 18-46, were assigned to one of four
7 stretching protocols or a control group. The stretching protocols consisted of either daily or three
8 times/week stretching and performed once or twice each day. These protocols differed in terms
9 of frequency and total weekly stretching time. All subjects stretched their hamstring muscles for
10 four weeks and were measured weekly for hip range of motion (ROM). Stretching ceased the
11 final four weeks as the weekly measurements continued. Results revealed no significant
12 differences in the rate of gain or the rate of loss between the different stretching protocols (2-way
13 ANOVA, $F = 2.60$, $p > 0.05$). All stretching groups gained in hip ROM from pre to week four (F
14 $= 269.24$, $p < .001$). Following cessation, the rate of loss was similar for all four stretching groups
15 ($F = 102.86$, $P < .001$); all groups retained significant gains at the end of the study ($p < 0.001$).
16 The control group did not change over time. Those who stretched at least six times/week gained
17 more than those who stretched three times/week (24% and 16.8% respectively, $F = 5.20$, $p <$
18 0.05). Subject sex did not influence ROM changes ($p > 0.05$). Stretching appears to be equally
19 effective, whether performed daily or three times/week, provided individuals stretch at least two
20 times each day. Moreover, while females are more flexible than males, there was no sex
21 difference in terms of stretching response.

21

22 Key words: stretching, flexibility, hamstrings

1 INTRODUCTION

2 Muscle stretching is a common form of exercise. Athletes, recreational enthusiasts, and
3 clinicians are among those who utilize stretching exercises. The advantage of stretching is
4 primarily associated with increased joint range of motion (ROM). Current evidence supports
5 that stretching increases motion in a healthy joint as well as restores movement to an injured or
6 restricted body segment (4,5,21,33). And while the acute effect of stretching on sport
7 performance has been called into question (28,30,31,35), sufficient evidence supports the long
8 term use of stretching to improve flexibility and athletic performance, contribute to injury
9 prevention, and reduce post activity muscle soreness (3,5,12,20,27,32,33,42,45,47,48,50).
10 Improvements in joint ROM have been reported following a single stretching bout as well as
11 after long- term stretching interventions (4,12,17,19,20,21,27,38,42,43,46,47,50). The potential
12 physiological adaptations that allow for ROM changes include modifications in
13 musculotendinous length, increased stretch tolerance, and viscoelastic stress relaxation
14 (27,32,33).

15 Various stretching protocols have been studied in prior research, with the emphasis on
16 optimal stretch duration and frequency per day (4,5,12,24,42). There appears to be consensus
17 that the total stretching time per day is more important than the duration of a stretch hold
18 position. Cipriani et al (13) found that the total daily stretching time was the key factor related to
19 ROM gains, more so than the number of repetitions or the duration of a single stretching bout.
20 Specifically, six repetitions of ten seconds performed twice daily produced a similar increase in
21 ROM when compared with two repetitions of 30 seconds, performed twice daily. Thus, the main
22 factor for either group was one minute of stretching, repeated two times each day. These findings
23 support the work of others who also found that total time, regardless of the daily dosing, was the

1 main factor influencing the effectiveness of stretching. Roberts and Wilson (37) found that nine
2 repetitions of five seconds a day produced similar gains in ROM when compared with 3
3 repetitions of 15seconds a day. Doebler et al. (21) found that a static stretch time of two minutes
4 per day yielded greater gains in ROM at the hip joint than durations less than two minutes.

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

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

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

3 Most studies that examine the influence of regular stretching only look at intermittent
4 time points, such as, the beginning, middle, and end of the study. Therefore, it is not possible to
5 determine if the gain and decline in ROM occurred immediately prior to start/cessation of
6 stretching or if the changes occurred incrementally over the course of total time period. Further,
7 it is unknown how much the frequency (i.e., days/week and repetitions/day) influences the rate
8 of gain or the rate of decline in ROM. Finally, the influence of the individual's sex, which has
9 been demonstrated to influence flexibility, has not been studied in terms of varying stretching
10 protocols. Males have been shown to adapt quicker to fitness protocols than females, while
11 females have been shown to demonstrate greater flexibility than males
12 (1,2,7,8,9,11,14,15,22,23,25,26,39,43,49). It is not clear whether males or females respond
13 differently to stretching frequency.

14 The purpose of this study was to document the rate of gain and rate of decline in
15 hamstring flexibility over the course of an eight-week stretching and cessation program, and to
16 examine whether males and females respond differently to stretching. We intended to determine
17 if less frequent stretching each week (i.e., three days per week) would yield similar changes in
18 flexibility as high frequent stretching each week (i.e., daily stretching). Because Rancour (36)
19 found that as little as two days per week could maintain or possibly improve flexibility, we did
20 expect that differences in weekly stretch frequency, (i.e., daily or three times each week)
21 would result in similar gains over time. We chose four different stretching prescriptions that
22 would provide a variety of stretch frequency over the course of each week, ranging from highly
23 frequent (daily, two times/day) to least frequent (three times/week, once/day). From practical

1 experience, we are aware of athletes who stretch highly frequently, while others struggle to find
2 the time each week. Because athletes and individuals involved in fitness must find the most
3 efficient means to address their fitness, flexibility, and performance training, we wished to
4 determine if less frequent stretching could yield similar gains as more frequent stretching; this
5 could be helpful to the individual in terms of time management. We also did not expect that sex
6 would influence the rate of change. Research is inconclusive as to whether males or females
7 gain at a different rate in response to stretching. Finally, we intended to document the actual rate
8 of change over time, on a weekly basis, to provide information that is currently missing from the
9 literature. Current research has examined changes over intermediate time points, but not on a
10 weekly basis. Particularly from an injury and recovery standpoint, it is important to know the
11 rate of change in flexibility that might be expected on a weekly basis.

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

22

23

1 METHODS

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

10 **Subjects:** This study was approved by the Institutional Review Board (IRB) for
11 Research Ethics at XXXX (name of institution deleted for review), protocol approval number
12 23009. Furthermore, all subjects signed an informed consent form approved by the Institutional
13 Review Board at XXXX (name of institution deleted for review), prior to being enrolled in this
14 study. Seventy-three healthy adults between the ages of 18 and 50 were initially screened for the
15 study. All subjects came from the University campus population (students, faculty, and staff);
16 subjects were not part of any formal athletic program (i.e., all subjects were non-athletes).
17 Following initial screening, eleven subjects were excluded based on the following exclusion
18 criteria: all subjects must be free of lower back pain, hip, or knee pain at the time of the study (n
19 = 2); subjects could not be currently involved in a hamstring stretching program (n = 6); subjects
20 could not be pregnant (by self-report) (n = 0). In addition, subjects were excluded if they
21 presented with excessive hamstring ROM (i.e., greater than 100 degrees of hip flexion in the
22 straight-leg-raise test) (n = 5). Based on these criteria, a total of sixty-two subjects (30 male, 33
23 female) mean age = 24.91 years, SD = 6.40, range = 18 - 46 years were initially enrolled in the

1 study. Subjects enrolled in the study refrained from any hamstring stretching, during the course
2 of eight weeks, except for the stretching protocol imposed by the study itself. There were no
3 other restrictions placed on the subjects' activities of daily living or any other recreational
4 activities. The data from each of the variables were evaluated and met the criteria for skewness
5 and the assumption of a normal distribution. Descriptive statistics for the sixty-two initial
6 subjects are presented in Table 1.

7
8 [TABLE 1 about here]

9
10
11 **Procedures:** The total duration of this study was eight weeks. During the first four
12 weeks of this period subjects participated in a static hamstring stretching program, or were
13 assigned to a control group of no intervention. The four stretching programs varied in terms of
14 weekly frequency. This study chose to use static stretching because it has been shown to provide
15 similar gains in motion, over an extended period of time with dynamic stretching (50). Static
16 stretching is defined as a sustained tension applied to a muscle group in a slow and controlled
17 manner (3,5,20,47). In addition, static stretching is commonly used by the general public, based
18 on its simplicity (17). In this study, subjects assigned to a stretching protocol performed static
19 stretching for the initial four weeks of the study. Stretching was then discontinued for the final
20 four weeks (cessation period). All stretching was performed independent of any active exercise
21 or possible recreational programs. Subjects were instructed to avoid stretching two- hours prior
22 to an active exercise regime or performance, as well as within one- hour following the exercise
23 program.

24

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

- 4 1) Daily stretching, twice each day (14 minutes/week): S14
- 5 2) Daily stretching, once each day (seven minutes/week): S7
- 6 3) Three-four days/week stretching, twice each day (six-eight minutes/week): S6
- 7 4) Three-four day/week stretching, once each day (three-four minutes/week): S3
- 8 5) A control group refrained from any hamstring stretching (zero minutes/week): C

9
10 Following the pre-screening process to assure eligibility, subjects were randomly
11 assigned to one of the five groups (i.e., S14, S7, S6, S3, and C), as illustrated in Figure 1. Only
12 the subject and one investigator knew the subject's group assignment. All remaining
13 investigators involved in the measuring process remained blind, including the data
14 processor/analyzer.

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

1
2 The stretch position was held for a total of 30 seconds, using a standard count-down stop
3 watch. All subjects were issued a standard count-down stop watch. Following a ten-second rest,
4 the stretch was repeated for an additional 30 seconds. The total stretch time for a session was
5 one-minute. The same procedure was repeated for the contralateral leg. Depending on the group
6 assignment, stretching was performed either one or two times each day and the designated
7 number of days per week.

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

11 ***Measurement Protocol:*** A standard 12-inch, double arm plastic goniometer was used to
12 take weekly ROM measurements of hip joint flexion. Goniometric assessments have been shown
13 to yield reliable data in measuring lower extremity joint ROM, and are considered appropriate
14 when measurements are taken by the same tester (10,13). Using the procedures described by
15 Cipriani et al (12) and Norkin and White (34), all subjects were measured on a weekly basis for
16 the entire duration of this study (eight weeks). Including the pre-intervention measure, all
17 subjects were measured nine times over the course of the study . The day of the week for each
18 measurement period (pre-intervention, week one, week two, etc.) was the same for all subjects,
19 as was the time of day. Three investigators measured the subjects. One investigator positioned
20 the subject in the straight-leg-raise position, securing the leg to be measured. The second
21 investigator measured the hip flexion angle with the goniometer, and recorded this value on a
22 card. The card was then given to a third investigator who entered the data in to a data
23 spreadsheet. All three individuals involved in the acquisition of data were blind to the group

1 assignment of the subjects. Subject data were recorded using a coding system that did not reveal
2 group assignment. Finally, all subjects were asked to self-report their average stretching time for
3 each week. The self-reported times are provided in Table 2.

4

5 [TABLE 2 about here]

6

7 **Statistical Analysis:** The independent variables (factors) in this study were time (nine
8 time points), the stretching protocol (five levels) as well as sex (male and female). The
9 dependent variable was hip flexion range of motion (ROM) measured at the angle formed by the
10 hip and the pelvis, with the knee extended. Intrarater reliability of the data, with a single
11 measurer was evaluated prior to the study with an ICC_{1,3} of 0.92 (0.88 – 0.96). The initial power
12 analysis of having at least 11 subjects in each group was met (Effect size $d = 1.5$, $\alpha = 0.05$,
13 $1 - \beta = 0.95$). A factorial (three-way) analysis of variance was used to analyze the interaction
14 between group x sex x time. Two-way ANOVA's were performed in an absence of a three way
15 interaction and investigated the time x sex and group x time interactions, during the stretching
16 time period and also during the cessation time period. These analyses were followed by a simple
17 repeated measures ANOVA for time, in the absence of a two-way interaction. Univariate
18 approaches for main effects and t-tests for simple main effects were also used as required
19 depending on the presence or absence of any interaction effects. A p-value < 0.05 was
20 established as the criteria for statistical significance.

21

22

23

1 RESULTS

2 Fifty-three subjects completed the entire nine weeks of the study. Nine subjects were lost
3
4 to follow-up at the mid-point measure of four weeks. Table 1 includes the descriptive data of
5 those lost to follow-up along with those who remained in the study. There were no differences in
6 terms of initial hip ROM or age between those who completed the study and those who dropped
7 from the study. The subjects lost to follow-up did not differ from the remaining subjects in terms
8 of age, gender, or initial hip ROM values. Loss to follow-up was attributed to lack of interest (n
9 = 2), school obligations (n = 5), and too much time commitment (n = 2). At baseline, the
10 average age and hip ROM were not different across the five groups ($p > 0.05$). The average self-
11 reported stretching time for each week can be found in Table 2. All group self-report times are
12 significantly different ($F = 58.2, p < 0.05$) from each other except the S7 and S6 groups, which
13 were not different.

14

15 [FIGURE 1 about here]

16

17 **Stretching Period:** The three-way ANOVA was significant for an interaction, when
18 including the control group ($F = 2.89, p < 0.05$). However, once the control group was removed
19 from the analyses, the three-way ANOVA was no longer significant for the interaction effects (F
20 = 0.46, $p > 0.05$). The subsequent two-way ANOVA for time x sex was not significant for an
21 interaction ($F = 2.53, p > 0.05$). The two-way ANOVA for group x time was also not significant
22 for an interaction ($F = 1.59, p > 0.05$). Hence it was determined that neither sex nor stretching
23 group influenced the changes over time. The main effect for time was significant ($F = 266.64, p$
24 < 0.001). All four stretching groups demonstrated significant gains in hip ROM from the pre-

1 measure to week four (mean gain = 18.1 ± 6.3 degrees, $p < .05$, $\eta^2 = 0.88$). In addition, all four
2 groups demonstrated significant gains in ROM when compared to the control group ($p < .05$); the
3 control group did not demonstrate any change in hip motion at any point in the first four weeks
4 ($p > 0.05$). When comparing the four stretching groups to each other, the change in ROM did
5 not differ statistically between any of the four groups ($p > .05$) at any time point during these four
6 weeks. Finally, the change from week to week was not significant. However, when comparing
7 the initial hip ROM with hip ROM at weeks two, three and four, these time points were all
8 significantly greater ($p < 0.05$) from the initial. Thus, while week-to-week changes were not
9 significant, subjects had achieved significant gains from pre-testing by week two. Finally, when
10 collapsing groups based on stretching frequency, a significant interaction was detected.

11 Individuals who stretched at least six times per week (S14, S7, and S6) gained greater hip ROM
12 than those who stretched three times per week (S3), a relative difference of 24.9% vs. 16.8% (F
13 = 5.20, $p < 0.05$, $\eta^2 = 0.11$). Table 3 provides the average range of hip motion values for the
14 five groups, during the first four weeks of the study. The Table contains weekly ROM values for
15 each group as well as the relative changes between the initial measure and week four.

16 **Cessation Period:** Table 4 provides the mean ROM values across the five groups during
17 the cessation period. The three-way ANOVA was significant for an interaction, when including
18 the control group ($F = 2.91$, $p < 0.05$). However, once the control group was removed from the
19 analyses, the three-way ANOVA was no longer significant for the interaction effects ($F = 1.76$, p
20 > 0.05). As during the stretching period, the control group did not change over time during the
21 cessation period. The subsequent two-way ANOVA for time x sex was not significant for an
22 interaction ($F = 3.63$, $p > 0.05$). The two-way ANOVA for group x time was also not significant
23 for an interaction ($F = 1.72$, $p > 0.05$). Hence it was determined that neither sex nor stretching

1 group influenced the changes over time during the last four weeks. The main effect for time was
2 significant ($F = 115.58$, $p < 0.001$, $\eta^2 = 0.76$). The four stretching groups all demonstrated a
3 decrease in hip ROM over time, from week four to week eight (mean loss = 9.2 ± 3.1 degrees, p
4 < 0.05). There were no differences in the change in motion between any of the four groups (p
5 $> .05$) at any time point. Just as with the stretching period, when looking only at the factor of
6 time, week-to-week changes were not significant. The decline in motion did not approach a
7 significant level until week eight, when compared to week four. Finally, the final hip ROM
8 values at week eight were significantly greater than the hip ROM values at the onset of the study.
9 All stretching group subjects retained approximately 11.2% of the gain in ROM following the
10 four week cessation period ($F = 82.78$, $p < 0.05$, $\eta^2 = 0.70$). Table 4 provides the average ROM
11 values for the five groups, during the final four weeks of the study (the cessation period). The
12 Table contains weekly ROM values for each group as well as the relative changes between week
13 four and week eight.

14

15 [TABLES 3 and 4 about here]

16

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

22

23 [TABLE 5 about here]

1 **DISCUSSION**

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

16

17 [FIGURES 2 and 3 about here]

18

19 In terms of weekly frequency, which was our primary interest, we found that all four
20 groups gained at similar rates, whether stretching twice each day, every day or only three times
21 each week. The group that only stretched once each day, three times each week demonstrated
22 the smallest change between the four stretching groups. Thus, even those who stretched only
23 three days/week, provided they stretched twice each day, gained at a similar rate as those who

1 stretched every day and those who stretched every day, twice each day (Figure 4). It appears that
2 stretching three times each week can yield ROM gains similar to a daily stretching program,
3 provided the stretching is performed at least twice/day. These results are somewhat in support
4 of those found by Rancour et al (36), in that even two days per week of stretching, twice per day,
5 was able to maintain the flexibility gained following a typical stretching program. It is likely
6 that even the occasional attention to ROM on the part of the subjects was able to provide
7 sufficient physical stress to promote ROM gains. We cannot determine if these gains are a result
8 of reduced sensitivity to being stretched or if the gains are a direct result of increased connective
9 tissue length.

10

11 [FIGURE 4 about here]

12

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

19 In terms of loss of ROM when a stretching program is discontinued, all subjects lost
20 ROM at the same relative rate, once stretching ceased, regardless of their prior stretching
21 protocol. Hence, independent of the stretching frequency (i.e., whether a subject stretched every
22 day, twice a day, or only once a day, three days/week), once a stretching program was
23 discontinued , the rate of decline was similar for all subjects. The findings from this study

1 provide evidence that the decline in ROM does occur incrementally over the course of 4-weeks
2 (Figure 3). Even with this gradual loss, our subjects retained a significant improvement in hip
3 ROM at the end of four weeks. We are not able to determine how long before subjects would
4 return to their baseline values, but we can speculate that individuals can expect to retain some
5 flexibility even after four weeks of cessation of a stretching program.

6 In regards to our findings between the sexes, as expected the female subjects in our study
7 demonstrated higher hamstring ROM at pre, week four and week eight. These findings support
8 previous studies which show that females are more flexible than males for most body regions
9 (1,2,7,25). However, the relative rate of change over time did not differ between men and
10 women (Figure 5). These findings contradict Starring et al (43) who found that male subjects
11 are not expected to gain or maintain as much ROM as female subjects. We attribute the
12 inconsistencies to the difference in the methodologies of these two investigations. Starring et al
13 examined individuals with tight hamstring muscles and utilized a mechanical stretching device
14 however, our study recruited subjects with normal hamstring flexibility and had subjects perform
15 a one legged hamstring stretch without the use of additional equipment. It is possible that
16 individuals with tight muscles may respond differently to stretching compared to individuals
17 with less tight muscles. The effect of a mechanical stretching device can also potentially
18 influence stretching gains as subjects are no longer in control of the stretching force. Also, while
19 there is evidence suggesting that males tend to respond faster to exercise programs compared to
20 females, this difference was not exhibited in our stretching study (16,29,41,44).

21

22 [FIGURE 5 about here]

23

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

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

17

18 **PRACTICAL APPLICATION**

19 When prescribing a stretching program for patients, clients, or athletes, it is important to
20 identify the optimal frequency and hold duration of a stretch. Thirty second hold time appears to
21 be effective, based on this study and previous studies. We now have evidence that stretching as
22 infrequently as three days each week can be as equally beneficial as stretching every day, in
23 terms of hip ROM. Our data support at least six times/week of stretching, in any one week

1 period, which can be accomplished either once each day, on a daily basis, or twice each day and
2 only three days each week. Less frequent stretching (i.e., three days/week rather than daily)
3 might appeal to individuals who struggle to fit stretching into their already busy schedule of
4 training and conditioning. Athletes can consider devoting only a few days each week to
5 stretching, while continuing with other forms of conditioning and training. Fewer days each
6 week might also appeal to individuals who do not enjoy the process of stretching, yet require the
7 benefits of this activity. Hence, a reduced frequency protocol might provide greater compliance
8 for these patients, clients and or athletes. Coaches, trainers and therapists should also expect to
9 see fairly consistent changes over time, with a stretching program. We did not find that the
10 weekly gains were significantly different from one week to the next. Based on our data, we
11 recommend that individuals strive to stretch two times per day, to optimize the ability of
12 stretching to create ROM gains. Further, as observed by others, it is possible to maintain gains in
13 ROM by continuing with stretching only two or three days each week. Individuals should be
14 aware though that the gains achieved with a stretching program will decline gradually over time
15 if all stretching ceases.

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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

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

Group	^aSelf-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

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

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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

^aControl group significantly less than all stretching groups ($p < 0.05$)

^bValues significantly greater than the Pre values ($p < 0.05$)

^cRelative change significantly less than the relative change of groups S6, S7, and S14 ($p < 0.05$)

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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

^aControl group significantly less than all stretching groups (p< 0.05)

^bValues significantly less than Week four values (p < 0.05)

^cValues significantly greater than Pre values (p < 0.05)

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

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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

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Figures Legend

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3 **Figure 1.** Group randomization process and retention

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

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

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

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