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TITLE PAGE

Title: Comparison of active stretching technique in males with normal and limited hamstring flexibility.

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ABSTRACT

Objective: (1) to analyse the accumulative effects of a 12-week active stretching program on hip flexion passive range of motion (HF-PROM), and (2) to compare whether participants with different PROM baseline scores (normal and limited hamstring flexibility) respond in the same way to stretching.

Design: Repeated measures design.

Setting: Controlled laboratory environment

Participants: 138 males were categorized according to hamstring flexibility in the unilateral passive straight-leg raise test (PSLR) and assigned to one of two groups: normal hamstring flexibility (≥80º) or limited hamstring flexibility (<80º). In each group, participants were randomly distributed into one of two treatment subgroups: (a) control or (b) active stretching. The active stretching subgroups performed 12 weeks of flexibility training, the control subgroups did not stretch.

Main Outcome Measures: HF-PROM was determined through the PSLR test.

Results: Both stretching subgroups significantly improved ($p < 0.01$) their HF-PROM from baseline. The control subgroups did not.

Conclusions: 12 weeks of an active stretching program performed 3 days per week with a daily stretch dose of 180 seconds improved HF-PROM in both populations (normal and limited hamstring flexibility). The stretching program was equally effective in terms of absolute improvement values for males with normal and limited hamstring flexibility.

Key words: stretching, ROM, flexibility, hamstring muscles, tightness.

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MAIN TEXT

1. Introduction

The length of the hamstring muscles is considered to play an important role in both the effectiveness and the efficiency of basic human movements, such as walking and running (Gajdosik, 1991). Clinical observations have suggested that limited hamstring flexibility is very common in general populations (Hellsing, 1988) as well as athletic populations (Witvrouw, Danneels, Asselmann, Dhave and Cambier, 2003) and is associated with various musculoskeletal alterations, including specific disorders of the lumbar spine, such as low back pain (Biering-Sorensen, 1984) and changes in lumbo-pelvic rhythm (Esola, McClure, Fitzgerald and Siegler, 1996). Likewise, in sports therapy, short hamstrings have been related to muscle strains (Croisier, Forthomme, Namurois, Vanderthommen and Crielaard, 2002), development of patellar tendinopathy (Witvrouw, Bellemans, Lysens, Danneels and Cambier, 2001) and patellofemoral pain (Witvrouw, Lysens, Bellemans, Cambier and Vanderstraeten, 2000), muscle damage following eccentric exercise (McHugh, Connolly, Eston, Kremenic, Nicholas and Gleim, 1999), and a reduction in athletic performance (Kovacs, 2006).

Stretching programs have generally been shown to increase muscle flexibility, most likely as a result of enhanced stretch tolerance rather than mechanical/physiological changes in the muscle that is being stretched (Chan, Hong and Robinson, 2001; Laroche and Connolly, 2006; Law, Harvey, Nicholas, Tonkin, De Sousa and Finniss, 2009). Several studies have proposed various stretching programs to improve hamstring muscle flexibility (Bandy and Irion, 1994; Cipriani, Abel and Pirrwitz, 2003; Davis, Ashby, McCale, McQuain and Wine, 2005). In general, these studies have reported that joint range of motion (ROM) is improved in the long term after approximately 3-6 weeks of regular passive stretching.

However, when the body of literature regarding the methodology of the studies and the design of the stretching programs proposed to improve flexibility is carefully scrutinized, some important limitations are noted that may question their applicability in the physical training and rehabilitation context. A recent systematic literature review regarding the effects of hamstring stretching on ROM demonstrated that the methodological quality (assessed using the Physiotherapy Evidence Database [PEDro] [10-point] scale) of the studies that investigated the most effective positions, techniques, and durations of stretching to improve hamstring muscle flexibility was poor (the average score was 4.3 out of 10 points) (Decoster, Cleland, Altieri and Russell, 2005). The most critical deficiencies noted were the lack of a blinded data collection technician and whether the assessors were blinded to the treatment groups. These issues significantly impact the validity of the evidence that can be deducted from these studies.

Furthermore, most of these studies used a pre-test and post-test design (Bandy and Irion, 1994; Bandy, Irion and Briggler, 1997; Chan, Hong and Robinson, 2001; Laroche and Connolly, 2006; Law et al., 2009; Reid and McNair, 2004; Webright, Randolph and Perrin, 1997), which does not demonstrate the progression of the ROM throughout the stretching program or whether a plateau effect may occur in ROM improvement.

Typically, the length of stretching programs used by the studies that were examining the accumulative effects of stretching on joint ROM ranged from 10 days to 6 weeks (Bandy and Irion, 1994; Bandy, Irion and Briggler, 1997; Cipriani, Abel and Pirrwitz, 2003; Davis et al., 2005; Ford, Mazzone and Taylor, 2005; Gribble, Guskiewicz, Prentice and Shields,1999; Laroche and Connolly, 2006; Webright, Randolph and Perrin, 1997); thus, it is not well known whether longer stretching programs may allow greater improvement of joint ROM.

Further, with regard to stretching dose, several studies proposed training programs consisting of 5 days per week or more (Bandy and Irion, 1994; Bandy, Irion and Briggler, 1997; Cipriani, Abel and Pirrwitz, 2003; Ford, Mazzone and Taylor, 2005; Webright, Randolph and Perrin, 1997), which is not representative of the typical training regimen performed by recreationally active people.

Most of these authors have reported that the hamstring baseline scores of the sample who took part in their studies could be categorized as poor or limited when using the reference criterion established for each hamstring flexibility measurement test (Bandy and Irion, 1994; Bandy, Irion and Briggler, 1997; Chan, Hong and Robinson, 2001; Cipriani, Abel and Pirrwitz, 2003; Davis et al., 2005; Ford, Mazzone and Taylor, 2005; Gajdosik, Allred, Gabbert and Sonsteng, 2007; LaRoche and Connolly, 2006; Nelson and Bandy, 2004). Therefore, how stretching programs affect the hamstring flexibility baseline scores in populations who have moderate (not limited) hamstring flexibility is not well known. Furthermore, to the authors' knowledge, no studies have investigated whether participants with different ROM baseline scores (normal and limited hamstring flexibility) respond in the same way to stretching programs with consistent stretching parameters.

Therefore, the main purposes of this research study were: (1) to analyse the accumulative effect of a 12-week active stretching program with a contextualized training load (3 days per week with a total daily dose of 180-s) on hip flexion passive range of motion (PROM), and (2) to compare whether participants with different PROM baseline scores (normal and limited hamstring flexibility) respond to stretching in the same way in a randomized, controlled trial at 4, 8 and 12 weeks into a training program.

2. Methods

2.1. Participants

One hundred and sixty-one young adult male university students (mean ± SD; age = 22.1 ± 1.5 years; height = 176.3 ± 8.4 cm; body mass = 75.4 ± 8.8 kg) took part in this study. All participants reported being recreationally active (engaging in 1-5 hours of moderate physical activity 3-4 days per week). Participants were recruited voluntarily through the University Sports Science Department.

The participants met 4 basic requirements: (1) participants had no history of impairments to the knee, thigh, hip, or lower back in the 2 years prior to the study, (2) all participants were free of delayed onset muscle soreness, (3) participants who were not already involved in an exercise program for the trunk or lower extremities agreed not to start a program for the duration of the study, and (4) participants who were already undertaking a regular exercise program agreed not to increase the frequency or intensity of their program during the 12-week training period. Additionally, two exclusion criteria were established: participants who missed (1) more than 2 stretching sessions per month and/or 5 total stretching sessions and/or (2) one testing session were eliminated from the study.

The participants were verbally informed about the procedure that was going to be utilized as well as the purpose and risks of the present study, and written informed consent was obtained from all participants.

Further, the study was approved by the "Review Committee for Research Involving Human Subjects" at the Catholic University San Antonio (Spain).

2.2. *Procedure*

One week before the first testing session, all participants from the stretching subgroups completed a familiarization session in order to prepare and practice the active stretch technique and the testing procedures that were to be employed in the study. On the other hand, the control subgroups only practiced the testing procedure. The familiarization sessions for the stretching and control subgroups were performed separately and on different days.

In the first testing session, all participants were categorized according to their hamstring flexibility and assigned to one of two groups: (1) normal hamstring flexibility (n = 76) or (2) short hamstring flexibility (n = 62). To categorize the participants with normal or limited hamstring flexibility, the reference criterion reported by Palmer and Epler (2002) and Kendall, McCreary and Provance (1993) was used, which established that the cut-off for passing the passive straight leg raise (PSLR) test (normal hamstring flexibility) should be greater than or equal to 80º for adults. Within each group, all participants were randomly distributed (using software at http://www.randomizer.org) into one of 2 subgroups: (a) control or (b) stretching.

Flexibility of the hamstring muscles (hip flexion ROM) was measured at the beginning of the study, at 4 and 8 weeks after the stretching program began, and immediately after the stretching program finished. Two days of rest were provided before the post-test (Ford, Mazzone and Taylor, 2005). Measurements were performed throughout the study by the same two examiners, at the same time of the day, and under the same environmental conditions. The examiners were blinded to the purpose of the study, to the group assignment, and to test results from previous testing sessions throughout the investigation.

No training or stretching was performed on testing days, and all participants were tested on the same day, at the same time of day, in the same indoor track facility. Participants were examined in sports clothes and without shoes. Moreover, no warm-up or stretching exercises were performed by the participants prior to test measurements (Ford, Mazzone and Taylor, 2005; Sainz de Baranda and Ayala, 2010). Room temperature was 25º Celsius.

2.3. Hamstring flexibility test

The criterion measure for hamstring flexibility was determined by executing a maximum PSLR on each limb (American Academy of Orthopedic Surgeons, 1965). Variations in pelvic position and joint stability have been reported as factors that could affect the PSLR score (Bohannon, Gajdosik and LeVeau, 1985; Fredriksen, Dagfinrud, Jacobsen and Maehlum, 1997). Bohannon et al. (1985) reported that for every 1.7° of hip motion, there is 1° of pelvic motion when performing the PSLR test. To accurately measure hamstring muscle flexibility, the testing procedure in this study provided suitable stabilization of the pelvis during the PSLR test.

The participant was placed in the supine position with his legs straight and the ankle of the tested leg in a relaxed position (Boland and Adams, 2000; Gajdosik, Leveau and Bohannon, 1985). A low-back support (Lumbosant, Albacete, Spain) (figure 1) was used to maintain the normal lordotic curve (Sainz de Baranda and Ayala, 2010). The first test administrator kept the contralateral leg straight and in place to avoid external rotation and fixed the pelvis to attempt to minimize posterior pelvic tilt (initial position). The second test administrator placed the ISOMED inclinometer (Portland, OR, USA) over the external distal tibia (close to the lateral malleolus) and the free hand was placed over the knee to keep it straight (figure 2). The inclinometer was calibrated to the level table top before each testing session. The participant's leg was lifted passively by the second test administrator into hip flexion. The ankle was kept in a relaxed position throughout to minimize the influence of the gastrocnemius muscle (Boland and Adams, 2000). Both legs were randomly tested using the software at http://www.randomizer.org. The endpoint for straight-leg raising was determined by 1 or both of 2 criteria: a) the examiner's perception of firm resistance, and b) palpable onset of pelvic rotation. The score criterion of hip flexion PROM was the maximum angle read from the inclinometer at the point of maximum hip flexion. Two maximum PSLR trials on each limb were carried out and the average of the two were used for the subsequent statistical analyses.

2.4. Flexibility training

All stretching subgroups performed 12 weeks of flexibility training, 3 days per week, always on non-consecutive days (36 stretching session). The total stretch time for a session was 180s. In each training session, both legs were stretched using 2 unilateral and 2 bilateral un-assisted active stretching exercises (figure 3). Specifically, one repetition of each unilateral stretching exercise and two repetitions of each bilateral stretching exercise were performed, and participants held each stretch position for 30s. Consequently, 6 sets of 30s were performed in each training session. Between each stretching repetition, the participants' hip extensor muscles were returned to a neutral position for a 20s rest period. The order of application for the stretching exercises was random for each stretching session (using the software at http://www.randomizer.org). All these stretching program parameters (single duration, daily dose, and frequency) were selected according to the American College of Sports Medicine (ACSM) stretch recommendations (2011).

Such an active technique is based on reciprocal inhibition between agonist and antagonist muscles, which increases muscle flexibility whilst concomitantly improving the muscle function of antagonist muscles (Blackburn and Portney, 1981). In addition, stretching instructions were based on work initially described by Sullivan, Dejulia and Worrell (1992) and later applied by Kolber and Zepeda (2004), Winter et al. (2004) and Ford, Mazzone and Taylor (2005). From a biomechanical perspective, this active stretch technique was followed: hands were kept on hips; head was held in a neutral position with the participant looking straight ahead; the leg to be stretched was kept fully extended; and the cervical, thoracic, and lumbar spine was extended. In each stretching exercise, participants tilted the pelvis forward to create a lordosis (hip flexors and paraspinal and abdominal muscles) in the lumbar spine that would place the hamstring muscle group in a position of maximal stretch (Meroni et al., 2010).

After the initial instructions and demonstration, each participant from the stretching subgroups was given a home-exercise sheet that included a schematic representation of the stretching mode and written instructions on flexibility training. To monitor their training program, each person had to complete a personalized calendar of their stretching activity and was contacted every week by an external investigator. In addition, this external investigator coordinated all stretching-related activities (i.e., group assignment, initial demonstration, supervision and compliance recordkeeping) to keep the two test administrators blinded to all stretching activities. The control subgroups did not receive a training program. To supervise the stretching subgroups, the participants were contacted every week to check their compliance with the stretching program. Participants in the control subgroups were asked to complete a questionnaire half-way through (week 6) and at the end of the study. The main goal of this questionnaire was to make sure that the participants in the control subgroups did not undertake additional stretching exercises during the intervention period (Mahieu, McNair, De Muynck, Stevens, Blanckaert, Smits and Witvrouw, 2007).

2.5. Statistical Analyses

Before data collection, the reliability coefficient of the measurement of the hamstring muscles using the procedures just described was determined by the test administrators using a test-retest design. Twenty healthy male participants who were not involved in this study agreed to participate in a pilot study to assess the measurement reliability. Range of motion was measured twice within a one-week interval. An intraclass correlation coefficient and a coefficient of variation (CV) were calculated from the results of subsequent measurements. Results of the two measurements showed a high reliability (ICC = 0.95 [95% confidence interval = 0.89-0.98]; CV = 5.3%) consistent with previous studies (Sainz de Baranda and Ayala, 2010; Santonja, Sainz de Baranda, Rodríguez, López and Canteras, 2007).

Means and standard deviations for all groups and measurements were calculated for hip flexion PROM as were the mean differences between pre-test and post-test scores (gain scores) for the dependent variable, PROM (in degrees). To verify the normality of the PROM scores, the Kolmogorov-Smirnov test was used. Two-way analysis of covariance (4X4), stretching program (training group with normal hamstrings versus training group with short hamstrings versus control group with normal hamstrings versus control group with short hamstrings) and moment of measurement (pre-test versus 4-week test versus 8-week test versus post-test), with repeated measures in the last factor were used to analyse whether hip flexion PROM scores varied by group (Morton, 2009). The baseline measurement was used as a covariate to equalize any influences across the groups due to the pre-test. When significant intergroup differences were noted, post hoc Bonferroni tests were carried out. All data were analysed using SPSS 15.0 for Windows, and statistical significance was accepted at the 95% level ($p<0.05$).

Further, a post hoc power analysis was conducted using the software package, G*Power 3.1.2. (Faul, Erdfelder, Buchner and Lang, 2009; Faul, Erdfelder, Lang and Buchner, 2007). The sample size of 138 was used for the statistical power analyses (ANCOVA). The alpha level used for this analysis was $p < .05$ and the effect size (d) was fixed at 0.80.

3. Results

One-hundred and thirty-eight young adult male university students (mean ± SD; age = 21.9 ± 1.7 years; stature = 177.4 ± 8.5 cm; body mass = 74.9 ± 8.4 kg) completed this study (figure 4). Twenty-three participants were excluded from the study because they missed more than two stretching sessions per month and/or 5 stretching sessions throughout the entire study (n = 15) or more than 1 testing session (n = 8).

The mean and standard deviation values for hip flexion PROM in each subgroup and in each testing session are reported in table 1. The results show no significant differences ($p > 0.05$) in the joint ROM between right and left sides for the four groups. Thus, the average score of the two legs are presented.

The two-factor (4x4) (experimental groups and testing session) repeated measures analysis of covariate (initial measurement) [RMANCOVA] revealed an interaction effect among groups ($p<0.0005$). Post-hoc testing revealed significant differences between the control subgroups and their respective stretching subgroups ($p<0.05$). Additionally, no significant differences in the improvement of hip flexion ROM were found between the different stretching subgroups (normal and short hamstring subgroups) (table 1).

The intra-group analysis showed significant differences in hip flexion ROM across all the measured time periods for each stretching subgroup ($p<0.0005$). Further analysis revealed that at each testing session, significant passive hip flexion ROM improvements were found in both stretching subgroups from their previous testing sessions.

Finally, the post hoc analyses revealed that the statistical power for this study was 0.82. It could be concluded that the given sample size was large enough to detect significant effects (Morton, 2009; Atkinson & Nevill, 2001). Therefore, the baseline measurement that was used as a covariate exerted a statistically significant influence on hip flexion ROM in all stretching subgroups ($p<0.0005$).

4. Discussion

The main purpose of the current study was to analyse and compare the accumulative effects and PROM improvement tendency on hip flexion PROM after 12 weeks of active static stretching in participants with normal and limited hamstring flexibility.

The current study has found significant improvements in hip flexion PROM after 12 weeks of active static stretching in both normal (Δ13.36º) and limited (Δ14.97º) hamstring stretching subgroups whilst no significant changes occurred in either control subgroups. Furthermore, after 4 and 8 weeks of the stretching program, both normal and short hamstring stretching subgroups showed significant improvement in hip flexion PROM (from the pre-test and the 4-week test, respectively); therefore, a plateau effect was not reached.

These increases in hip flexion PROM after 12 weeks of an active stretching program, which demonstrate a quantitative improvement in hamstring flexibility, are consistent with the findings of previous studies that have examined the effect of active (Cipriani, Abel and Pirrwitz, 2003; Ford, Mazzone and Taylor, 2005; Sainz de Baranda and Ayala, 2010) and/or passive (Bandy and Irion, 1994; Bandy, Irion and Briggler, 1997; Chan, Hong and Robinson, 2001; Gribble et al., 1999; Laroche and Connolly, 2006; Law et al., 2009; Reid and McNair, 2004; Webright, Randolph and Perrin, 1997) static hamstring stretching in a similar manner to that used in this study, generally in participants with limited hamstring flexibility baseline scores. However, it should be noted that although the majority of these studies have reported similar increases in hamstring flexibility after performing a systematic stretching program with a shorter duration (4 to 8 weeks) than the current study, most of them have used much higher stretching frequency (5-7 days per week), which are not contextualized (Bandy and Irion, 1994; Bandy, Irion and Briggler, 1997; Cipriani, Abel and Pirrwitz, 2003; Ford, Mazzone and Taylor, 2005; Law et al., 2009; Webright, Randolph and Perrin, 1997).

An increase in hip flexion PROM may be achieved by (a) mechanical/physiological changes of the muscle-tendon unit being stretched (expressed as changes in the stiffness and work-absorption capacity) or (b) by increased tolerance to stretch (evidenced by increases in passive resistance to stretch). However, since the current study did not directly measure any viscoelastic properties of the hamstring (only the hip flexion PROM was assessed), we are unable to discern the exact mechanism by which hamstring flexibility was increased.

On the other hand, the findings of the current study showed that active stretching improved hip flexion PROM at 4, 8 and 12 weeks after beginning a stretching program; therefore, a plateau effect was not reached. However, it should be noted that although the magnitude of the improvements in hip flexion PROM during the last 4 weeks were statistically significant, they were lower compared to those in the previous 8 weeks. Thus, it may be suggested that the effects of the stretching program were diminishing and a plateau effect may be approaching. This investigation contradicts the findings of Davis et al. (2005) and Gribble et al. (1999) about length of the stretching program. Davis et al. (2005) found that active stretching did not result in a significant increase in hip ROM when compared to a control after performing a 4 week stretching program for 3 days per week. Perhaps a possible explanation is the fact that that study used only 30s of total daily stretch duration whereas the present study used 180s of total daily stretch. Moreover, Gribble et al. (1999), after performing a 6-week static stretching program 3 days per week reported that their participants reached a plateau in flexibility improvement between weeks 4 and 5. Although it is difficult to explain the reason for these results when compared to the results found in the current study, perhaps there are two possible explanations. First is the fact that Gribble et al. (1999) assessed the hip PROM immediately after having performed a stretching session (which could influence the results). The other possible explanation is that after a first short period of flexibility training (4 weeks), more than 2 weeks of stretching may be necessary to see a significant improvement in joint ROM. In the current study, hip flexion PROM was always tested two days after having performed the last stretching session and it was tested every 4-weeks.

To our knowledge, this is the first study to have compared the accumulative effect of stretching between participants with normal and short hamstring flexibility in the same population. The results have shown no significant improvement differences in hip flexion PROM in the two stretching subgroups (normal and short hamstring flexibility) when absolute values were analysed (13.36º and 14.97º, respectively). These data suggest that participants with normal and short hamstring flexibility respond in a similar way when a stretching program is performed. Participants with limited hamstring flexibility may have been more prone to improve hip flexion PROM because of their low baseline values. Perhaps the stretch frequency and daily dose used in the current study was strong enough to elicit the highest improvement in flexibility that can be assumed by the hamstring muscles in both participants with normal hamstring flexibility and those with limited hamstring flexibility. Future studies using lower stretch daily doses are needed to check this theory.

5. Conclusion

The present study demonstrates that a 12-week active stretching program improved hip flexion PROM when performed 3 days per week with a stretch daily dose of 180 seconds in both populations (normal and limited hamstring flexibility). Furthermore, the stretching program was equally effective in terms of absolute improvement values for males with normal and limited hamstring flexibility.

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Table 1: Results of the general linear model for repeated measures on hip flexion PROM measurements (mean ± standard deviation [SD])

	Stretching Groups				Control Groups			
	Normal Hamstring Flexibility (n=39)		Limited Hamstring Flexibility (n=32)		Normal Hamstring Flexibility (n=37)		Limited Hamstring Flexibility (n=30)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Baseline (pre-test)	90.1°	±8.8	71.4°	±5.7	89.7°	±7.2	71.1°	±4.6
4-week test	94.9°	±10.9*	79.2°	±7.2*	92.4°	±9.7	69.3°	±5.3
8-week test	100.7°	±11.9†	84.6°	±9.1†	91.4°	±8.4	72.1°	±6.2
12-week (post-test)	103.7°	±12.5‡	86.1°	±9.2‡	91.1°	±6.4	70.6°	±7.6
X4-X1	13.6°		14.7°		1.3°		- 0.5°	

Analysis of covariance (ANCOVA) baseline values as covariate:

- Main effect time $p < 0.001$
- Post hoc: *: significant difference from pre-test ($p<0.05$); †: significant difference from 4-week test and pre-test ($p<0.05$); ‡: significant difference from 8- and 4-week tests and pre-test ($p<0.05$).

X1-X4: differences between the pre-test and post-test averages

Figure legend:

Figure 1: Low-back protection support use to maintain the normal lordotic curve during passive straight leg raise test.

Figure 2: Passive straight leg raise test.

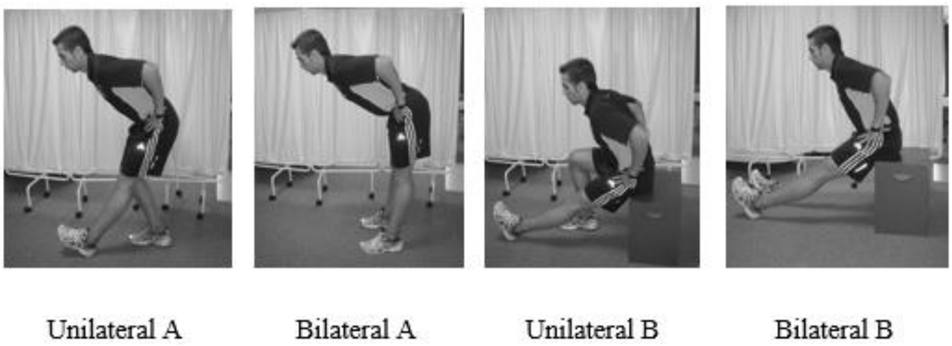

Figure 3: Active stretching exercises

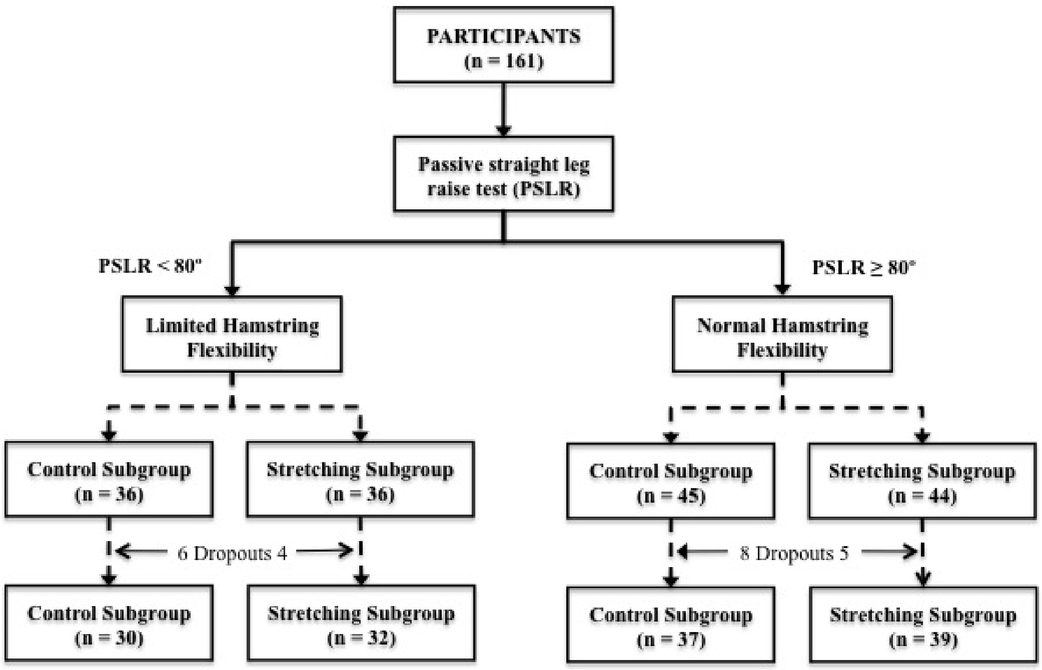

Figure 4: Flow of participants through experimental phase of the study.