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EXERCISE PHYSIOLOGY

Investigation into the long-term effects of static and PNF stretching exercises on range of motion and jump performance

Bekir Yuktasir[a,*], **Fatih Kaya**[b]

[a]*Abant Izzet Baysal University, Bolu, Turkey*
[b]*Marmara University, Istanbul, Turkey*

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Summary The purpose of the present study was to investigate the long-term effects of two different stretching techniques on the range of motion (ROM) and on drop jump (DJ). DJ scores were assessed by means of a contact mat connected to a digital timer. ROM was measured by use of a goniometer. The training was carried out four times a week for 6 weeks on 10 subjects as passive static stretching (SS), and on 9 subjects as contract–relax PNF (CRPNF) stretching. The remaining nine subjects did not perform any exercises (control group). One-way Analysis of Variance (ANOVA) results indicated that the differences among groups on DJ were not statistically different ($F(2,27) = .41$, $p > .05$). ROM values were significantly higher for both stretching groups, while no change was observed for the control group. In conclusion, static and proprioceptive neuromuscular facilitation (PNF) stretching techniques improved the ROM, but neither of the stretching exercises had any statistically significant effect on the DJ scores.

Introduction

Recent advancement in sports medicine and rehabilitation indicate that flexibility is important to general health and physical fitness. Most of the studies have been conducted to assess the effects of stretching exercises on range of motion (ROM). It is well known that static muscle stretching techniques enhance ROM (Hortobagyi et al., 1985; Marek et al., 2005). In the literature, the increase in ROM, often reported after passive stretching, which may involve biomechanical, neurological and molecular effects, appear to be understood (De Deyme 2001).

Among stretching techniques, proprioceptive neuromuscular facilitation (PNF) stretching, which inhibits tonic reflex activity as a limiting factor during stretches, and increases ROM markedly

*Corresponding author.
E-mail address: yuktasir_b@ibu.edu.tr (B. Yuktasir).

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(Moore and Hutton, 1980; Etnyre and Abraham, 1986; Guissard et al., 1988). Both mechanical and neural adaptation mechanisms are responsible for these changes during stretching (Guissard and Duchateau, 2004). Studies suggest that autogenic and reciprocal inhibition mechanisms occur during the PNF stretching technique application. An isometric contraction of stretched muscle during applied PNF stretching technique triggers the autogenic inhibition mechanism, creating a subsequent reduction in muscle tension through stimulation of Golgi tendon organs. This mechanism lowers resistance to stretch, and is important in improving ROM. In addition, tension during the maximum isometric contraction of the stretched target muscle results in less resistance to length changes in the same muscle. Alternatively, concentric contraction of an antagonist muscle causes reciprocal inhibition. Because of this reciprocal inhibition, an active reduction in resistance takes place in the target muscle. A reduced excitability of motor neurons located in the stretched muscle, causing reciprocal inhibition, provides muscle compliance by allowing muscle lengthening (Prentice, 1983; Moore and Hutton, 1980; Etnyre and Abraham, 1986).

Jump performance can be described as an explosive force production of the lower extremities. Byrne and Eston (2002) explained types of jumps such as the squat jump, which is considered a pure measure of concentric muscle performance; another is the counter-movement jump, which uses the stretch-shortening cycle by a downward counter-movement from a standing position; and the drop jump (DJ), which involves rebounding vertically after a drop from a specified height and which also uses the stretch-shortening cycle. In this cycle, an explosive concentric muscle action is preceded by an eccentric action which causes higher force and power in the muscle (Graham, 2005).

Although acute stretching exercises can enhance ROM, it may also reduce peak force, rate of force production and power output (Stone et al., 2006). Recent studies conducted on the acute effects of static stretches and PNF have shown that these stretching techniques may result in a significant reduction or no change on jump performance and on power output (Power et al., 2004; Little and Williams, 2006; Wallmann et al., 2005; Unick et al., 2005; Knudson et al., 2001; Young and Behm, 2003; Church et al., 2001). These studies addressed acute changes that were due to decreased stiffness, increased strength in extreme positions and hypertrophy. In contrast, our present study was conducted in order to evaluate the long-term effects of the static and PNF stretching exercise on jump performance.

Research have shown that stretching exercise programs provide positive outcomes such as preventing injuries, facilitating rehabilitation and are also used as a warm-up regimen. Hence, these studies emphasize the importance of stretching in sports and rehabilitation of muscle–tendon injuries (Malliaropoulos et al., 2004; Witvrouw et al., 2007).

Although, effects of static and PNF stretching (e.g., acute, long-term, etc.) on DJ have been well documented in sport sciences, there have been only a limited amount of studies evaluating the same factor for rehabilitation purposes. Hence, conducting similar studies on patients and/or healthy persons regarding static stretching (SS) and PNF stretching on DJ might produce new data regarding their rehabilitation processes. In this research, we focus on the long-term effects of static stretching and PNF stretching on healthy subjects.

In particular, the present study was designed to investigate the chronic effects of 24 sessions of passive static stretching and contract–relax PNF (CRPNF) stretching on ROM and on DJ performance.

Material and methods

Twenty-eight healthy male volunteers, who were students at a School of Physical Education and Sports, participated in the study. The age range of the subjects was between 18 and 26 years (mean age: 21.82 ± 1.90). The subjects were all well accustomed to the experimental procedure and had no signs of any neurological or orthopedic disorder. All subjects were informed about the experimental procedures. Written consent was obtained from the subjects after that they had been informed of the purpose, procedure and risks of participating in the study. They were also informed that they could withdraw from the study at any time, even after giving their written consent.

The subjects of the study were randomly divided into three groups: a passive static stretching group ($n = 10$), a CRPNF stretch group ($n = 9$) and a control group ($n = 9$).

The data were collected in two stages. The first measurement (pre-test) was taken a day before the stretching training, and the second (post-test) a day after the training program. None of the investigators, who took the measurements, knew which group the subjects belonged to.

The knee joint ROM measurements were performed using a standard handheld goniometer (Whitehall) by two investigators, while the subjects were supine on a table. The knee was passively extended until the subject felt discomfort while the hip was stabilized at 90° of flexion. The center of the fulcrum was positioned over the lateral condyle of the femur. The proximal fixed arm of the goniometer was aligned with the axis of the femur, by using the greater trochanter as a reference point. The distal mobile arm was aligned by using the lateral malleolus as the reference point (Figure 1). Measurements were recorded in degrees (Bandy and Irion, 1994; Feland et al., 2001).

The DJ (60 cm) measurements were done with a Newtest 1000 (a digital timer connected to a contact mat) (Figure 2). The mat measures flight time and it is started by the feet of the subject at the instant of take-off, and is stopped at the instant of contact on landing. DJ was performed using bilateral foot contact. The subject dropped from a box (60 cm height) onto the contact mat, and jumped straight upward immediately as high as possible, while keeping hands on hips during the entire test. The trial was repeated twice for each jump and the best time was recorded. The flight time was utilized in calculating the height of rise of center of gravity. It was computed as follows: $h = g \times t^2/2$, where h is the height of rise of the center of gravity, g is the acceleration due to gravity (9.81 m/s^2) and t is flight time.

Training program

At the beginning of the training program, subjects were informed about the stretching techniques. Static stretching or CRPNF stretching exercises were performed by the respective group four times per week for 6 weeks for a total of 24 sessions. Control group did not participate in any exercise program. Volume of the training periods of the two stretching groups was the same. In this study, training volume refers to 24 sessions; 30 s hold and comfort level not exceeding 5 on a standard visual analogue scale (VAS).

Passive static stretching training

In the stretching exercises each subjects lay supine on the floor. For hamstring muscle group stretching, the knee joint was extended while the hip was held at 90° of flexion while simultaneously the ankle joint was flexed to 90° (neutral ankle dorsi-flexion) (Figure 3) to stretch the triceps surae for 30 s. Stretching was performed at the maximum range tolerated by the subjects. For each leg, the stretching was repeated four times with a rest period of 10 s between stretches.

Contract–relax PNF stretching training

The contract–relax PNF procedure consisted of three stages. In the first stage, with each subject

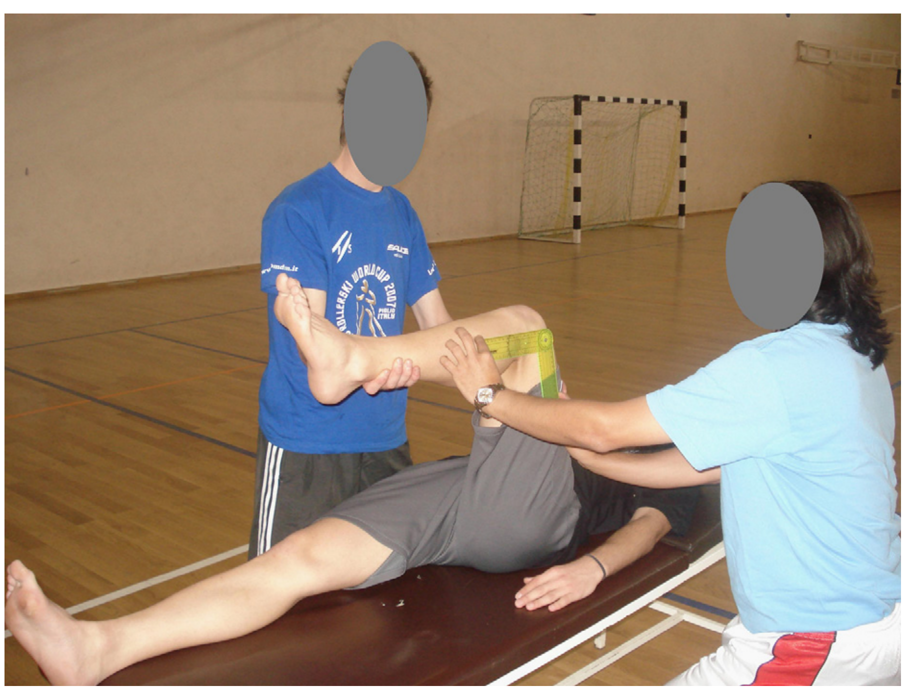

Figure 1 Measurement of the knee joint range of motion measurements (ROM) using a standard handheld goniometer.

Figure 2 The drop jump test.

lying supine, the knee joint was extended while the hip was held at 90° of flexion while simultaneously the ankle joint was flexed to 90° (neutral ankle position) and then the ankle joint was flexed dorsally for 10 s (Holcomb, 2002). In the second stage, for 5 s, hip extension and ankle plantarflexion was requested, against a force executed submaximally by the investigator. Following the subject's 5 s voluntary contraction, each subject relaxed for 5 s and then in the third stage, the investigator applied hip- and dorsi-flexion stretching forces for an additional 15 s (Figure 4). For each leg, the stretching was repeated four times with a rest period of 10 s between each procedure.

Statistics

Descriptive statistical methods were used for calculating the means and standard deviation of the means. Paired-sample *t*-test was run to compare the pre- and post-training results of each group. The One-way Analysis of Variance (ANOVA) was run to analyze (gain/loss scores) differences among groups on ROM and DJs variables. Then the Scheffe post-hoc test was run to determine which of the three pairwise comparisons contributed to the significant findings. The alpha level was set at .05 level for this study.

Figure 3 Passive static stretching.

Figure 4 Contract–relax PNF stretching.

Results

Table 1 shows the DJ mean values for pre- and post-measurements. Accordingly, no statistically significant mean value differences were observed between the pre-test and post-test mean scores for all groups.

The gain in joint ROM from pre- to post-test was observed in all the subjects in both stretching groups (Table 2).

ANOVA was employed to test statistical mean differences among the three groups on DJ and ROM. As can be seen from Table 3, the results indicated that the differences among groups on DJ were not

Table 1 Paired *t*-test results for all three groups on drop jump.

Group	Period	Drop jump (s) mean±S.D.	d.f.	*t*	*p*
SS ($n = 10$)	Pre-training	0.365±0.04	9	−1.92	.086
	Post-training	0.394±0.05			
PNF ($n = 9$)	Pre-training	0.348±0.05	8	−.99	.350
	Post-training	0.362±0.06			
Control ($n = 9$)	Pre-training	0.362±0.04	8	−.83	.429
	Post-training	0.374±0.03			

Table 2 Paired *t*-test results for all three groups on ROM.

Group	Period	ROM mean±S.D.	d.f.	*t*	*p*
SS ($n = 10$)	Pre-training	21.6±7.45	9	7.96	.001[a]
	Post-training	6.2±3.67			
PNF ($n = 9$)	Pre-training	26.33±6.28	8	18.52	.001[a]
	Post-training	7.11±4.64			
Control ($n = 9$)	Pre-training	20.44±13.23	8	1.65	.138
	Post-training	17.22±11.12			

[a]The mean difference is significant at the .01 level.

Table 3 Summary statistics for both ANOVAs on drop jump and ROM.

		Sum of squares	d.f.	Mean square	*F*	Sig.
Drop jump	Between groups	.001	2	.000	.41	.666
	Within groups	.050	25	.002		
	Total	.052	27			
ROM	Between groups	1264.20	2	632.10	22.91	.001[a]
	Within groups	689.51	25	27.58		
	Total	1953.71	27			

[a]The mean difference is significant at the .01 level.

Table 4 Scheffe post-hoc results of ROM among groups.

Dep. variable	Groups	Groups	Mean diff.	Std. err.	Sig.
ROM	SS	PNF	−3.82	2.41	.303
		Control	12.17	2.41	.001[a]
	PNF	SS	3.82	2.41	.303
		Control	16.00	2.48	.001[a]

[a]The mean difference is significant at the .01 level.

statistically different ($F(2,27) = .41$, $p > .05$). On the other hand, the ANOVA results indicated a statistically significant differences for at least one group on ROM ($F(2,27) = 22.91$, $p < .05$). In order to determine which group(s) mean scores were statistically different, the Scheffe post-hoc analysis was carried out. The results of this statistics indicated that both PNF and static stretching groups showed a pronounced statistically significant increase in ROM values when compared with control group's scores (Table 4).

Discussion

The present study was designed to assess the prolonged effects of two different stretching techniques performed four times per week for 6 weeks on ROM and DJ. The obtained results showed that neither the static stretching nor CRPNF stretching exercises caused any change on the DJ scores. However, both stretching exercises improved ROM.

This finding comes to no surprise because the literature reports similar positive findings on ROM related to different stretching methods. A number of studies have demonstrated that ROM remains significantly increased after the PNF stretching protocols had been applied.

- Handel et al. (1997) found up to 6.8° increase in active and passive flexibility after 8 weeks of CRPNF stretching training.
- Similarly Schuback et al. (2004) observed the effectiveness of a self-stretch incorporating PNF components involving a therapist-applied PNF technique. The researchers found both stretching regimes resulted in a significant increase in hamstring flexibility.
- Hutton (1993) pointed out that PNF stretching activities causes a neural inhibition of muscle group being stretched. The neural inhibition reduces reflex activity which causes greater relaxation and decreased resistance to stretch.
- Similarly Rees et al. (2007) examined the effect of PNF stretching (three times per week for 4 weeks) on musculotendinous unit (MTU) stiffness of the ankle joint. The researchers found an increase on ankle ROM (7.8%), maximal isometric strength (26%), rate of force development (25%) and MTU stiffness (8.4%). The increased MTU stiffness after the training period is explained by adaptations to maximal isometric muscle contractions applied in PNF stretching bouts. As a stiffer, MTU system is linked with an improved ability to store and release elastic energy, PNF stretching should benefit certain athletic performance due to a reduced contraction time or greater mechanical efficiency.

As in the case of PNF stretching on the positive effect on ROM, findings of the present study support previous investigations using static stretching protocols of long durations as well (Gregory et al., 2004; Bandy and Irion, 1994; Roberts and Wilson, 1999; Bandy et al., 1997; Borms et al., 1987; Decoster et al., 2004, Nelson and Bandy, 2004; Chan et al., 2001).

The results showed that 30 s of static stretching protocols resulted in significant gains in ROM of the hamstring muscle group. This gain in ROM obtained in the static stretching experimental group is in agreement of similar studies on the effects of the duration of static stretching.

- For example, Nelson and Bandy (2004) found an increase on ROM after a (30 s 3 days per week for 6 weeks) bout of static stretching of the hamstring muscle.
- Decoster et al. (2004) investigated the effectiveness of standing and supine hamstring stretching (each leg three times for 30 s each) in hamstring flexibility. The gains in the ROM after 6 weeks of statically stretching the hamstring muscle for 30 s are quite similar to gains by the static stretching group in the present study.
- In another study, Cipriani et al. (2003) compared two static stretching protocols on hip ROM, for a variety of durations, including 30 s. The two protocols were a 10 s duration and a 30 s duration stretch. They found no differences between the two protocols.
- The results of the present study are in agreement with those of reported by Bandy et al. (1997) who found similar increases in the hamstring muscles ROM when stretching once or repeating the stretch three times for 30 or 60 s. Furthermore, these investigators claim that 30 s static stretching bouts caused an increase on ROM.

In addition, stretch tolerance improves the joint flexibility. Magnusson et al. (1998) reported that static cyclic stretching increases joint ROM by increasing stretch tolerance while viscoelastic characteristics of the muscle remain unaltered. When the differences observed between the static stretching and PNF groups were compared, there were no significant differences in improvements made in ROM.

- Worrell et al. (1994) found no differences on increase ROM between PNF and static stretching techniques.
- Similarly, Godges et al. (1989) observed that both static stretching and soft-tissue mobilizitation with PNF significantly increased ROM in both hip extension and flexion.

- On the other hand, Sady et al. (1982) found that PNF stretching increased ROM more than ballistic or static stretching did, in a group of 43 college men who performed stretching activities 3 days per weeks for 6 weeks. This finding does not agree with our present study's findings. A possible reason for the difference could be that our study used a 30 s static stretch whereas Sady et al. (1982) applied a 6 s static stretch.
- Similarly, Davis et al. (2005) studied the effects of three stretching protocols (self-stretching, static stretching and PNF techniques) on the length of the hamstring muscle group during a 4-week training program. Obtained results indicated that that static stretching, involving one repetition for 30 s 3 days per week, increased hamstring length in young healthy subjects. On the other hand, self-stretching and PNF-R stretching, involving one repetition for 30 s, 3 days per week, was not sufficient to significantly increase hamstring length. In our present study, ROM values increased significantly in the PNF group. The increase in ROM is different to that obtained by Davis. The difference in PNF effectiveness between Davis and our study may be associated with repetition. The four repetitions, for 30 s, were used in our study whereas Davis used one repetition. Taylor et al. (1990) suggested that maximal muscle–tendon unit elongation occurs after approximately four stretches (repetitions).

Jump performance and power output

The purpose of this study was to determine the long-term effects of static and PNF stretching on power (DJ performance) and to investigate whether power was altered following after both stretching methods. Only a limited number of studies have been reported examining the effects of different types of long-term stretching on jump performance: below, the results of our present study are compared with those previous relevant studies reported in the literature.

- Hortobagyi et al. (1985) investigated some changes, in the maximal voluntary contraction, half-relaxation time, fast isometric contraction and concentric contraction of the knee extensors of the hip joints after 7 weeks passive stretching in 15.33 years old secondary school students. Pre- and post-test measurement showed a significant improvement in speed of concentric contractions.
- In a study by Handel et al. (1997), a significant improvement was found in maximum torque (up to 21.6%) and work, as compared to untrained control limbs after an 8-week unilateral contract–relax (CR) stretching training program. They also observed increases of concentric work for the knee flexor and extensor muscles, which they associated with an increased number of sarcomeres in series. These findings differ from the findings of our present study. A possible explanation for the differences may be that Handel et al. (1997) used torque measurements under isokinetic condition whereas our study used the DJ measurements.
- Wilson et al. (1992) examined the effect of long-term stretching exercises on the use of the stiffness of series elastic components (SEC) in the bench press lift activity. Results showed performance achieved by the experimental group consequent to flexibility training. They found that flexibility-induced performance enhancement, may be caused by increased muscle-tendinous compliance, facilitating the use of elastic strain energy in the stretch-shorten cycle activities.
- Similarly Godges et al. (1993) found that a 3-weeks intervention program of hip extension stretching or trunk flexion exercises significantly improved trunk flexor muscle performance (pre-test = 45.1°, post-test = 60.4°). The results of Wilson et al. (1992) and Godges et al. (1993) differ from our present study's findings. The differences are most likely because these researchers used upper body performance measurements. Using different body regions makes it difficult to compare the results.
- Ferreira et al. (2007) investigated the impact of flexibility on muscular performance where they showed significant increases in knee flexors (at both speeds of 60°/s and 300°/s) and knee extensors (at both speeds of 60°/s and 120°/s) for the associated torque productions after the application of a 30 s of static stretching for a 6-week long period.
- Similarly, Worrell et al. (1994) examined effects of two stretching methods, static and PNF for a period of 3 weeks. The results showed that there was a significant increase in peak torque of hamstring acting eccentrically at speeds of 60°/s and 120°/s and concentrically at 120°/s. A possible justification for the differences reported for both studies may be due to the different types of data collection procedures used. The data collection in our study was

done through DJ as a power measurement while the above study did not utilize the same procedure.

Improvements in performance through long-term stretching exercises are likely related to stretch induced hypertrophy. Coutinho et al. (2004) reported that long-term stretching exercises induced an increase for both, in serial sarcomere number and in the cross-sectional area of the muscle fibers. These findings encourage the use of stretching exercises in sports and rehabilitation activities. However, further studies would supply greater evidence as to which stretching technique might be most advantages to utilize in a rehabilitation setting. The importantance of determing the most efficient and effective stretching technique to achieve desired outcomes, needs further research.

The results of the present study refer to the lack of change of vertical jump height after 6 weeks static and CRPNF stretching which are in agreement with previous studies using different stretching methods. For example, Woolstenhulme et al. (2006) determined the effects of four different warm-up protocols (two times a week for 6 weeks) on flexibility and vertical jump height. And they found that while flexibility increased for ballistic and static stretching groups compared to control group, vertical jump height did not change for any of the groups. No change in power values in our study could be associated with reduction in muscle stiffness. Similarly, a stretch-induced decrease in muscle stiffness has been reported by Magnusson et al. (1996). Cornwell et al. (2002) found that passive static stretching bouts reduced the active stiffness of plantor flexors (0.84 kN/m or 2.8%), while static jump height remained unchanged. Furthermore, they found 7.4% reduction in counter-movement jump scores. A possible explanation provided for these results were that the stretching bout affected the storage and return of elastic energy. In another study, Hunter and Marshall (2002) studied the effects of power and flexibility training on counter-movement and DJ techniques. They found that stretching appeared to have no significant effect on counter-movement jump or DJ technique. These investigators reported that during the DJs, the level of eccentric lower-limb stiffness produced decreased, but time and magnitude of the counter-movement used increased, at the same time that ground contact time increased. Furthermore, applying the stretching bouts produced no apparent advantage.

Evidently, more research studies are needed in order to clarify the effects of long-term stretching exercise on power and how this affects choice of exercise in sports and rehabilitation.

Conclusion

The study indicates that a 30 s PNF and passive static stretching program significantly increases ROM in the lower extremity. Despite the significant effect on ROM, both stretching exercises had no statistically significant effect on the DJ scores. The general findings of the present study clearly indicated that 30 s duration PNF and passive static stretching exercises may be useful for individuals who wish and or need to increase their flexibility. Regarding clinical purposes we can infer that a similar exercise program that incorporate either PNF or static stretching in training and rehabilitation programs may improve lower extremity ROM. However, for practical purposes in clinical applications, we do recommend the passive static stretching technique. This technique provides several advantages over PNF. First of all, the passive stretching technique is easier to perform and does not need any advanced skills on the side of clinicians. Furthermore, PNF requires the individual to actively participate in the exercise by applying an opposite resistive force for this particular procedure.

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