The Effect of Proprioceptive Neuromuscular Facilitation and Static Stretch Training on Running Mechanics

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Abstract

Caplan, N, Rogers, R, Parr, MK, and Hayes, PR. The effect of proprioceptive neuromuscular facilitation and static stretch training on running mechanics. *J Strength Cond Res* 23(4): 1175–1180, 2009—There is a long-standing belief that increased range of movement (RoM) at the hip or knee will improve running mechanics; however, few studies have examined the effect of such an increase in RoM. The aim of this study was to determine the influence of 2 methods of stretch training (static and proprioceptive neuromuscular facilitation [PNF]) on high-velocity running. Eighteen rugby league players were assessed for maximum sprinting velocity. They were randomly allocated into 2 stretch training groups: PNF or static. Each group trained their hamstrings 4 $d \cdot w^{-1}$ for 5 weeks. Pre- and posttraining subjects were videoed while running at 80% of maximum velocity. The video was digitized to identify biomechanical changes in hip flexion (HF), knee extension (KE), stride length (SL), stride rate (SR), and contact time (t_c). Stretch training resulted in gains ($p < 0.05$) in HF for the static stretch (SS) (4.9%) and PNF (7.6%) groups. There were reductions in KE ($p < 0.05$) for SS (1.0%) and PNF (1.6%) groups. Stride mechanics were also altered after training. There were increases in SL ($p < 0.05$) for SS (7.1%) and PNF (9.1%) and a concomitant reduction in SR ($p < 0.05$) for SS (1.9%) and PNF (4.3%). No changes were observed in t_c in either group. In conclusion, both SS and PNF training improved HF RoM and running mechanics during high-velocity running. These findings suggest that stretch training undertaken at the end of regular training is effective in changing running mechanics.

Key Words mobility, range of movement, sprinting, biomechanics

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23(4)/1175–1180

Journal of Strength and Conditioning Research

Introduction

Stretch training is regarded as an essential component of many athletic training programs (2). A variety of stretching methods have been reported to increase range of movement (RoM) (2). Range of movement has been shown to increase with both static and proprioceptive neuromuscular facilitation (PNF) stretching regimens (13,17,18,20,19,22,25,27,30); however, there is debate about which method is the most effective (14,18). Many of the studies have focused exclusively upon RoM and not on the effect of changing RoM on running mechanics.

A small number of studies have investigated the role of chronic stretch training on flexibility and performance. Both Handle et al. (17) and Worrell et al. (36) observed increases in flexibility and isokinetic muscular performance of the knee flexors after a program of PNF stretching. Wiemann (34) found an increase in peak isometric force for women but not for men, after training. The effects of chronic stretch training on running economy have been investigated, although conflicting evidence is reported (4,27). Running economy is usually measured at velocities below the lactate threshold, and these velocities are slow in comparison to those used for high-velocity running and sprinting in many sports (3,7,9,16).

Kivi et al. (21) have shown that the functional range of motion of the lower limbs increases with increasing running velocity, *V*, which is given by:

$$V = SR \times SL, \tag{1}$$

where SR is stride rate and SL is stride length (29). Many sports involve running at high intensities, and there is a long-standing belief that a lack of RoM is detrimental to running velocity. The role of RoM in running velocity is equivocal; Tolsma (32) suggested that because the hamstrings are not stretched to the limits of the RoM during running, excessive RoM is therefore unnecessary. Some authors (11,26,32) have suggested that greater RoM reduces both passive and active forces within the muscle during running. This line of reasoning is logical but not empirically based and therefore potentially specious.

Weyand et al. (33) found that during high-velocity running, the increases in running velocity were not due to increases in SR. They noted that high-level sprinters did not have appreciably quicker SR than slower runners. Any gains in running velocity therefore are due to increases in SL (see equation 1). Stride length can be increased through an increase in ground reaction force (33). By increasing the RoM at the hip and knee, the angular range over which the thigh and shank must rotate during the downswing of the running cycle would increase. If the timing ratios between phases of the gait cycle remained constant, then larger angular accelerations about the hip and knee would be required, resulting in an increase in ground reaction force. Any increase in RoM would require an increase in flexibility in the hamstrings, which would potentially influence hip flexion (HF) and knee extension (KE) during the running gait (26,31,32).

Despite considerable research demonstrating an improving RoM with stretch training, the impact of increased RoM on performance has received little attention. The aim of this study was to compare the influence of PNF and static stretch (SS) stretch training on running mechanics during high-velocity running. It was hypothesized that both groups would show changes in running mechanics through stretch training, with a greater change for PNF training.

Methods

Experimental Approach to the Problem

Previous research (30) has demonstrated that both static and PNF stretching are effective in increasing RoM. Very few studies have looked at the impact of an increase in RoM on running mechanics. Subjects in this study were randomly allocated to 1 of 2 training groups: PNF or SS. As both methods have consistently shown to be effective at increasing RoM, a control group was deemed unnecessary. This approach is consistent with some previous studies (13,20,25). Each group stretched the hamstring muscle group because Wilson et al. (35) suggested that SL in sprinting could be impaired by poor hamstring flexibility. The dependent variables were, therefore, HF and KE angles, SR, SL, and contact time during sprinting. The independent variable was the stretch training method used.

Subjects

Eighteen trained Rugby League players were recruited from the University team, who trained at least 4 times each week in addition to competition. The study was conducted during their in season. Their mean age, height, and body mass were 20.2 (±1.1) years, 1.82 (±0.09) m, and 84.9 (±14.4) kg, respectively. The study was approved by an institutional ethics committee, and subjects gave informed written consent before their participation. Subjects were randomly allocated to either an SS training group ($n = 9$) or a PNF training group ($n = 9$). The mean age, height, and body mass for the SS group were 20.1 (±1.1) years, 1.77 (±0.08) m, and 85.9 (±18.9) kg, respectively. The mean age, height, and body mass for the PNF group were 20.3 (±1.1) years, 1.85 (±0.08) m, and 84.1 (±11.0) kg, respectively.

Procedures

Each subject was required to attend 3 testing sessions and follow a 5-week supervised stretch training regimen. Each subject undertook a supervised stretching regimen, using the method prescribed for their group, training 4 days per week for 5 weeks, at the end of their normal training sessions. The training sessions lasted approximately 60 to 90 minutes consisting of technical, tactical, and fitness work.

Testing Sessions

The initial testing session was performed at the start of one of the subjects' scheduled training sessions. Each subject performed 3 maximal velocity 30-m sprints from a moving start. They were asked to ensure that the acceleration and deceleration phases occurred outside the 30-m sprint distance. The fastest 30-m sprint trial was used to calculate their maximum sprint velocity. Before and after stretch training, subjects were required to run at 80% of this velocity on a treadmill for video analysis.

Before the run at 80% of maximum sprint velocity, subjects performed a standardized warm-up consisting of a 3-minute run at 3 $m \cdot s^{-1}$. No stretching was performed during the warm-up. A similar warm-up has previously been used before high-intensity exercise (37). After a 1-minute rest period, the subjects were asked to run at 80% of their previously determined maximum sprint velocity on a motorized treadmill (Pulsar 3.4.0; HP Cosmos, Nussdorf, Germany) for 15 seconds. Subjects stepped onto a slow-moving treadmill belt, which was then rapidly accelerated to the test velocity. This velocity was then maintained for a 15-second data collection period. All subjects wore a chest harness suspended from the treadmill frame to prevent injury in the event of a fall.

During the data collection period, the subjects were filmed from a lateral view using a miniDV video camera (HVR-A1E; Sony, Tokyo, Japan). The camera was attached to a tripod set to a height of 1.0 m, to be approximately half the height of the subjects. The camera was located at a distance of 2.7 m away from the treadmill. The frame rate of the camera was 50 Hz, and the shutter speed was set to 1/500th of a second. Before each testing session, a rectangular calibration object was placed in the camera field of view, which covered the area in which the subjects would be positioned when running. This calibration object allowed the raw coordinates (in pixels) to be scaled into SI units (in meters). Retroreflective markers were attached to the acromion process of the left shoulder, the greater trochanter of the left hip, the lateral epicondyle of the left knee, and the lateral malleolus of the left ankle, to assist in locating of the shoulder, hip, knee, and ankle during data processing. Markers were placed on these bony landmarks by the same researcher throughout all testing sessions to ensure consistency. A halogen floodlight was positioned in line with the camera to increase the visibility of the markers on the video image.

Stretch Training

For both stretching methods, the subjects assumed the same supine starting position. The legs were extended along the ground with the hands by the subjects' sides. Each leg was then alternately flexed about the hip with the knee fully extended, so that the knee moved closer to the chest. Three repetitions of each stretch were performed, with each stretch being held for 10 seconds. A 10-second rest was given between stretches. This stretching frequency was reported by Davis et al. (10) as being most effective for increasing flexibility.

Static Stretch Training. The static group was instructed to raise each leg, as described above until the hamstring in the raised leg was stretched to the point of discomfort. Subjects were permitted to use their hands to support the leg but were told not to apply any force to increase the stretch and to ensure that the nonraised leg remained flat on the ground. At the end of each stretch period, the leg was slowly lowered back to the start position.

Proprioceptive Neuromuscular Facilitation Training. In the PNF group, each leg was raised in turn, in the same manner as described above, except with assistance. The assistant pushed the raised extended leg into HF until the subject reported a maximum stretch on a scale from 1 to 10. The subject then resisted a force applied by the assistant by attempting to extend the hip. The nonraised leg was kept firmly on the ground by the assistant's leg. Again, the leg was slowly lowered to the ground after each stretch period.

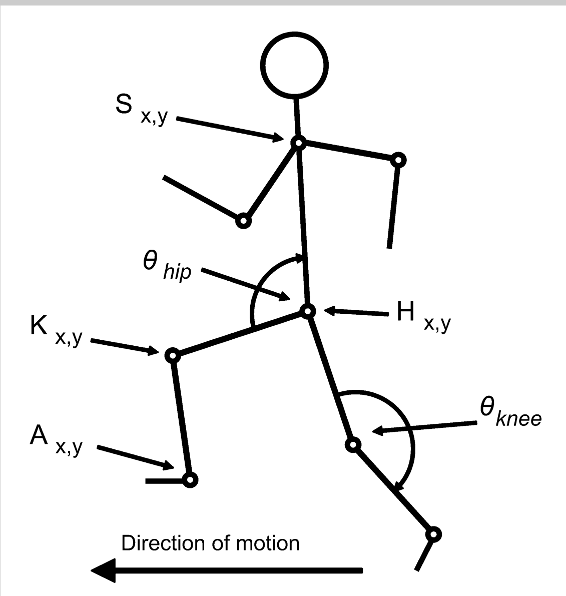

Figure 1. Stick figure representation of a sprinter illustrating the joint locations at the ankle ($A_{x,y}$), knee ($K_{x,y}$), hip ($H_{x,y}$), and shoulder ($S_{x,y}$) and joint angles at the knee (θ_{knee}) and hip (θ_{hip}).

Table 1. Maximum marker digitizing errors are shown, which were determined by digitizing an example trial on 2 separate occasions.*

	X(m)	*Y*(m)
Ankle	±0.008	±0.007
Knee	±0.005	±0.003
Hip	±0.004	±0.004
Shoulder	±0.001	±0.004

*The maximum errors between the 2 data sets for each coordinate are shown in the *x*and *y*directions.

Statistical Analyses

To extract the kinematic and temporal data from the video images, the video images had to be digitized (Vicon Motus, Vicon, Oxford, UK) and a spatial model (Figure 1) was used to map the marker positions and body segments onto the video images. This allowed for the calculation of the 2-dimensional coordinates of the ankle, knee, hip, and shoulder and the 2-dimensional angles at the knee and hip joints. Digitizing accuracy was determined by digitizing the same trial on 2 occasions. Table 1 shows the digitizing accuracy for each marker in the horizontal (x) and vertical (y) axes. The resultant joint angle errors are shown in Table 2. Intraclass correlation coefficients were calculated for the x and y coordinates of the ankle ($r_x = 1.00$; $r_y = 1.00$), knee ($r_x = 1.00$; $r_y = 1.00$), hip ($r_x = 1.00$; $r_y = 1.00$), and shoulder ($r_x = 1.00$; $r_y = 1.00$).

The first 3 strides were extracted for analysis (12). Peak HF angle was determined for each of the 3 strides and occurred just before heel strike. Peak KE angle was also extracted and was found to occur close to toe-off. As well as, peak HF and peak KE angles, the following spatiotemporal variables were determined for each stride: SL (toe-off to heel strike of the left leg), SR (strides·min^{-1}), and contact time (milliseconds) during the contact phase of the left foot.

Mean ± *SD* was used for descriptive statistics. Factorial analysis of variance (2 × 2) with repeated measures on one factor (pre/post) was performed to determine if any significant main effects or interactions were present between

Table 2. Maximum errors in joint angle calculations due to digitizing errors are shown.*

	Angle (°)
Knee angle	±1.814
Hip angle	±1.061

*An example trial was digitized twice and the maximum angular error calculated.

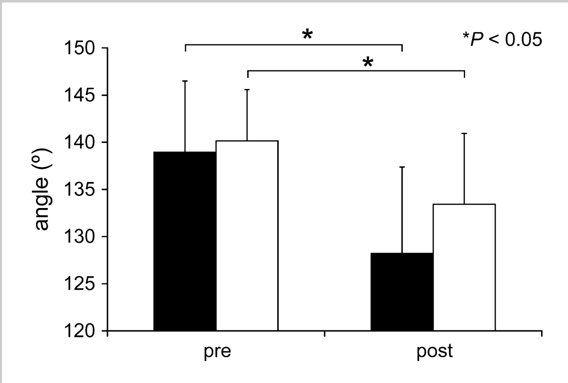

Figure 2. Mean (±*SD*) peak HF angles are shown for PNF (■) and SS (□) training groups, pre- and post-familiarization ($n = 18$; $F_{1,46} = 42.106$; $p < 0.05$). HF = hip flexion.

pre- and post-stretch training and between static and PNF stretching methods for the variables detailed above. The alpha level was set at $p \leq 0.05$. Effect sizes were also calculated according to the method of Cohen (8) where 0.2 indicates a small effect size, 0.5 is a moderate size, and 0.8 is a large effect size.

Results

Joint Angles

Hip Flexion. Both PNF and SS groups demonstrated significant gains ($F_{1,46} = 42.106$; $p < 0.05$) in HF with training. There was no significant difference between groups ($F_{1,46} = 3.269$; $p > 0.05$) (Figure 2). The PNF group increased by 7.6%, representing an effect size of 1.29. Static stretch training resulted in a 4.9% gain and an effect size of 1.054.

Knee Extension. The mean values for KE before and after training for both PNF and SS groups showed small but significant ($F_{1,46} = 4.674$; $p < 0.05$) reductions in KE (Figure 3). Range of movement changed by 1.6% for PNF and 1.0% for SS, representing effect sizes of 0.379 and 0.288, respectively. Although both groups reduced KE with stretch training, there was no significant difference between stretch training groups ($F_{1,46} = 0.145$; $p > 0.05$).

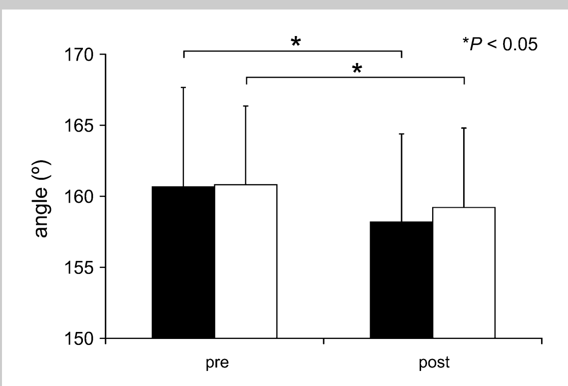

Figure 3. Mean (±*SD*) peak KE angles are shown for PNF (■) and SS (□) training groups, pre- and post-familiarization ($n = 18$; $F_{1,46} = 4.674$; $p < 0.05$). KE = knee extension.

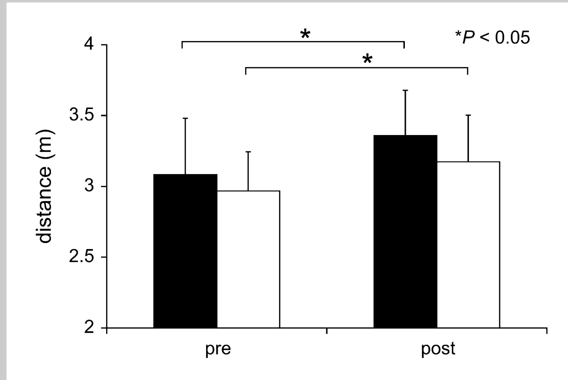

Figure 4. Mean (±*SD*) SLs are shown for PNF (■) and SS (□) training groups, pre- and post-familiarization ($n = 18$; $F_{1,46} = 52.736$; $p < 0.05$). SLs = stride lengths.

Stride Mechanics

Contact Time. The foot contact time exhibited very little change with stretch training. For the PNF groups, contact time was unchanged (0%) from 184 milliseconds (±25) before training to 184 milliseconds (±23) after training. Static stretch training resulted in a small (3.9%) reduction in contact time from 180 milliseconds (±35) to 173 milliseconds (±24), constituting an effect size of 0.233. The differences neither with training ($F_{1,46} = 0.666$; $p > 0.05$) nor between training methods ($F_{1,46} = 1.133$; $p > 0.05$) were considered significant.

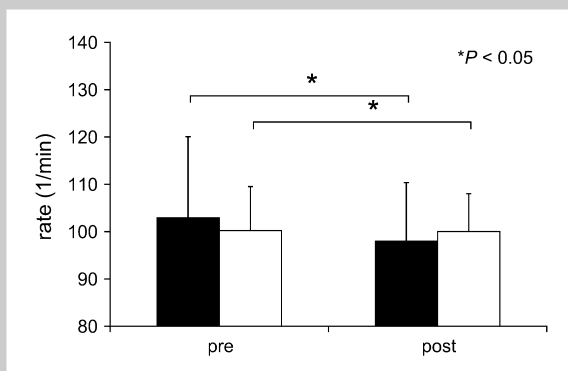

Figure 5. Mean (±*SD*) SRs are shown for PNF (■) and SS (□) training groups, pre- and post-familiarization ($n = 18$; $F_{1,46} = 9.967$; $p < 0.05$). SRs = stride rates.

Stride Length. Stride length in the PNF group increased from 3.08 m ($\pm$0.40) to 3.36 m ($\pm$0.32) after training, an increase of 9.1%. With SS, there was an increase in SL from 2.96 m ($\pm$0.28) to 3.17 m ($\pm$0.33) after training, representing a 7.1% increase (Figure 4). The increases in SL with stretch training were significant ($F_{1,46} = 52.736$; $p < 0.05$). Effect size for PNF training was 0.78, whereas for SS, the effect size was 0.69. There were no significant differences between PNF and SS groups ($F_{1,46} = 2.660$; $p > 0.05$).

Stride Rate. Stride rate decreased by 4.3 and 1.9% with PNF and SS training, respectively (Figure 5). The reductions in SR were significant ($F_{1,46} = 9.967$; $p < 0.05$) for both PNF and SS training methods. These changes, although significant, only represented effect sizes of 0.36 (PNF) and 0.26 (SS). There were no significant differences between PNF and SS groups ($F_{1,46} = 0.062$; $p > 0.05$).

Discussion

The aim of this investigation was to determine the influence of chronic stretch training, using SS and PNF methods, on RoM at the hip and knee and stride mechanics during high-velocity running. It was found that both PNF and SS resulted in an increased peak HF, and these gains in peak HF were associated with an increase in SL and reduction in SR when running at the same absolute velocity after stretch training.

The significant increase in HF RoM ($p < 0.05$) for both the PNF and SS groups is in keeping with previous literature (13,17,20,19,22,25,27,30,35,36). Despite the nonsignificant difference between PNF and SS groups, there was a larger effect size for the PNF group, which is consistent with previous studies (14,20,19,30). Range of movement during KE was reduced significantly. This reduced KE RoM, however, was close to 1% for both groups, which could be explained by measurement error; the small effect size observed supports this.

To determine the influence of the increased RoM in HF on running performance, it is necessary to examine the changes in stride mechanics elicited by the stretch training programs. Our findings indicated that contact time did not change significantly. Weyand et al. (33) found that contact time was negatively correlated to running velocity. As the same absolute running velocity was used for the pre- and post-stretch training experimental trials, the lack of change in contact time was to be expected.

Stride length was seen to increase significantly ($p < 0.05$) for PNF and SS groups, and SR was shown to significantly decrease for both groups ($p < 0.05$). As SL increased, the observed significant ($p < 0.05$) reduction in SR was to be expected, due to the relationship between velocity, SL, and SR (equation 1). Weyand et al. (33) reported an increase in ground reaction force with increasing SL. Farley and Gonzalez (15) similarly showed that as SR decreased by up to 10%, peak ground reaction force increased with a corresponding increase in hip RoM. In line with these studies, the increased SL, increased hip RoM, and decreased SR found in the present study would suggest that ground reaction force had increased after stretch training.

Leg stiffness is given by $F/\Delta L$ (6), where F is peak ground reaction force and ΔL is the change in leg length. If ground reaction force did increase as discussed above, it would seem logical that leg stiffness would also increase. However, Farley and Gonzalez (15) showed an increase in ΔL with decreased SR. This increased ΔL may offset any increase in force, resulting in minimal change to leg stiffness.

The compliance of the series elastic element (SEE) of the muscle tendon unit has recently been shown to have an influence on muscular performance. Kubo et al. (23,24) showed that muscular performance was increased as the compliance of the tendon-aponeurosis complex increased. In the present study, stretch training probably altered the structure of the muscles, increasing the compliance of the SEE (35). The changes in stride mechanics reported here were most likely due to an increase in the storage and release of elastic energy from the more compliant SEE. Increased muscle compliance could enhance muscle function by an increase in either SEE or contractile element (CE) compliance. An increase in CE compliance is unlikely as Handle et al. (17) showed no change in maximum concentric torque and a gain in maximum eccentric torque with an increased RoM through stretch training. The gain in RoM due to stretch training is, therefore, most likely to be the result of increased SEE compliance. An increase in sarcomere number in both series and parallel has also been suggested to account for this increased RoM (17). It has been suggested that this allows the CE to operate over a reduced length (1,5). This would reduce the contraction velocity of the muscle fibers, enabling them to make more efficient use of the muscle's force-velocity relationship.

The present study suggests that stretch training in parallel to an athlete's sport-specific training can help improve running mechanics. This study did not retest for maximum sprinting velocity. Future studies are, therefore, required to determine whether the observed changes in running mechanics could lead to an increased maximum running velocity. This study was conducted on a treadmill; however, Riley et al. (28) showed similar kinematic and kinetic responses to overground and treadmill running.

In conclusion, this study found changes in running mechanics after either static or PNF stretch training. The changes in running mechanics were an increase in SL and a concomitant decrease in SR. Whether this would lead to an increase in maximum running velocity is still to be determined.

Practical Applications

Twenty stretch training sessions of the hamstring muscle group resulted in an increase in SL. Both static and PNF stretching methods provided these gains. As running velocity is given by the product of SL and SR, any increase in SL due to increased hip RoM could possibly lead to an increase in running velocity. Stretch training undertaken at the end of regular training is effective in changing running mechanics.

Acknowledgments

No support, funding, or otherwise was provided by any external bodies in relation to the completion of this study. There were no conflicts of interests to be declared.

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