

# Mastergradsoppgave

## The Effect of Stretching on Muscle Force Production in Hamstring Muscles

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Juni 2009



# Sammendrag: Effekten av stretching på evnen til kraftutvikling i hamstring

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Formålet med dette studiet var å undersøke de akutte effektene som proprioceptive neuromuscular facilitation stretching (PNF) har på maximal voluntary contraction (MVC), rate of force development (RFD), power (P) og time to peak power (TPP) både i en isometrisk og en dynamisk kontraksjon av hamstring.

10 mannlige kickboksere deltok i studiet som bestod av to testdager. Forsøkspersonene gjennomførte før hver testdag en oppvarming, bestående av 10 minutter løping på tredemølle med et intensitetsnivå på 60% av deres  $HF_{max}$ . Etter denne oppvarmingen ble hver enkelt forsøksperson testet i de to styrkeøvelsene, enten med eller uten stretching i forkant. Halvparten av utvalget startet første testdag med PNF før de fullførte styrkeøvelsene, mens det andre utvalget testet uten PNF. Testprosedyren (med og uten PNF) for de to utvalgene ble byttet om på andre testdag. Det var tilfeldig hvem som startet med stretching før gjennomføringen av styrkeøvelsene. Den dagen hvor det ikke ble foretatt noen stretching, ble brukt som en kontrollbetingelse for den neste dagen med stretching.

Resultatene viste en signifikant nedgang i MVC og en signifikant forbedring i TPF på den isometriske øvelsen, men ingen signifikant endring i den dynamiske styrkeøvelsen på variablene MVC, TPF, P og TPP.

Det ble derfor konkludert med at PNF stretching har en negativ effekt på styrkeprestasjonen målt som MVC i isometrisk styrke, men at det er en trend at PNF har en positiv effekt på både isometrisk og dynamisk TPF.

**Nøkkelord:** Stretching, styrkeproduksjon, prestasjon, oppvarming, knee-flexion.

## **The Effect of Stretching on Muscle Force Production in Hamstring Muscles**

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### **Abstract**

The purpose of this study was to explore the acute effect of proprioceptive neuromuscular facilitation stretching (PNF-S) on maximal voluntary contraction (MVC), rate of force development (RFD) and power in both isometric and dynamic contractions of hamstring (knee flexion).

10 volunteer male kickboxers participated in the experiment. The subjects underwent two days of testing, and randomly the subjects were tested with or without stretching the first or the second day of testing. The day without PNF-S was used as a control condition for the day with PNF-S.

Each experimental condition conducted of a 10min warm up on at treadmill at approximately 60% of the subjects  $HF_{max}$ . Immediately after warm up the day without stretching the dependent variables in both the isometric and dynamic contractions of the hamstrings were tested. After warm up the other day with PNF-S the subjects underwent a controlled PNF-S sequence of the hamstring that was immediately followed by a test of the dependent variables. The result shows a significant decrease in MVC and a significant improvement in RFD in the isometric contraction, but no significant changes in the dynamic condition.

It is concluded that PNF has an acute negative effect on muscle force production measured as MVC in the isometric contraction, but there is a trend that PNF has a positive effect on both isometric and dynamic TPF.

**Key words** : stretching, force production, performance, warm-up, knee-flexion.

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## Introduction

Today stretching is commonly promoted as a method to improve performance in various sports and recreational activities. Flexibility of the muscles and joints is an important component of many different athletic movements, from a sidekick in kickboxing to a volleyball serve. Taylor, Dalton & Seaber (1990) recommended that four sets of stretching is performed for each muscle groups, with 10-30 seconds duration in each stretch position before a main exercise session. However, numerous studies have suggested that stretching for different muscle groups utilizing strength has a negative effect on muscular performance (Ogura et al, 2007). Strength performance and peak force is a result of many factors. Skeletal muscle fiber type, muscle architecture, muscle length, torque moment arm and muscle coordination are all involving the strength performance and force of development (Raastad 2005).

Even though most studies appear to have a negative effect on muscular performance, some studies didn't find any decrease in strength performance. Gantiraga et al (2006) examined the effect of static stretching on maximal voluntary contraction (MVC) and isometric force-time curve characteristics of leg extensor muscles and electromyographic (EMG) activity of rectus femoris, biceps femoris and gastrocnemius. This study indicated that a moderate volume of static stretching did not alter significantly the MVC and the isometric force-time curve characteristics.

Scientists theorize that stretching induced force deficit involve both mechanical and neurological factors. Many authors agree that both factors interact and contribute to a muscular-force deficit following stretching (Janot et al, 2007)

The mechanical factor which can provoke decreases in power production and force is the temporary loss of muscular stiffness following stretching (Kokkonen, Nelson & Cornwell 1998). The number of myosin cross-bridges that are attached to actin filaments at any instant in time, decides how much force is being produced in the muscle. A reduction of musculotendinous (MTU) stiffness, can reduce the muscle's ability to effectively generate force (Guadagnoli et al 2008). This kind of stiffness is a mechanical property describing the relationship between the force applied to the muscle- tendon complex and the change in length of the unit. Because of the loss of muscular stiffness following stretching, this loss

increases the length of sarcomeres within individual muscle fibers. This decreases the contact between actin and myosin, which also decreasing the force (Nelson et al. 2001).

Sense organs and the central nervous system are also factors which affect a person`s ability to develop maximal external force.

In a muscle fiber contraction there is a communication between both the nervous and the muscular system. Therefore, the effect of stretching on muscular performance could not be explained by mechanical factors alone, but also by different neurological factors.

The motor unit is the functional unit of the neuromuscular system and consist of the alfa motor neuron in the spinal cord, its axon, axonal branches and the associated muscle fibers this neuron activates (Åstrand, 2003). When a motor unit is activated, all of its fibers contract, and groups of motor units often work together to coordinate the contractions of a single muscle. Fowles et al (2000) found a decrease in motor unit activation and in EMG activity immediately following stretching on plantar flexors.

Another aspect of the nervous system most related to stretching is Golgi tendon organs (GTO) and the muscle spindles. Both proprioceptors which are specialized sensory receptors that provide the central nervous system with important information needed to perform complex coordinated movements and to maintain muscle tone.

The muscle spindles that is located within intrafusal muscle fibers that run parallell to extrafusal fibers, monitor changes in muscle length (Alter, 1996). Changes in length detected by muscle spindles plays also an important role in regulating the contraction of muscles (Åstrand, 2003).

They convey length information to the central nervous system via sensory neurons. When the whole muscle is elongated, the spindle is also stretched, and this deformation activates the sensory neuron of the spindle, sending an impulse to the spinal cord. This impulse then connects with the motor neuron, which supply the same muscle, stimulating it to contract (Alter, 1996). This property is demonstrated by the stretch reflex. For example, tapping the patellar tendon elicits the knee jerk, a stretch reflex of the quadriceps femoris muscle, because the tap on the tendon stretches the muscle. This is a monosynaptic reflex that provides automatic regulation of the contraction of the muscles, and this reflex consists of only two neurons (one sensory neuron and one motor neuron (Alter, 1996).

It has been suggested that the inhibited excitability of alpha motor neurons is a related cause of decreased muscular strength and muscular power after stretching (Ogura et al, 2007).

Authors have suggested that stretching can cause a delay in the neuromotor responses, and these alterations can lead to a decreased in strength performance and power (Ogura et al, 2007). Even though their data support this theory, the practical effects and functions of stretching is not well understood.

Contract-relax PNF stretching have been suggested to cause autogenic and reciprocal inhibition, which activated the Golgi tendon organ. This proprioceptor then produce an inhibitory respons in motor neurons which return to the same muscle and it's synergist (Alter 1996). Marek et al (2006) looked at the effects of pre-exercise PNF stretching on exercise performance and examined the short-term effects of PNF stretching on ROM; peak torque and mean power output, determined by isokinetic strength testing. The results showed significant decreases in peak torque and mean power output.

Unick et al (2005) and Burkett, Phillips and Ziuraitis (2005) did not find any decrease in vertical jump performance after static and ballistic stretching. Muscular strength is one of the most important factors in performing vertical jump, and if stretching has an acute negative effect on strength performance, it would be expected a reduction in vertical jump. Numerous studies have suggested that stretching generate a negative effect on muscular performance.

Researchers have begun to study different types of stretching in order to identify whether any of them might enhance exercise performance in strength and power. Young & Elliot (2001) compared the effects of different warm-up protocols on explosive-force production and jumping performance. Subjects held each stretch for 15 seconds, and performed two vertical-jump tests after each warm up trial. The investigators found no differences in jumping performance following different warm-ups including 5 minutes of jogging and static or PNF-stretching. Several studies has documented that some types of stretching has a negative effect on isometric task, while there is less clear effects found in dynamic tasks. The research literature regarding the acute effect of stretching on short time and high intensity activities is unclear and debated, and therefore, further research is required. The purpose of this study was to explore the acute effect of proprioceptive neuromuscular facilitation stretching (PNF-S) on maximal voluntary contraction (MVC), rate of force development (RFD), power (P) and time to peak power (TPP). These dependent variables were analyzed in both isometric and dynamic contractions of the hamstring (knee flexion).

## Methods

### *Participants*

Twelve male kickboxers volunteered to participate in the study, which was approved by the Human Research Ethics Committee of Nord – Trøndelag. The ethical approval was obtained from the Norwegian Data Inspectorate and the Regional Committee for Ethics in Medical research following the principles outlined in the Declaration of Helsinki.

The participants met the following criterias:

Age= 20 ± 2 years. Physical activity status required involvement in regular kickboxing training (1,5 h-day, 3 times a week) in one year, good physical shape and they all had stretching-experimence. None of these subjects were doing regular strength training.

These participants were given oral and written information about the purpose of the exerperience, procedures, and possible risk of participating in the study. Thereafter, the subjects gave a written informed consent to participate in the study. Two of the subjects dropped out during the study, and baseline characteristics of the remaining 10 athletes are shown in Table 2.

**Tabell 1:** Characteristics of 10 male kickboxers

Characteristic	Minimum	Maximum	Mean	SD
Age	19	22	19,7	1,49
Height	168	192	179	7,77
Weight	60	84	73	7,33
1RM Leg curl	20	30	25	2,35
30 % 1RM	20	30	7,5	0,70

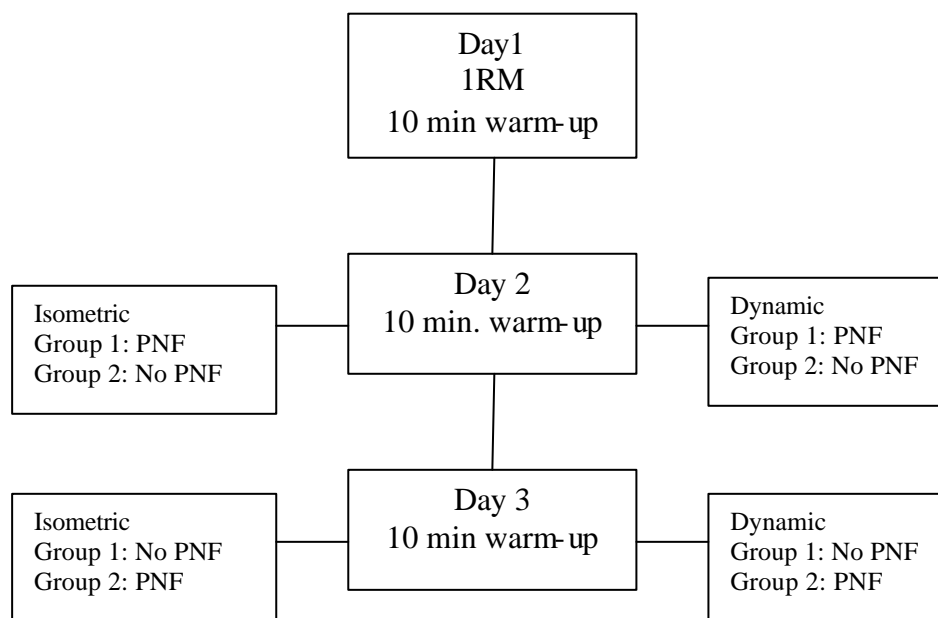


## Procedure

The purpose of this study was to explore the acute effect of PNF stretching on MVC, RFD and P in both isometric and dynamic contractions of hamstring (knee flexion). Before the experiment, all the participants were familiarized with the experimental protocol. Firstly they completed a warm up using treadmill for 10 minutes, at 60 % of the subjects  $HF_{max}$ . Afterwards 1 RM was determined by dynamic strength of knee flexion, because the load in the dynamic strength task in this study was set to 30% of 1RM.

In day 2 the subjects performed the dynamic strength task using leg curls (see figure 4). Thereafter the MVC of the subjects were determined performing a maximal effort of knee flexion in a isometric strength task (see figure 1). Randomly the subjects were tested with or without the first and the second day of testing (half of the subjects started the first day with a stretching condition, while the other half with a nonstretched condition) The day without PNF stretching was used as a control condition for the day with PNF stretching.

Day 3 was similar to day two, but the subject changed from either nonstretched to stretched conditions before the muscular performance.



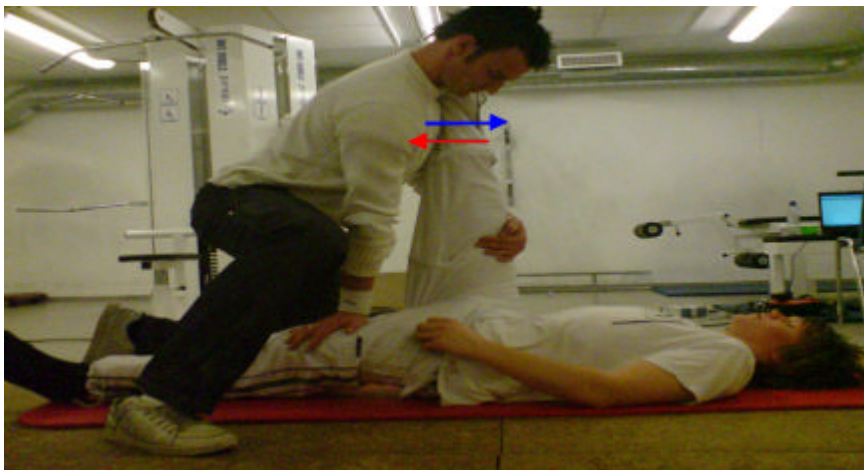
**Figure 1.** Summary of the experimental design

## *Stretching protocol and warm up protocol*

PNF stretching is a more advanced form of flexibility training that involves both the stretching and a isometric contraction of the muscle group being targeted. Certain precautions needs to be taken when performing PNF as they can put added stress on the targeted muscle group, which can increase the risk of soft tissue injury. To help reduce this risk, it is important to include a conditioning phase before a maximum, or intense effort is used, preparing the muscle for the stretch.

Performing the PNF-stretch used in the study in hand involves a hold- relax technique: The athlete and partner assume the position for this stretch, and then the partner extends the body limb until the muscle is stretched and a feeling of tension in the hamstring is felt.

After assuming an initial passive stretch to the hamstrings, this muscle was isometrically contracted for 10 seconds and the partner inhibited all movement.



**Figure 2.** Isometric contraction of the hamstring for 10 seconds .

→ Investigator push the dominant leg forward

← Subject push the dominant leg in the opposite direction, and contract the hamstring.

After the contraction, the muscle had a relaxation phase, and immediately thereafter an cautiously push from the partner extended the range of movement (ROM) for 30 seconds. Between each stretch the investigator allowed 30 seconds recovery before repeating the procedure two times. The stretching exercise was held in a position that the subjects self reported onset of pain. Participants were asked to inform the researcher when the maximal pain-free end ROM was attained.

### ***Measurement of the isometric and dynamic strength performance***

Maximal isometric force of the hamstring was measured with the body in a horizontal position with a knee angle at 90° (figure 3). A custom designed leg press apparatus was used for this MVC test. This apparatus consisted of a metal bar and a steal wire, connected to a load cell (model 333A). The cell was connected MuscleLab Model 4010/4020e (Ergotest Technology A.S) which was used for maximal isometric force measurement. Subjects dominant leg was strapped to the wire, and when the investigator signaled to start, they flexed the dominant leg with maximal effort for three seconds, followed by a one minute rest interval. Hands were kept across the chest, and a strap was placed around the waist of each subject to stabilize the body, and to isolate other muscles groups during the performance of the test.

Measurements of MVC were completed three times each day. The MVC and time to peak force (TPF) was expressed as the mean of the peak value of the 3 measurements



**Figure 3.** Maximal voluntary contraction of the hamstring and the apparatus used for maximal isometric force assessment.

On the dynamic strength test the subjects were laying face down on a leg curl machine, and hands gripping on the handgrips (see figure 4). The posterior side of the subjects` ankle was pressing against the pads, and the knee in line with the rotation cam of the machine. When the investigator signaled to start, they curled the dominant leg with maximal effort keeping their hips on the bench.

Leg curl was completed with a load of 30 % of 1RM, and test was repeated three times with one minute rest interval. The result of this task was expressed as the mean of the peak value, TPF, power (P) and time to peak power (TPP) of 3 measurements. Before the measurement of the pre-test each subject performed two repetitions in order to get familiarized with the experimental tasks.

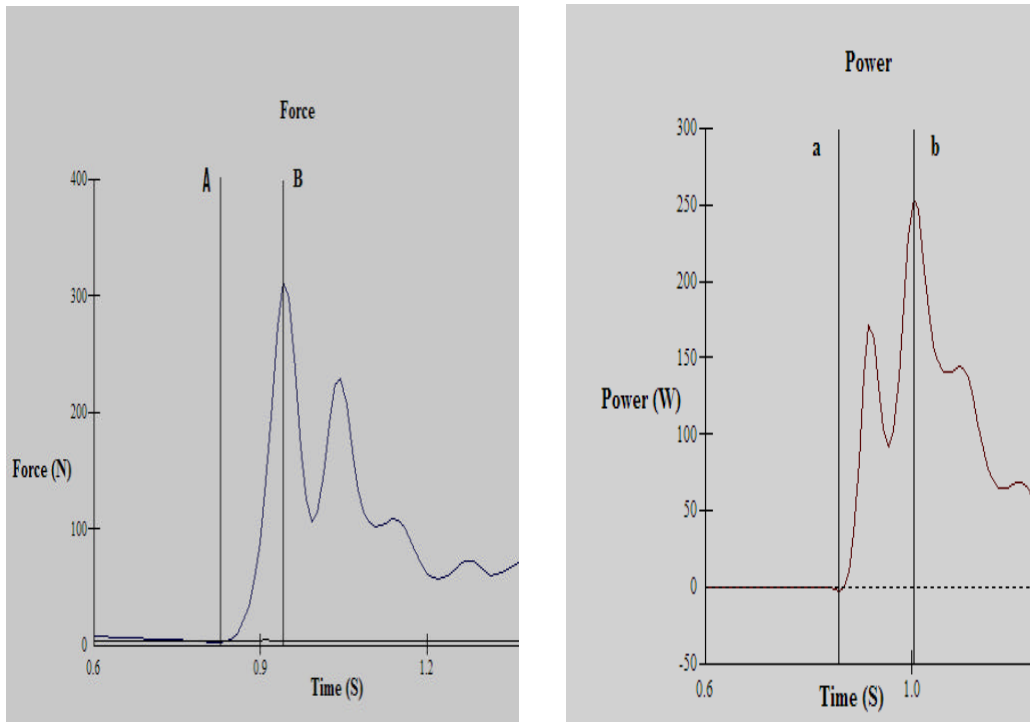
The leg curl machine was connected to a load cell (model 333A) and the linear encoder was connected to a moving part of a load stack on the machine.



**Figure 4.** Schematic of the instrumented machine used for Leg curl with load of 30 % of 1RM.

### *Apparatus*

In order to measure MVC, TPF, P and TPP, the MuscleLab system 4010/4020e (Ergotest Technology) was used. MuscleLab is designed to use the most common type of force sensor, and during the present study the load cell (333A) was used in both isometric and dynamic contractions. One of the dependent variables in the dynamic contractions was power (P), and for this purpose a linear encoder was used in combination with the force transducer. The linear encoder measure motion as a function of time together with the load cell, and the MuscleLab Software then calculates distance, velocity and power.



**Figure 5.** When analyzing the dependent variables MVC and TPF, the startplot on the graph (A) were the first positive value in the concentric phase and the peak force (B) is indicating the MVC. TPF is the time - interval between these two lines (A and B). The same methods were used in the powergraph, analyzing the dependent variables P and TPP. The value b is peak power and the time interval between a and b shows TPP.

### *Statistical Analysis*

Descriptive statistics were calculated for all variables, and all data in this study were expressed and reported as mean  $\pm$  SD. The differences between the stretched or nonstretched conditions of the isometric and dynamic task were analyzed by using F-test and a paired Student's  $t$ -test, in both stretching and nonstretching conditions. To conduct the graphs Microsoft Exel and Sigmaplot version 10.0 (Systat Software INC) were used. A level of  $p = 0,05$  was selected as the significance criterion for all data analysis.

## Results

The aim of this study was to determine the acute effect of PNF stretching on MVC, RFD and P in both isometric and dynamic contractions of hamstring (knee flexion). Changes in mean in MVC both in stretching conditions and the nonstretching condition in isometric and dynamic strength are compared in figure 6.

The results of the present study indicated a significantly decrease in MVC measured by isometric strength of knee flexion ( $p= 0,0385$ ).

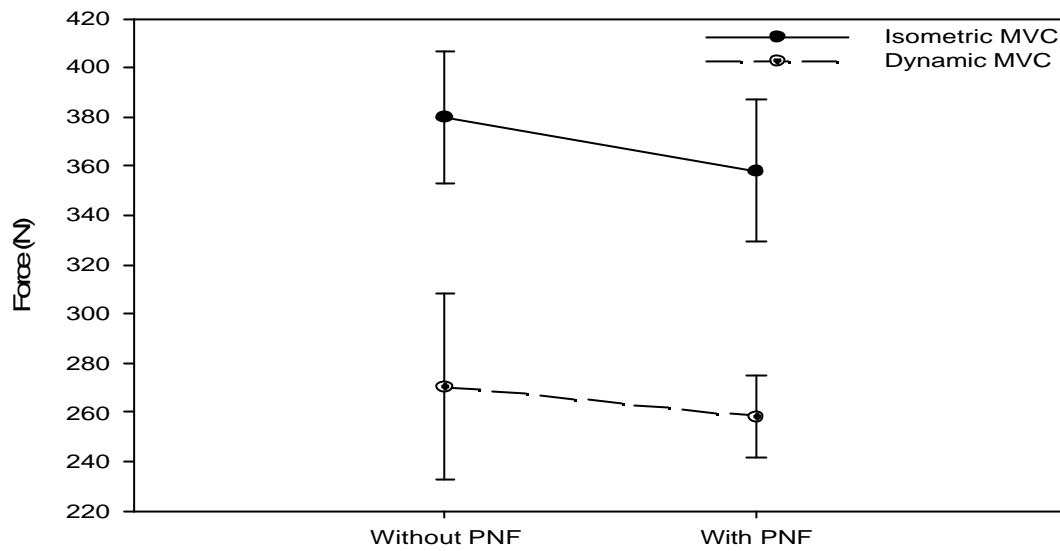
Changes in mean of TPF in dynamic and isometric strength are compared in figure 4. There were a significant improvement of TPF in isometric contractions using PNF stretching ( $p=0,036$ ) before the measurement.

**Table 2.** Difference of the dependent variables in stretched and nonstretced conditions (n=10; mean  $\pm$  SD)

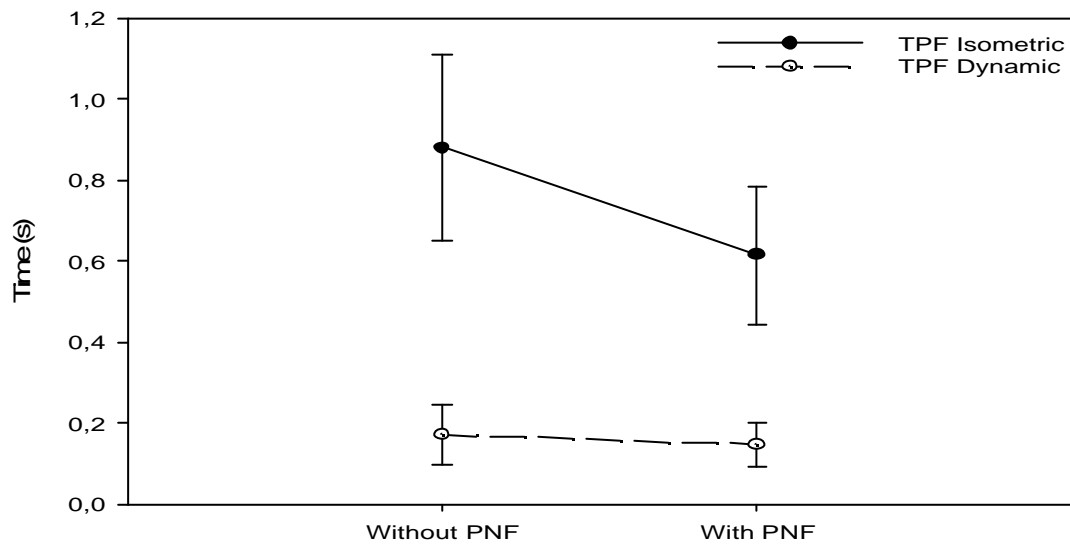
Variable	Total (n = 10)	
	Stretched	Nonstretched
Isometric.MVC	357,87 $\pm$ 28,92	379,64 $\pm$ 26,81*
TPF	0,616 $\pm$ 0,17*x	0,88 $\pm$ 0,23
Dynamic. MVC	258,21 $\pm$ 16,71	270,31 $\pm$ 37,94
TPF	0,148 $\pm$ 0,053	0,173 $\pm$ 0,072
P	210,283 $\pm$ 28,750	214,274 $\pm$ 21,114
TPP	0,194 $\pm$ 0,024	0,202 $\pm$ 0,045

\* Indicates a significantly decrease within the group.

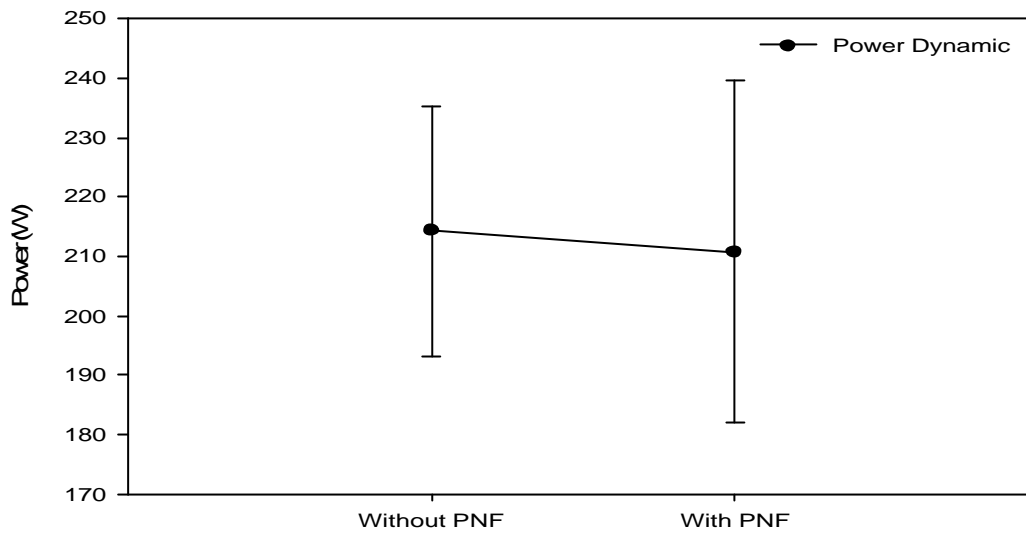
\*x Indicates that the group has improved significantly.



**Figure 4.** Comparisons of changes in mean of maximum voluntary contraction in both the stretching and nonstretching conditions in static and dynamic strength ( $p < 0,05$ ). Measured in Newton (N) and the values are means  $\pm$  SD (n = 10 for each condition).

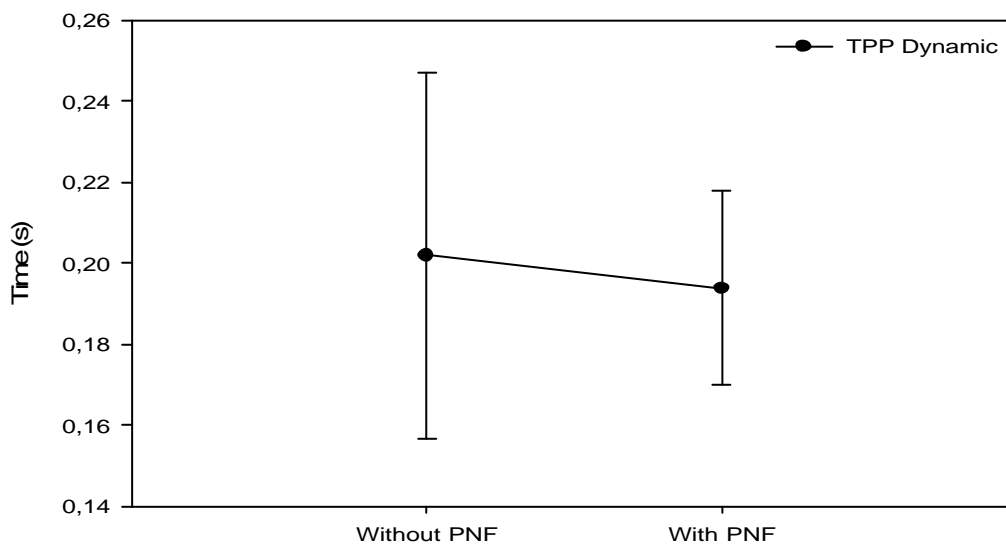


**Figure 5.** Comparisons of changes in mean in time to peak force (TPF) in both the stretching and nonstretching conditions in static and dynamic strength ( $p < 0,05$ ). Measured in seconds (S) and the values are means  $\pm$  SD (n = 10 for each condition).



**Figure 6.** Comparisons of changes in mean power in both the stretching and nonstretching conditions. ( $p < 0,05$ ). Measured in watts and the values are means  $\pm$  *SD* ( $n = 10$  for each condition).

There is a trend in the data showing a decrease in power as a result of PNF stretching condition, but there is not a significant decrease ( $P = 0,81$ ).



**Figure 7.** Comparisons of changes in means time to peak power in both the stretching and nonstretching conditions ( $p < 0,05$ ). Measured in seconds (S) and the Values are means  $\pm$  *SD* ( $n = 10$  for each condition).



## **Discussion**

The aim of this study was to explore the acute effect of PNF stretching on MVC, RFD and P in both isometric and dynamic contractions of hamstring (knee flexion). The results indicated a significant decrease in MVC and a significant improvement of TPF in isometric contraction. There is a trend in the data that also shows decrease in MVC and improvement of TPF in the dynamic contraction, even though this was not significant. Measurement of the power (P) shows a nonsignificant decrease in P, and nonsignificant improvement of TPP.

However, Ogura et al. (2006) propose that 30 seconds of static stretching does not have negative effects on MVC, and 30 seconds of static stretching is better than 60 seconds of static stretching as a warm up before performing higher muscular strength. This means that the duration of the stretch can influence the muscular performance. In the present study the subjects stretch the muscle isometrically contracted for 10 seconds, then pushed past its normal range of movement for about 30 seconds.

### ***Isometrically vs dynamic***

The result of the present study indicated a significant decrease in MVC in isometric contraction. This verified the hypothesis that PNF stretching has negative effects on MVC in isometric strength, which were in line with a study using the same muscle group (Ogura et al. 2007). Significant improvement in TPF occurred in the isometric contraction. This indicates that PNF not necessarily affect the RFD negatively, although isometric MVC was lowered. PNF stretching for 40 seconds did not have any significant negative effect on MVC, TPF, P and TPP measured by dynamic strength of knee flexion. Nevertheless, McBride, Winchester & Bazett (2005) compared the effects of static stretching vs. potentiation on subsequent maximal force and RFD, and they concluded that stretching did not appear to have a negative or positive effect on RFD. The mechanisms behind PNF stretching are still relatively unknown, and further research is needed to improve our understanding of this topic. The present study did not examine the mechanisms responsible for the decrease in muscular performance. Nevertheless, it has been suggested two main factors, which have a negative effect on muscular performance, and this is both mechanical and neural factors (Ogura et al. 2006).

### *Mechanical factors*

The mechanical factor is the decrease in stiffness of musculotendinous units (MTU). Scientists theorize that the reason for the acute effect of stretching (decrease in force and power production) is the temporary loss of muscular stiffness. This loss increases the length of sarcomeres within the muscle fibers, and decreases the contact between actin and myosin. This can alter the length-tension relationship and decreasing force (Nelson et al. 2001).

The effect of flexibility training on MTU stiffness has largely been investigated only by using static stretching, and researchers have reported decrease in MTU stiffness after static stretching (Guissard & Duchateau, 2004).

Participants in this study performed PNF stretching before each strength task, having a voluntary contraction during the stretch, which can lead to an increase in tension of the muscle and increase the MTU stiffness (Rees et al. 2007). The rationale for the increased MTU stiffness may be explained by the specific adaptation to resistance training. In this study the result shows a significant increase in TPF of isometric contractions and a small but not significantly, improvement in TPF and TPP of the dynamic strength task in stretching conditions. In support of these findings, Young & Elliot (2001) found no difference in jumping performance following different warm-ups including 5 minutes of jogging and static or PNF-stretching. Wilson et al. (1994) reported that stiffness of musculotendinous units were significantly related to both isometric and concentric performance, and suggested that a stiffer musculotendinous unit would be more effective during the initial transmission of force. A stiffer MTU is often linked with an ability to store and release energy, and this may explain the improvement in TPF performing PNF stretching before the isometric strength performance.

Anyway, in the present study PNF stretching caused a significant decrease only in isometric MVC, and therefore these facts imply that the difference in results could not be explained by possible mechanical factors alone, but also by different neurological factors.

## *Neurological factors*

As a result of stretching, it has been suggested that neural factors might negatively affect muscular performance. Fowles, et al. (2000) suggested that neurological mechanisms which change reflex sensibility and motor unit activation is observed to decrease after passive stretching. However, passive (static) stretching and PNF stretching can not be compared. A strategy used by many athletes as a pre- event warm- up is a performance of high intensity contractions to increase the motor unit excitability and enhance force production (Gullich & Schmidtbleicher, 1996). Isometric resistance contraction during the PNF stretch in this study, may have lead to recruiting more motor units, so that during the strength tests the subsequent contractions provided a better RFD, even though the MVC was lowered.

Static stretching produce a myotic reflex, while contract-relax PNF stretching cause autogenic and reciprocal inhibition, which in turn can decrease neural activity in the stretched muscle (Alter, 2004).

In the present study the subjects pushed the dominant leg pasts its normal ROM for 30 seconds, and because of the isometric contraction, allowing the muscle to be stretched to an increased ROM compared to static stretching. Ogura et al. (2006) suggested that autogenic inhibition of the golgi tendon organ did not affect the motor neuron excitability using static stretching, because such inhibition was induced only by extremely intense stretching of the tendon units.

The PNF for the hamstring in this study was performed with a relatively high threshold, and therefore the significant decrease in MVC measured by isometric strength of knee flexion, could be due to an additive effect of autogenic and reciprocal inhibition of neural excitability.

However, because stiffness of musculotendinous units and neuromuscular activity levels were not monitored in this study, the effects of these phenomena could not be clarified. Further studies are needed to elucidate both the mechanicals and neural mechanisms underlying the acute effects of PNF stretching, and how this kind of stretching effect force production.

## **Conclusions and practical applications**

The present study showed a decrease in MVC in isometric contraction, but a significant improvement in TPF. The subject had no significant decrease in dynamic MVC, P, TPP or TPF. Actually the result showed an improvement in TPF and TPP in leg curl using PNF stretching, even though this was not significant. PNF do not seem to decrease RFD and P, which means that PNF stretching is a method which can be effective in sports that require high power and flexibility (e.g. kickboxing and other martial arts). However, the result suggested that activities involving heavy force production such as weight lifting, PNF stretching may have a detrimental effect on MVC. Although most studies have found acute decreases in force production following stretching, further research is needed especially focusing on different stretching methods and dynamic movements.

## **Acknowledgements**

I would like to thank my supervisor Tore Kristian Aune for supporting and guiding me through this master` thesis, and to John Arne Nilsen the janitor at Nord Trondelag University College for all help with the equipment.

I would also like to thank the participants in the study, and especially Thomas Lian Benum, one of my students in Trondelag Kickboxing Team, who helped me making the apparatus for the isometric contraction test and participating as a subject in the experiment. Thomas past away two days before his last measurement of the experiment, and I would like to dedicate this thesis to him. A great kickboxer and a good friend!

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