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# Development of a Proprioceptive Neuromuscular Facilitation Stretching System Using a Low-Speed, High-Torque Motor

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**Abstract:** This study aimed to develop a proprioceptive neuromuscular facilitation (PNF) stretching system using a low-speed, high-torque motor and to investigate the acute response in hip flexion range of motion by applying PNF stretching using this system. The PNF stretching system consisted of a low-speed, high-torque motor with a rotational torque of 157 Nm, a braking torque of 1470 Nm, and a rotational speed of 6 degrees/s, a lever arm attached to the motor and its rotating shaft, and a pedestal mounted on the lever arm. The system, which targets hamstrings, enabled the subjects to raise the leg in a supine straight leg raise position and perform passive muscle lengthening and isometric muscle contractions by operating an electric motor. The study included 21 healthy male students aged between 18 and 21 years. The hold-relax (HR) technique was employed, in which the target muscle was lengthened step by step by performing three 10 s isometric contractions. The hip joint flexion angles were measured at the limit of leg raising without discomfort before and after HR (pre-HR and post-HR) and compared using Wilcoxon signed-rank sum test. The results showed that the hip flexion angle at post-HR (81.4 ± 18.0 degrees) was significantly greater than that at pre-HR (63.9 ± 15.2 degrees) ($P < 0.05$, effect size = 0.88). In conclusion, the PNF stretching system, which uses a low-speed, high-torque motor, effectively leads to an immediate improvement in hamstring flexibility.

**Keywords:** PNF stretching; range of motion; flexibility; hamstrings; low-speed high-torque motor

## 1. Introduction

Proprioceptive neuromuscular facilitation (PNF) stretching is a technique that uses the neurophysiological action of proprioceptors to increase the joint range of motion (ROM) and is widely used in physical therapy and athletic settings (Borges et al., 2018). PNF stretching has been reported to have greater immediate (Miyahara et al., 2013) and medium-to-long-term (Yildirim et al., 2016) effects than static stretching (SS). However, many studies have found that these effects are comparable to those of SS (Borges et al., 2018), and PNF stretching is as effective as SS if the effectiveness of stretching is evaluated only by ROM (Hill et al., 2017).

PNF stretching uses contractions of target and antagonist muscles as the stimuli and uses autogenic and reciprocal inhibition by tendon spindles (Golgi tendon organ) and muscle spindle reflexes (Hindle et al., 2012). Kay et al. (2015) reported mechanical changes in the muscle-tendon complex during stretching as a decrease in muscle stiffness in SS but reported that PNF stretching (contract-relax technique) decreases not only muscle but also tendon stiffness. As acute reductions in tendon stiffness occur after repeated maximal isometric contractions that generate a relatively greater tissue load in the tendon (Kay & Blazevich, 2009; Kudo et al., 2002), the muscle contraction that loads the tendon reduces tendon stiffness, which is the specificity of PNF stretching. Thus, a partner is essential in PNF stretching.

Partners must have an adequate understanding of the PNF stretching technique and basic training to perform it safely. PNF stretching is a technique that produces mechanical changes in the muscle-tendon complex, which are not observed in SS, and the absence of a trained partner does not provide the opportunity to enjoy its specific benefits. Therefore, developing a system that can replace a partner and enable PNF stretching without a partner is necessary.

This study aimed to develop a PNF stretching system using an electric motor with high rotational and braking torque at low speeds (low-speed, high-torque motor) to mechanically provide assistance in place of partners and to investigate the acute response in hip flexion ROM by applying PNF stretching using this system.

## 2. Materials and Methods

*Subjects* —A total of 21 healthy male students aged 18–21 years (mean ± standard deviation (SD); age: 18.6 ± 0.7 years, height: 172.3 ± 5.4 cm, weight: 62.7 ± 9.0 kg) were enrolled. The purpose of this study and the content of the experiment were explained to the subjects in detail. Written informed consent to participate in the experiment was obtained from the subjects. This study was approved by the Research Ethics Committee for Human Subject Research of the National Institute of Technology, Fukui College (Approval number: R4-1).

*Experimental procedure* —The main body of the PNF stretching system (hereinafter referred to as "the system") consisted of a low-speed, high-torque motor (Creative Design, RC5A) with a rotational torque of 157 Nm, a braking torque of 1470 Nm, and a rotational speed of 6 degrees/s, a lever arm attached to the motor and its rotational axis, and a pedestal mounted on the lever arm (Figure 1). The hamstrings were stretched by straight leg raising (SLR) in a supine position. Hamstring strain injuries account for 37% of all muscle injuries (Ekstrand et al., 2011), so preventing muscle injuries in this region is of paramount importance. Additionally, SS of this region has been reported to reduce hamstring strain injuries (Ruan et al., 2018), so hamstrings were selected as the target muscle in this study with the intention of stretching to prevent major injuries.

The system's main unit was placed on the left side of the subjects in a supine position on the bed, with the oblique axis at the center of rotation (Figure 2). The left leg was placed on the pedestal mounted on the lever arm that rotated with the motor shaft, and the subjects used a toggle switch to operate the motor, enabling passive SLR. The toggle switch is of an ON–OFF–ON type that allows either forward or reverse rotation of the motor, and a spring-return lever is employed. This allows the subject to release his finger from the lever to immediately stop the rotation, intentionally stop the leg raising, and return the leg position to its original position. A power breaker was installed at the outlet of the motor so that one of the researchers could stand in front of the breaker during the experiment and immediately shut off the power if a possible hazard occurred.

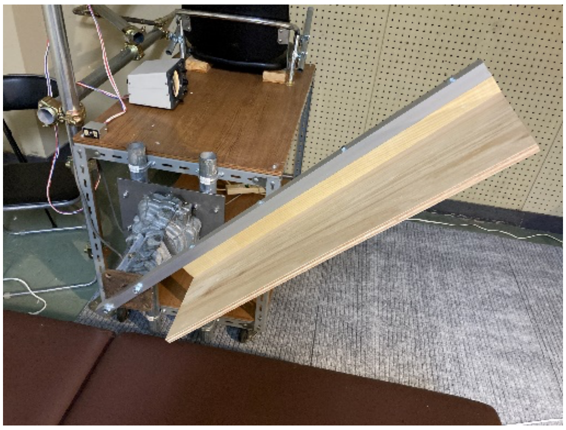

**Figure 1.** Overview of the proprioceptive neuromuscular facilitation (PNF) stretching system developed in this study.

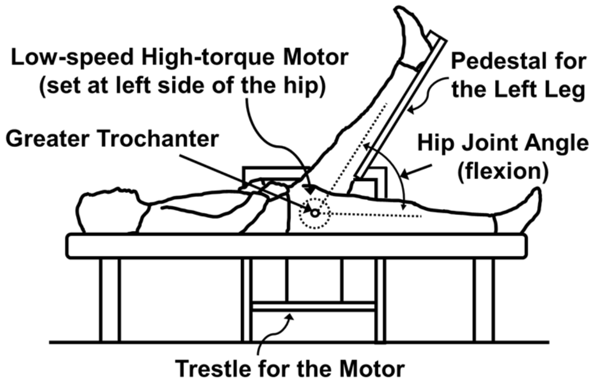


**Figure 2.** Schematic diagram of hold-relax (HR) stretching and defined hip joint angle for the measurement.

The simplest technique in PNF stretching, the hold-relax (HR) technique, was employed. HR is a technique that uses autoinhibition (Ib inhibition), which occurs when the Golgi tendon organ senses stretch due to muscle contractions of the target muscle (Hindle et al., 2012). The subjects placed the left leg on the pedestal and had the motor drive the leg up to the point just before pain or discomfort was felt (SLR), and in that state, the subjects performed prestretching for 10 s (Wicke et al., 2014; Konrad et al., 2017). Then, the subjects performed isometric contractions of the hamstrings for 6 s (Feland & Marin, 2004). After that, the muscles were relaxed, and the leg was further elevated by motor drive, stopping just before any pain or discomfort, and the posture was held for 10 s (Young & Elliott, 2001; Puentedura et al., 2011). This was repeated three times (Young & Elliott, 2001; Feland & Marin, 2004). The system performed the leg raising and holding during isometric contractions and prestretching. Before using the system, the subject experienced the HR with the hamstring of the right leg with the support of his partner and understood the HR procedure in advance. During the use of the system, the researcher gave verbal instructions to the subject, and the subject confirmed the instructions while performing the HR.

*Analysis* —The hip joint flexion angles, which are the limit at which the subject can raise the left leg without discomfort in SLR, were directly measured using a digital goniometer before and after HR (pre-HR and post-HR) using the system. And the acute response in hip flexion ROM using the system were evaluated.

*Statistical Analysis* —The hip flexion angles at pre-HR and post-HR were compared using the Wilcoxon signed-rank sum test. The significance level was set at 5%. The effect size (ES) for this comparison was calculated from the statistic of the Wilcoxon signed-rank sum test (z) and the number of subjects (n) using the following formula:

$$r = z\sqrt{n}.$$

## 3. Results

No subjects complained of anxiety, discomfort, or pain in this experiment. All subjects completed the self-stretching (HR) instructed by the system. Furthermore, the researcher did not use the circuit breaker.

The hip flexion angles at pre-HR and post-HR were 63.9 ± 15.2 and 81.4 ± 18.0 degrees, respectively, and significantly increased at post-HR compared with pre-HR (Figure 3; $P < 0.05$, ES = 0.88). The mean difference was 17.5 ± 15.6 degrees.

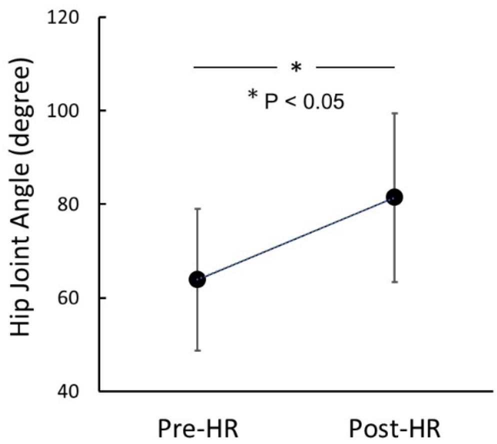


**Figure 3.** Means and standard deviations (SD) of the maximal flexion angles of hip joint at pre-HR and post-HR.

## 4. Discussion

In this study, the subjects attempted HR using a PNF stretching system with a low-speed, high-torque motor, which was originally developed to simulate the hamstrings as the target muscle. The improvement in muscle flexibility was evaluated as an immediate change in hip joint ROM. A comparison of the results of this study with those of previous studies that examined changes in hip flexion angles for improvement of hamstrings' flexibility in SLR would provide evidence for the effectiveness of this system. On the other hand, it should be noted that the high variance in the hip joint angles measured in this study was observed because the subjects in this study were not trained athletes, but ordinary people with varying degrees of flexibility.

Yadav & Lehri (2019) reported an average increase in ROM of 16.5–17.9 degrees with five repetitions of 3 s muscle contractions in HR, Ehsan et al. (2022) reported an average of 18.2 degrees with three sets of 10 s muscle contractions, and Sbardelotto et al. (2022) reported an average increase of 10 degrees with two sets of four repetitions of 10 s muscle contractions. These results are similar to those of our study, which showed that HR with three repetitions of 10 s isometric contractions increased ROM by 17.5 ± 5.6 degrees (mean ± SD). In other words, the system improved the flexibility of hamstrings comparable to that of PNF stretching performed by a partner. However, the degree of ROM increase has been reported to vary depending on the PNF stretching technique and muscle contraction time (Decoster et al., 2005), so it can be inferred that different gains are obtained with this system when the conditions vary.

The key points of the HR procedure were leg holding during isometric contractions and subsequent passive muscle lengthening. Sufficient braking torque (1470 Nm) for leg holding was one of the factors that allowed the system to function effectively. Another factor was that passive extension was achieved by a slow motor speed (6 degrees/s) and sufficient rotational torque (157 Nm) to safely allow the subject to control the movement (to raise the leg). The motor's low speed and high torque were sufficient for HR. Therefore, it was considered that the specificity of PNF stretching in terms of acute reductions in tendon stiffness caused by repeated relatively greater tissue loading (maximal isometric contraction) within the tendon was demonstrated (Kay & Blazevich, 2009; Kudo et al., 2002), increasing ROM.

The immediate gain in the ROM of the hip joints resulting from this system was objective evidence of its practicality. However, the operability and feel of the system are also considered important factors in considering its practicality. The most important feature of this system was that the partner's assistance is mechanically (pseudo)reproduced by the system user's own switch operation. In this study, the toggle switch operated by the users was a spring-return type, and the motor can be stopped as soon as the users remove his/her finger from the lever, so the users' anxiety is considered low with regard to misoperation and related malfunctions. However, in terms of the extent to which the subject's muscles can be stretched without discomfort during muscle relaxation after an isometric contraction (i.e., the extent to which the legs can be raised in SLR), communication between the partner and subject is generally essential in HR and the misperception of the subject's subjective view by the partner is a serious risk. Azuma & Matsui (2021) reported that, in the prototype phase of the system, the users' reflection that being able to perform alone and not having to be concerned about their partner were major advantages taken up by the users. Since this system does not involve any communication issues between the partner and user, it has the potential to avoid risks related to discrepancies in communication with the partner. In other words, it is possible to evaluate the utility of this system from a subjective perspective, including the operability of the system.

## 5. Conclusions

In this study, we developed a system that enables HR in PNF stretching using a low-speed, high-torque motor and investigated its practical feasibility. The system safely raised the leg on the pedestal mounted on the lever arm attached to the motor and its rotating shaft during the supine SLR under the subject's control and enabled passive extension and isometric contractions of the hamstrings. The motor had enough torque to withstand leg raising and isometric contractions of the raised leg, enabling muscle activity similar to that of general (partner-assisted) HR. PNF stretching (HR) using this system increased the hip flexion angle (increased ROM) and showed immediate improvement in hamstring flexibility. The degree of improvement was equivalent to the gain in ROM by PNF stretching (HR) reported previously, suggesting that this system works well enough for practical use. In addition, the system developed in this study is obviously not useful in environments without electricity, but is expected to be used in sports facilities and training rooms and suggests the possibility of being a useful device in terms of replacing the assistance of a partner.

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**Conflicts of Interest:** The authors declare no conflicts of interest.

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