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TITLE

The effect of a four week proprioceptive neuromuscular facilitation stretching program on isokinetic torque production.

ABSTRACT

Flexibility is widely accepted as an important component of fitness, yet flexibility training can be detrimental to muscle performance particularly where a high number of stretch cycles are performed. The purpose of this study was to investigate whether chronic PNF stretch training could successfully improve the knee flexion range of motion without having a detrimental effect on the peak isokinetic torque of the quadriceps. The minimum knee angle in flexion and the peak isokinetic quadriceps torque was measured at 120 and 270 degrees per second. Subjects then participated in a four week quadriceps flexibility training program consisting of three cycles of PNF stretching performed three times a week. The range of motion was recorded before and after the first stretching session of each week. At the end of the four week period the peak isokinetic quadriceps torque and flexibility was again measured. The mean (standard error) improvement in the knee flexion range of motion over the whole programme was 9.2 (1.45) degrees, typical gains following a single stretching session were around three degrees. Post-hoc analysis showed that the pre training session range of motion was significantly improved in Week 4 compared to the pre training session range of motion in Weeks 1 and 2 ($p < 0.05$). There was no change ($p = 0.9635$) in the peak isokinetic torque produced at 120 degrees per second (Week 1: 121.9 (4.6) N.m; Week 2: 121.9 (5.2) N.m) or at 270 degrees per second (Week 1: 88.1 (3.4) N.m; Week 2: 88.6 (4.9) N.m). These findings suggest that it is possible to improve flexibility using three PNF stretch cycles performed three times a week without altering muscle isokinetic strength characteristics.

Key Words: PNF stretching, quadriceps, chronic

INTRODUCTION

Stretching exercises are typically carried out as part of warm-up routines and ongoing training programs. The primary aim of stretching is to maintain or improve flexibility. It has also been suggested that stretching may prevent injury (1), reduce delayed onset muscle soreness (9), and performed chronically can enhance performance (10), though these claims are more controversial not least because the processes by which these effects may arise are complex. Nevertheless, it is widely accepted that flexibility is an important component of general fitness, and it is likely that there is a certain minimum range of motion required to safely and optimally perform a given activity.

Few studies have investigated the chronic effects of stretching on muscle performance (18). Worrell et al. (21) investigated the effect of a three week static and proprioceptive neuromuscular facilitation (PNF) training program, involving fifteen training sessions of twenty minutes each, on isokinetic torque and flexibility. Peak eccentric and concentric torque increased by just over 10%, but neither the static stretching program nor the PNF program achieved a significant increase in hamstring flexibility. Similarly, Bazett-Jones et al. (1) found that a six week static stretching program did not result in improved flexibility and did not improve 55-m sprint time or vertical jump height. Handel et al. (7) however found that an eight week PNF stretching training program achieved statistically significant gains in quadriceps and hamstring flexibility in young males of 3.1 and 4.6 degrees respectively after four weeks and 5.6 and 6.3 degrees after eight weeks. These increases in flexibility were accompanied by increases in maximum knee flexion

and extension torque. The training program used by Handel et al. (7) involved ten minutes of PNF stretching on the two relevant muscles three times a week for eight weeks. These three studies are characterized by a large number of stretching cycles, yet recent evidence from ultrasound studies suggests that changes in visco-elastic properties occur within a small number of stretching cycles (e.g. 11, 14). These studies suggest that most of the beneficial effects of stretching occur after just a few stretch cycles. In addition, several studies of the acute effect of stretching have shown a detrimental effect on muscle performance immediately following extended stretching activity (e.g. 5, 18), with a rest period of at least 15 minutes required for the recovery of normal performance (2). However, many studies investigating the effect of stretching have used a high number of repetitions, for example Fowles et al. (5) used 33 minutes of passive static stretching that involved 13 stretches held for 135 seconds each. It may be that the acute reductions in muscle performance and the chronic improvements in strength following stretching are due to an overload response associated with muscle damage and adaptation due to the sheer number of stretch cycles performed. In support of this hypothesis, it has been shown in rabbits that static stretching of long duration is associated with large increases in insulin-like growth factor I mRNA and protein synthesis rates, and muscle fiber hypertrophy (22, 6). While the muscle hypertrophy accompanying prolonged stretching may be useful in certain circumstances, for example in the rehabilitation of frail older adults, it may also be the case that coaches and athletes simply desire a stretching program that increases flexibility so that the stimulus for hypertrophy can be controlled via other training methods that are aligned with the skill. In order to achieve this aim it would be

necessary to restrict the number of stretch cycles performed, however the stimulus to achieve flexibility gains may then be inadequate. Consequently it is of interest to know whether a small number of stretch cycles can provide a chronic stimulus that improves flexibility but that does not cause changes in strength.

The purpose of this study was to investigate the effect of three cycles of PNF stretching performed three times a week for four weeks on the maximum knee flexion angle and the peak isokinetic torque of the quadriceps. PNF stretch training was chosen for this study since this method has been shown to be the most effective at producing flexibility gains from a small number of stretch cycles (19). The hypothesis was that limiting the number of stretch cycles to three cycles performed three times a week would allow chronic flexibility gains without altering isokinetic strength.

METHODS

EXPERIMENTAL APPROACH TO THE PROBLEM

The study was performed as a longitudinal study with before and after training measurements of isokinetic torque performance at 120 and 270 degrees per second, and weekly measurements of flexibility. The primary research hypothesis of this study was that a chronic PNF stretch training program consisting of three cycles of stretching three times a week for four weeks would provide sufficient stimulus to improve flexibility while isokinetic knee extension torque remained unaffected. During the flexibility training program one session per week was supervised by the investigator, the

remaining two sessions were performed outside the laboratory with a partner. Flexibility was recorded once a week before and after the supervised stretching session. Subjects were instructed not to perform PNF stretching outside of these sessions, otherwise subjects were instructed to continue with their usual pattern of activity.

SUBJECTS

Nine female subjects were recruited to the study (mean \pm SD: age 20.4 years \pm 0.9, height 1.66m \pm 0.08, mass 61.2 kg \pm 10.8). All subjects were healthy and participated in physical activity on a daily basis. Six subjects were members of the university basketball team with mean weekly training duration 4.5 hours. One subject trained with the university running club with a mean training load of 19 miles of running per week. The remaining subjects were active but non-specifically trained. The experimental procedures and any risks were explained and demonstrated to all subjects and written informed consent was voluntarily given prior to participation. The study was conducted in accordance with the Declaration of Helsinki, and the Research Ethics Committee at Aberystwyth University approved all procedures.

PROCEDURES

At the first test session, subjects performed a light aerobic warm up consisting of two minutes of cycling on an ergometer at 60-80 rpm. Flexibility was measured as the minimum achievable knee angle in flexion (with 180 degrees defined as full knee extension) measured using an elongated orthopedic goniometer. Subjects lay prone on a raised bench with a hip joint angle of 180 degrees (i.e. full extension). The center of

the goniometer was aligned with the lateral femoral condyle and the arms of the goniometer were aligned with the greater trochanter and the lateral malleolus. The experimenter rested a hand on the ankle and moved the shank within pain free limits until resistance prevented further motion at which point the goniometer reading was taken.

After the flexibility assessment subjects were positioned in a Biodex III isokinetic dynamometer (Biodex Medical Systems, New York). The dynamometer axis was carefully aligned with the knee joint axis and all bolts and moving parts on the dynamometer were checked and tightened. Restraining straps were used around the mid-calf, thigh, waist and chest. The Biodex output was sampled at 100Hz and filtered at 20Hz, the subject's limb weight was subtracted from the torque record. All testing was performed on the right leg. Subjects performed practice contractions and then maximum effort isokinetic knee extension contractions at velocities of 270 degrees per second, and 120 degrees per second. The order of presentation of the velocities was randomized. Two sets of five contractions were performed at each velocity with a one minute rest period between each set. The peak torque was extracted from each contraction using Matlab 2007a (The MathWorks, Natick, MA), and the contraction resulting in the peak torque across all ten contractions at a given velocity was then selected for further analysis.

Following the first Biodex testing session, subjects participated in a four week PNF stretching program. The stretching program used a contract-relax PNF technique

based on that of Handel et al. (7) modified to stretch only the quadriceps muscle group. Stretching and testing was performed on only one leg to avoid the transfer of effects between legs (7). Prior to any stretching activity the subjects performed a short warm up of at least two minutes of running, jumping or cycling activity. During the stretch the subjects lay prone with their legs straight out behind them with a hip angle of 180 degrees and their upper body supported by their arms. The stretch itself comprised three parts: a partner knelt behind the subject and bent the knee by pushing the foot back towards the subject's body. This position was held for five seconds. This was followed by a 5-10 second isometric contraction of the quadriceps with at least 70% of the subject's maximal force against the partner's matching resistance. Finally the subject's extended their knee out of the stretch and relaxed their quadriceps for 5-10 seconds before going back into the stretch. These actions were repeated three times in the same order in each stretching session. Three stretching sessions were performed per week over a four week period meaning that twelve stretching sessions were performed in total. One session each week was performed in the laboratory under the supervision of the investigator, the remaining two sessions each week were performed outside the laboratory with assistance from a partner. Subjects continued with normal activity patterns and exercise routines over the four week period, however, these training routines did not include specific strength training activities. Flexibility was measured once a week before and after the stretching session that was performed in the laboratory. A report was taken from each subject at the weekly session that was supervised by the experimenter to verify that the PNF training had been carried out and

subjects were asked to demonstrate the way that the exercises had been performed. Also, information about the subject's other physical activity was collected each week.

The Biodex testing session was repeated at the end of the four week training period. Again, following a short warm-up and practice contractions, two sets of five maximum effort isokinetic contractions were performed at 120, and 270 degrees per second. Again, the contraction producing the highest peak torque out of the two sets of five contractions was selected for further analysis. Following the Biodex testing session flexibility was again measured before and after stretching.

STATISTICAL ANALYSES

Statistical analyses were performed in SAS 9.1.3. A three way analysis of variance (ANOVA), with condition (pre or post four week training) and isokinetic velocity (120 or 270 degrees) as fixed factors and subject as a random factor, was used to analyze the peak torque data. Inspection of the residuals plots demonstrated no evidence of unequal variance, non-normality, or unmodeled trends. An Anderson-Darling test showed that the residuals were normally distributed ($p=0.781$).

A three way repeated measures ANOVA was used to analyze the flexibility data: time (the weekly measurements), condition (before or after each stretching session) and subject were factors and the covariance structure between time points was estimated using the MIXED procedure in SAS and an unstructured covariance model. This model was chosen from candidate models on the basis of the lowest corrected Akaike

Information Criterion. This analysis was chosen in preference to a standard repeated measures analysis because there is likely to be different correlation structures between the measurements before and after each training session and between the week to week measurements. Inspection of the residuals plots demonstrated no evidence of unequal variance, non-normality, or unmodeled trends. An Anderson-Darling test showed that the residuals were normally distributed ($p=0.692$). Post-hoc comparisons were performed on the flexibility data using the Tukey-Kramer adjustment in order to determine which weeks were significantly different from each other. The alpha (significance) level for all statistical tests was set at $p<0.05$.

RESULTS

There was an improvement in the range of motion over the PNF stretching program defined as a decrease in the minimum knee angle reached (Figure 1). The mean (standard error) improvement in the range of motion over the four week training period was 9.2 (1.45) degrees. There was a consistent trend for an improvement in the pre-flexibility training range of motion from week to week, indicating retained improvements in the range of motion. Each flexibility training session also resulted in an improvement in the range of motion, the mean (standard error) improvement was 2.9 (0.72) degrees.

<<Figure 1 around here>>

The time (week to week) effect and the condition (pre / post training session) effect were both significant ($p=0.0047$ and $p=0.0037$ respectively), as was the interaction between these two effects ($p=0.0007$). On examination of the data and the estimated least squares means it was concluded that this interaction was significant because the mean improvement each training session was different each week. For example, there was a bigger improvement in flexibility following the training session on Day 1 compared to Day 21 (Figure 1). Tukey post-hoc comparisons showed that there was a significant improvement in flexibility after a training session compared to immediately before the same training session on Day 1 and Day 28. The range of motion before the PNF training session on Day 21 was significantly greater than the range of motion on Day 1 and Day 7.

There was no significant change in the peak isokinetic torque produced before and after the PNF flexibility training program ($p=0.9635$) and the week by velocity interaction was not significant ($p=0.9074$). The mean (SE) isokinetic torque at 120 degrees per second was 121.9 (4.6) N.m and 121.9 (5.2) N.m for Weeks 1 and 2 respectively. At 270 degrees per second the mean (SE) isokinetic torque was 88.1 (3.4) N.m and 88.6 (4.9) N.m for Weeks 1 and 2 respectively. The individual differences between the two test sessions were very small: seven of the nine subjects produced efforts that were within six Newton meters of each other on the two occasions, this represented a difference of 4-7%. There was no consistent pattern to suggest that the PNF training was detrimental to isokinetic torque production (Figure 2). There was a significant difference in the peak torque produced at each velocity ($p<0.0001$), such that the peak torque

decreased with increasing velocity (Figure 2), which is consistent with the force-velocity relationship.

<<Figure 2 around here>>

DISCUSSION

The hypothesis was that limiting the number of PNF stretch cycles to three cycles performed three times a week would allow chronic flexibility gains without altering isokinetic strength. These results show that it is indeed possible to improve the minimum knee flexion angle by around ten degrees over a four week flexibility training program without affecting the peak isokinetic knee extension torque. This finding is important since flexibility training is widely used both in training for specific sports and in general fitness programs.

An interesting finding is that a practically and statistically significant improvement in joint range of motion is achievable with only a moderate amount of PNF stretching. In this study a mean improvement of around 10 degrees was possible from twelve sessions of three PNF cycles. The low number of cycles required means that the time to perform the flexibility program is short, and would not detract from ongoing team training at the collegiate level. Similarly, while it is likely that any improvements in flexibility would only

be retained for a short period of perhaps a week after the flexibility training stops (19), the time required to maintain the flexibility gains would not be arduous.

The subjects recruited to this study were young, active females who trained regularly in college-level teams, yet an improvement in flexibility was still achieved with the training program used. In contrast, Bazett-Jones et al. (1) found that a six week static stretching program performed on female track and field athletes at a similar level did not improve knee joint range of motion. The discrepancy in findings may be due to the different stretching technique used. The findings in the present study agrees with previous results showing that PNF stretching is effective in producing flexibility gains (19). There is evidence that the greatest improvement from PNF stretching is seen after just one stretching cycle (15, 19) with subsequent repetitions producing relatively minor additional effects (15). It was for this reason that PNF stretching was chosen as the training method for this study: the aim was to achieve flexibility gains with a low number of stretching cycles so that strength characteristics would not be altered. Flexibility gains achieved as a result of PNF stretching seem to reverse relatively quickly after training ceases (19). However, in this study improvements in flexibility measured immediately after a training session were for the most part retained, such that resting or pre-stretch flexibility was improved over the four week training period. It has been shown that in order to maintain flexibility gains achieved by PNF stretching, that stretching sessions should be carried out at least twice a week (19). Therefore it seems it would be necessary to continue to carry out at least two sessions a week to maintain the improvements in flexibility seen here.

The subjects in this study were all active and participated in college level sporting performance, but none of the subjects had used PNF stretching previously in their training. Weekly reports were taken of training and activity to ensure that the only difference in the activity patterns over the four week training period was the addition of the PNF stretch training, and none of the subjects were otherwise engaged in trying to produce flexibility gains. While it is acknowledged that the ongoing activity of the subjects could affect the results seen, the lack of change in the isokinetic strength suggests that no training effect was occurring that could have affected the flexibility of the knee, other than the training effect of the PNF stretching.

The mechanisms by which PNF stretching results in flexibility gains have not been conclusively elucidated, although autogenic inhibition (3), reciprocal inhibition (15), tendon and connective tissue creep (13), and increased stretch tolerance due to reduced pain transmission (12) have all been suggested as mechanisms. It is possible that all of these mechanisms are involved to some extent in the short term adaptations seen following PNF stretching, however none of them explain the more long term improvements in flexibility seen in the results of this study particularly well (19).

Seven of the nine subjects demonstrated extremely high consistency at both velocities in the peak knee extension torque values before and after the training program. This finding agrees with previous work showing that subjects are consistently able to voluntarily activate the quadriceps muscle to above 90% of full activation. Suter et al.

(20) showed that healthy males and females were able to almost fully recruit the quadriceps of both the right and left legs during isometric contractions, such that neuromuscular stimulation produced only a 4% increase in torque. There is evidence that this ability to highly activate the quadriceps also applies to isokinetic contractions in unfatigued muscle (8). Furthermore Roos et al. (17) found that the ability to recruit the quadriceps to a high level during isometric contractions was unaffected by age: groups of young men with a mean age of 26 and old men with a mean age of 80 were able to voluntarily recruit the quadriceps to 94-96% of full activation. However, other muscles, such as some hand muscles, are typically less completely recruited during voluntary activation (16). While it may be the case that genuine strength changes have occurred as a result of flexibility training, it may also be the case that apparent changes in muscle performance arise due to variability in the degree of activation in some muscles.

This study has demonstrated that a coach or athlete wishing to improve flexibility independently of any change in joint torque production ability can achieve this outcome by restricting the number of stretch cycles performed. Several studies have shown that stretch training has a chronic muscle hypertrophy effect or an acute detrimental effect, for example Fowles et al. (5) who used static stretching and other studies using both PNF and static stretching that are reviewed in Rubini et al. (18). It may be that these effects are due to the high number of stretch cycles performed and/or the duration of stretch. This reasoning would suggest that stretching should be prescribed in moderation following consideration of the load exerted by other parts of an overall training program.

Coaches and athletes may wish to improve the joint range of motion for reasons of safety and performance. It seems reasonable that there is some limiting range of motion below which a particular movement cannot be performed without injury.

Sometimes optimal performance requires an increased knee joint range of motion, for example Domire and Challis (4) used a simulation model to show that an improved jump height could be theoretically achieved by increasing knee flexion during the jump by the order of ten degrees. This was because greater vertical impulse was generated before take off due to the increased ground contact time. However, in this particular study human subjects could not replicate the improved jump height when using an increased joint range of motion. The authors suggested that this was due to lack of co-ordination between muscles to create an optimized sequence of joint extensions. If true, this would suggest that simple increases in strength cannot increase performance without adequate co-ordination, and for this reason coaches may want to improve flexibility, alter strength characteristics and improve neural co-ordination sequentially or independently. It is likely that the optimal performance of other complex movements is similarly dependent on co-ordination issues such that improvements in performance may not be straightforwardly achievable by strength increases, and that a coach may therefore wish to systematically alter aspects of performance independently of each other.

In conclusion, this study has shown that a low number of PNF stretch cycles performed three times a week is sufficient to produce functionally meaningful flexibility gains without provoking any isokinetic strength changes.

PRACTICAL APPLICATIONS

This study has shown that as little as three PNF cycles performed three times a week is sufficient to produce meaningful improvements in flexibility for young, female, collegiate level athletes. A mean improvement of ten degrees in the minimum knee flexion angle may be expected from a four week program of three PNF cycles performed three times a week. Ongoing flexibility training is necessary to maintain gains achieved through PNF stretching. The typical improvements in knee range of motion seen in this study are likely to be of practical use in performing skills, such as maximum vertical jumping, that require a certain minimum range of motion for optimal performance. Coaches and athletes may wish to improve flexibility independently of altering muscle strength characteristics and this study has shown that this outcome is possible when using a low number of PNF stretch cycles. While the present study did not investigate the acute effects of stretching, evidence from the literature suggests that a large number of stretch cycles should be avoided immediately prior to activities requiring the production of high muscle force or power. Based on the findings of the present study, it seems that any chronic detrimental effects of stretching on strength may also be limited or avoided by using a low number of stretch cycles.

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LIST OF FIGURES

Figure 1: Mean (error bars show standard deviation) flexibility data shown as the minimum knee angle achieved (180 degrees represents full extension) on Days 1, 7, 14, 21 and 28 of the PNF training period (n=8).

Figure 2: The mean (error bars show standard deviation) data isokinetic strength data across subjects before and after PNF training (n=8): peak isokinetic knee extension moment at 120 and 270 degrees per second.

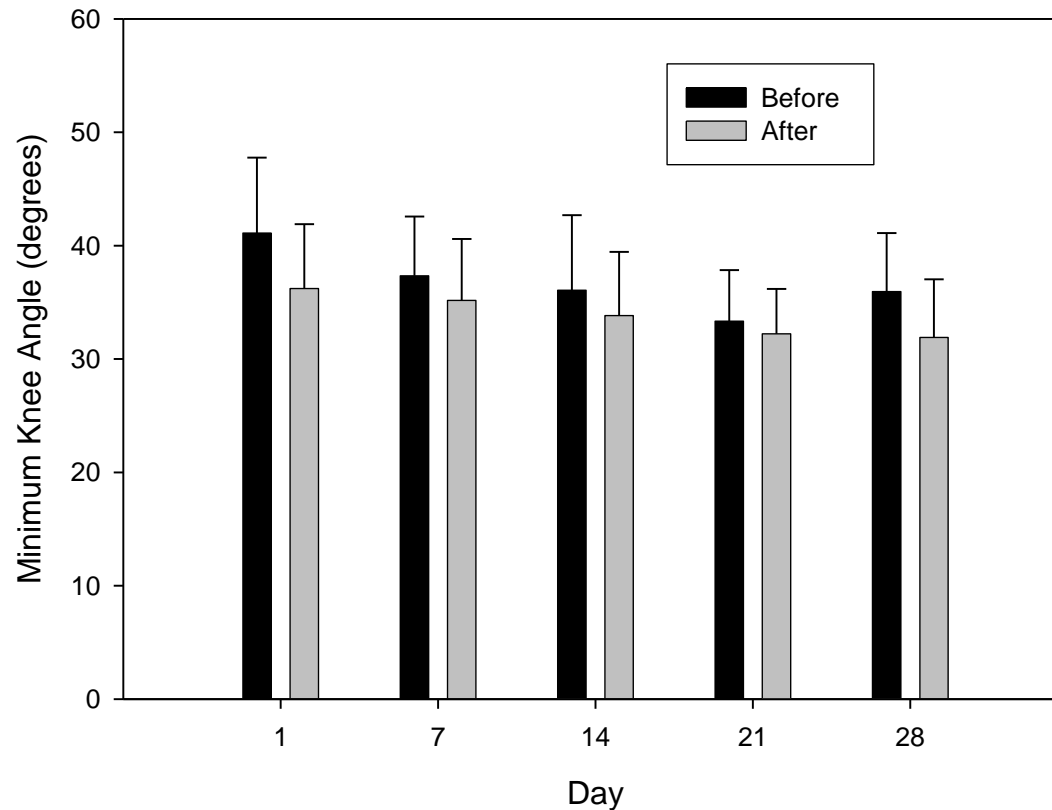


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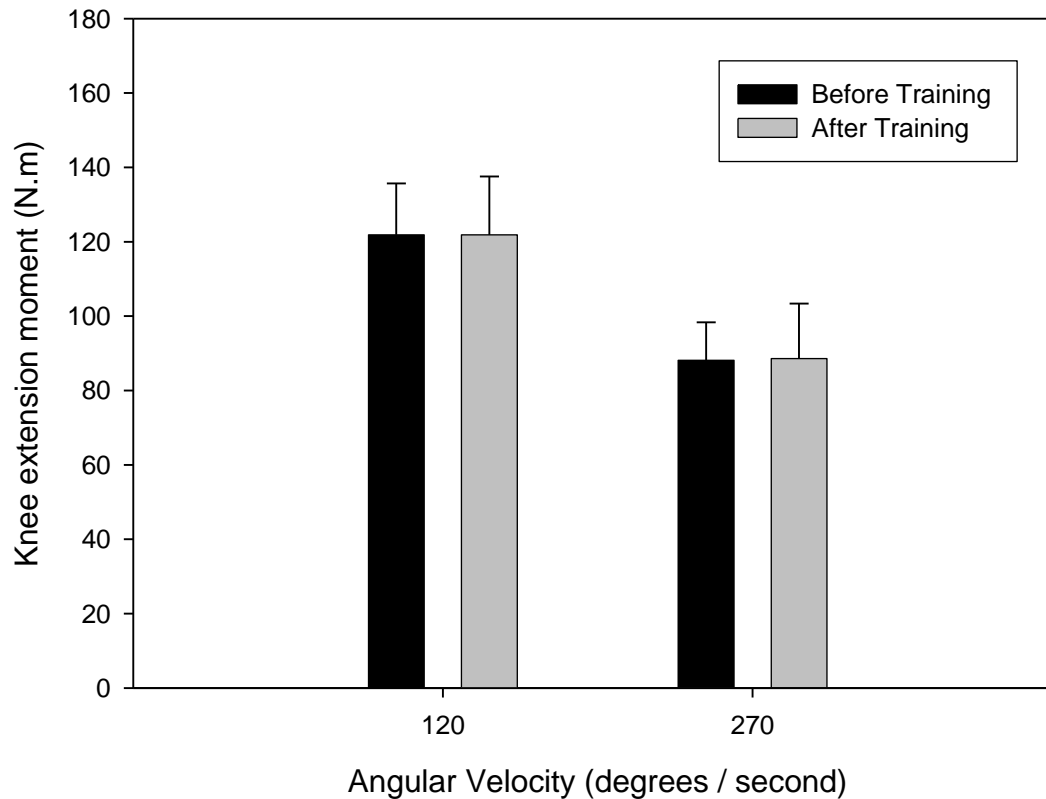


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