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Effect of Irradiation by Proprioceptive Neuromuscular Facilitation on Lower Limb Extensor Muscle Force in Adults

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Abstract

Background and purpose: This study aims at comparing the effectiveness of PNF technique applied by upper extremity and lower extremity on opposite lower limb muscle strength in adults.

Method: 200 subjects including both males and females of age 20-35 years were recruited. All selected subjects were randomly divided into 4 groups according to the PNF pattern applied to them through lottery system. PNF patterns were applied isometrically at final position and isotonically throughout the ROM on contralateral upper and lower limb (dominant). A pre-test post-test same subject design was used in which the maximum voluntary isometric contractions (MVIC) of the extension forces of non-dominant lower limb was measured during isometric PNF pattern at final position and after isotonic PNF patterns. Each subject received a two session of PNF. A strain gauge measured the extension force of lower limb.

Results: In subjects, the maximum voluntary isometric contraction (MVIC) of extension force of non-dominant lower limb improved significantly while performing extension PNF pattern (extension-abduction-internal rotation) on dominant lower limb.

Discussion and conclusion: The extension force of the opposite lower limb increased more with PNF pattern of contralateral lower limb than contralateral upper limb and in lower limb homologous pattern was most effective than non-homologous pattern. The result suggests that possible mechanism can be explained by "cross activation" hypothesis and the excitability of non-decussated descending motor fibers, coticospinal tract fibers.

Keywords: PNF; Cross education; Irradiation

Introduction

PNF consists of direct treatment and indirect treatment. Direct treatment may involve, use of treatment techniques on the affected limb, muscle, or motion or directing the patient's attention to stabilizing or moving the affected segment. Indirect treatment may involve use of the techniques on an unaffected or less affected part of the body. The literature has revealed two possible explanations for patterns of contralateral effects. One theory is based on the overflow of impulses from the muscles that are directly being exercised. The other theory is based on biomechanics: the effects are due to stabilization of the contralateral side when resistance is applied to the exercised limb.

Studies reported the development of muscle tension in unexercised parts of the body during and after maximal exercise of one limb [1,2] Other experiments have described electromyographic (EMG) activity in the agonistic and antagonistic muscles of the contralateral upper or lower extremity during resisted isotonic and isometric exercise [3,4].

Studies have also demonstrated

Cross education is an exercise applied to one side of the body to induce muscle activity on the contralateral unexercised part or parts. Studies reported cross-education of strength following unilateral exercise training [5]. Patients with burns, fractures, or arthritis may be unable to exercise the involved limb and would benefit from the indirect approach of exercising the non-involved limb in order to obtain contralateral muscle activity. Physical therapists often use cross-education effects to prevent a reduction in number of functioning motor units and muscle atrophy by exercising the sound limb or other healthy parts to stimulate muscle activity in the affected limb that cannot be directly approached [6-8].

Thus this study aims at comparing the effectiveness of PNF (indirect) technique applied by contralateral upper extremity and contralateral lower extremity on opposite lower limb muscle strength in adults.

Methods

Subjects

200 subjects were included in the study out if which 100 were females and 100 were males.

A sample of convenience of 200 subjects was selected on the basis of inclusion and exclusion criteria. All selected subjects were randomly divided into 4 groups i.e. group A, group B, group C, and group D through lottery system. 50 subjects were selected in each group.

Inclusion Criteria [4]:

- Male/Female
- Age group- 20-35 years

Exclusion Criteria [4,9]:

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- Subjects with history of orthopaedic disorders of arm, trunk and lower limb
- Subjects with history of neurologic disorders of arm, trunk and lower limb

Dependant variables

Extensor muscle force of opposite lower limb measured during application of PNF pattern isometrically at final position and after application PNF pattern isotonically for 3 sets of 10 repetitions and it was measured by strain guage [10].

This instrument is highly reliable and valid for strength measurement [11].

Protocol

Approval for the study was obtained from Institutional Review Board, Jamia Hamdard University, New Delhi. The patients were informed about the study and explained about the procedure. Participant's data was collected by the tester and an informed consent was signed by the subject.

Procedure

Subject selection and preparation

First the selected subjects were given subject information sheet and briefed about the study.

A detailed history of orthopaedic and neurologic disorders of arm, trunk and lower limb were taken from patient. History of deformity, sensation, strength, tightness, contracture, and pain etc. in last 3 months was taken from subjects.

Subjects were selected on the basis of inclusion and exclusion criteria and they were made to sign the informed consent form.

Dominance of the subjects was determined by the hand they used to sign the informed consent form. In right handers, the footedness follows the handedness, thus in right handers, the right foot was considered as dominant [12].

All selected subjects were randomly divided into 4 groups, i.e., 50 subjects in each group according to the PNF pattern applied to them through lottery method.

GROUP A: D2 Flexion pattern of contralateral upper limb (flexion-abduction-external rotation).

GROUP B: D2 Extension pattern of contralateral upper limb (extension-adduction-internal rotation).

GROUP C: D1 Flexion pattern of contralateral lower limb (flexion-adduction-external rotation).

GROUP D: D1 Extension pattern of contralateral lower limb (extension- abduction-internal rotation).

The subjects adopted a supine position on a treatment table. The table selected for the study had height (2.6 ft), breadth (2.5 ft), length (8 ft).

The subjects were asked to wear non-restrictive clothings.

Instrument preparation and positioning:

1 Strain gauge was used; it was attached to subject's non dominant lower limb to measure its extensor muscle force.

The instrument was placed on the measurement side i.e. if the measurement of left lower limb was taken, then it was placed on the left side of the patient. The position of the instrument remained same throughout the study.

The instrument was attached to the lower limb with the help of the strap. The strap was positioned around the mid-foot of the subject.

Measurement

The strain gauge was reset to 0 kgf at the starting of each measurement. Strain gauge measured the maximum voluntary isometric contraction (MVIC) of the extension forces of the opposite lower limb (non-dominant).

The patients were instructed to push down their feet so as to pull the chain of the strain gauge.

Command: "pull"

The measurement time was kept 3-4 seconds.

All the readings were noted by an independent observer. Independent observer was assistant at the rehabilitation centre, which had academic qualification upto 10th standard. He was taught about the method of taking readings from strain gauge. He was positioned near the instrument in such a way, that he can note the readings easily.

PNF patterns were performed on subject's dominant limb according to the groups in which they were selected. PNF patterns were applied by two methods:

Test 1- Immediate effects of single repetition [9]

PNF patterns were performed on subject's limb isometrically at final position holding for 3-4 seconds, simultaneously the extension force of opposite lower limb (non- dominant) was measured each time. This procedure was repeated 3 times.

"Hold" instruction was given to the patient when pattern was applied isometrically at end position [2].

Test 2- Effects of sets of pattern repetitions [10]

Again same PNF pattern were performed on subject isotonically throughout the range of motion for 3 sets of 10 repetitions. The extension force of opposite lower limb was measured after completion of the whole regime and this reading was taken 3 times.

These two tests were done on two separate days.

PNF Pattern:

UPPER LIMB:

Flexion pattern of upper limb (flexion-abduction-external rotation)

Starting Position:

Wrist in ulnar flexion and the forearm into pronation, elbow flexed, and shoulder adducted, extended, internally rotated.

Command:

"Hand up, lift your arm." "Lift!"

End Position:

The shoulder is in full flexion, abduction, external rotation, scapula is in posterior elevation, elbow extended, wrist is in full radial extension, fingers and thumb extended toward the radial side.

Extension pattern of upper limb (extension-adduction-internal rotation)

Starting Position:

Fingers and thumb extended toward the radial side, wrist in full radial extension, and the forearm into supination, elbow extended and shoulder full flexion, abduction, external rotation

Command:

"Squeeze my fingers and pull down and across your chest."

End Position:

The shoulder is in full adduction, extension, internally rotation, forearm into pronation, elbow is in flexion, wrist in ulnar flexion

LOWER LIMB

Flexion pattern of lower limb (flexion-adduction-external rotation)

Starting Position:

Toes flexed and foot is in planter flexion, eversion, knee flexion, hip is in extension, abduction, internal rotation

Command:

"Foot and toes up and in; bend your knee; pull your leg over and across."

End Position:

The hip is in flexion, adduction, external rotation, knee extension, foot dorsiflexion and inversion, toes extension

Extension pattern of lower limb (extension - abduction-internal rotation)

Starting Position:

Toes extended, foot dorsiflexed and inverted, knee extended and hip is in flexion, adduction, external rotation

Command:

"Push your foot down and kick down and out." "Kick!

End Position:

The hip is in extension, abduction, internal rotation, knee extended, foot is in planterflexion, eversion and toes flexed

Rest time: according to patient's fatigue

No. of session: 2

All data was recorded in the Data Collection Sheet.

Data analysis

Effect of irradiation by proprioceptive neuromuscular facilitation on lower limb extensor muscle force was tested by repeated measure Post HOC ANOVA for within group comparison which showed overall significant difference and Bonferroni was used for between group comparison which also showed overall significant difference. Pre-test and post-test readings are compared by paired t-test.

The independent variables were four different PNF patterns, i.e., flexion-abduction-external rotation, extension-adduction-internal rotation, flexion-adduction-external rotation, extension-abduction-internal rotation which were applied to upper limb and lower limb. The dependent variable was MVIC (maximum voluntary isometric contraction), measure of the strength of the extensor muscles of opposite lower limb. MVIC provides an indication of the force exerted by the extensor muscles of the opposite lower limb. The α level was set at 0.05 and very highly α level was set at 0.01 for analyses. MVIC was analysed during pre-test and post-test. Data analysis was accomplished with the following software packages: STATA: version 12. SPSS (version 16.0 SPSS Inc. Chicago, IL), EXCEL (Professional EDITION 2007; Microsoft Corp, Redmond, WA) (Tables 1-6).

Variables	GRP. A	GRP. B	GRP. C	GRP. D
SEX				
MALE (n)	25	25	25	25
FEMALE (n)	25	25	25	25
AGE				
Mean+S.D	23.8+1.3	23.4+1.4	23.5+1.6	23.8+1.5
Range	22-34	22-34	22-34	22-34

Table 1: Descriptive statistics for subjects.

	Post-test isometrics		Post-test isotonic	
Groups	Mean	S.D.	Mean	S.D.
Group A	19.5	6.9	19.2	7.4
Group B	23.1	7.9	27.7	11.2
Group C	22.9	5.4	24	5
Group D	23.9	7.9	30.5	9.7

Table 2: Within subject improvements in groups.

	Post-test isometrics	Post-test isotonic
Groups	P value	P value
1 v 2	0.06	<0.0001
1 v 3	0.09	0.04
1 v 4	0.01	<0.0001
2 v 3	1.0	0.2
2 v 4	1.0	0.6
3 v 4	1.0	0.002

Table 3: Between subject improvements in groups.

	Post-test isometric		Post-test isotonic	
Group	Mean	S.D.	Mean	S.D.
Group A	5.3	2.0	5.0	2.8
Group B	5.9	3.0	10.5	6.4
Group C	5.9	1.9	7.0	1.9
Group D	6.2	4.6	12.8	6.9

Table 4: Comparison of pre-test and post-test readings.

Variables	Group	n	Mean difference
Pre-test	Upper and lower limb	200	1.668
Post-test isometric	Upper and lower limb	200	2.132
Post-test isotonic	Upper and lower limb	200	3.804

Table 5: Comparison of combined upper limb and lower limb readings.

Group		n	Mean ± S.D.
Pre-test	UL	100	15.7 ± 6.5
	LL	100	17.3 ± 5.3
Post-test	UL	100	23.5 ± 10.3
	LL	100	27.3 ± 8.5

Table 6: Comparison of upper limb and lower limb PNF pattern.

Results

Statistical analysis revealed that irradiation by contralateral upper and contralateral lower limb PNF patterns showed statistically significant ($p<0.0001$) difference. Contralateral lower limb PNF patterns caused greater improvement of strength of extensor muscle of opposite limb than contralateral upper limb. In lower limb PNF patterns, extension PNF pattern (extension-abduction-internal rotation) was more effective than flexion pattern (flexion-adduction-external rotation) (Figures 1-4).

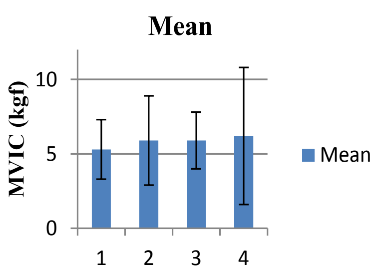

Figure 1: Comparison of Pre-test and Post-test readings (while giving isometric PNF patterns at the final position) of MVIC.

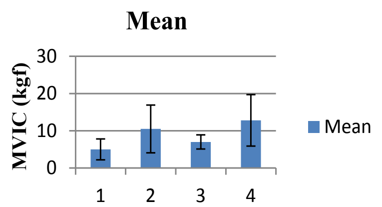

Figure 2: Comparison of Pre-test and Post-test readings (while giving isotonic PNF patterns) of MVIC:

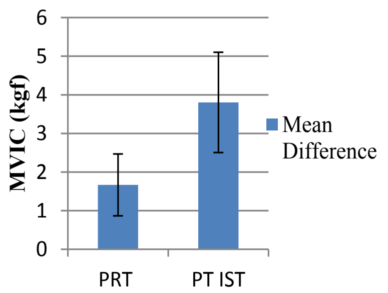

Figure 3: Comparison between pre-test and post-test readings of MVIC when PNF patterns are given isotonically in 2 combine group of upper limb and lower limb.

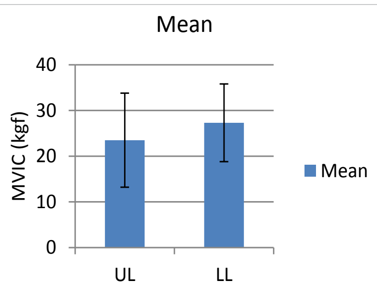

Figure 4: Comparison between upper limb and lower limb PNF patterns.

Discussion

The following discussion intends to explain the observations made and the results obtained through this study in the light of available scientific evidence.

The result of our study shows:

Irradiation by contralateral lower limb PNF patterns was better than contralateral upper limb PNF patterns

In lower limb, irradiation by homologous pattern was better than non-homologous pattern

Discussion of results within group

Effective irradiation by both contralateral upper and lower limb PNF patterns: Within group comparison of pre-test and post-test readings for all four groups have shown significant ($p<0.0001$) increase in MVIC of opposite limb, when PNF patterns were performed both isometrically and isotonically. This finding shows effective irradiation by contralateral upper and lower PNF patterns to opposite lower limb extensor muscles.

The possible factors responsible for cross-training or irradiation can be explained by the following hypothesis: "callosal access" hypothesis suggests that, motor engrams developed in the dominant hemisphere can be accessed by the opposite hemisphere via the corpus callosum to facilitate task performance with the untrained limb [13].

Our results can be supported by findings of Panin and associates. They demonstrated that overflow is not limited to contralateral agonists or antagonists but is widespread throughout all four extremities during resisted movements at the knee or elbow [14].

Hellebrandt [7,8] also stated that whenever unilateral exercise of large muscle groups is performed against heavy resistance, wide spread postural readjustment always occur and these call forth the synergistic co-contraction of many muscle groups involving the trunk and remote extremity as well as those of the opposite limb. This may be the possible mechanism for above findings [2,15,16] determined the influence of the different PNF upper limb positions on lower limb extension muscle strength in healthy individuals. They proposed that the D2 flexion PNF pattern take both legs in the direction of extension during isometric resistance. Also, the extension force of contralateral lower limb increased more when isometric resistance exercise was performed by an upper limb at final position of D2 flexion PNF pattern and it was significantly higher than ipsilateral leg [9].

It has been accepted that cross-education occurs from homologous to homologous muscle [16] (i.e., if the biceps brachii is trained on the right side, the biceps brachii on the left side will see an increase in strength via cross-education). This could be possible reason for effectivness of lower limb PNF pattern [17].

Between group

Irradiation was better when PNF patterns were given isotonically comparatively to isometric: On comparison between two combine groups of upper limb and lower limb, there was no significant (p at <0.01) difference at baseline, even at post intervention there was no significant (p at <0.01) difference in MVIC when PNF was given isometrically at final position. But, when PNF was given isotonically then there was significant (p at <0.01) difference in post intervention readings of MVIC. Our results signify that irradiation is better when

PNF patterns are given isotonically than isometrically.

Our findings can be supported by the results obtained by Gregg and associates. They did not record any EMG activity from unexercised triceps brachii and biceps brachii muscles during maximal isometric exercise and no resisted isotonic exercise of the contralateral muscles that flex the elbow. They did record EMG activity, however, from both unexercised muscles as resistance was applied during isotonic exercise of the contralateral elbow flexor muscles [18].

Similarly, Sills and Olson reported an increase in EMG activity recorded from an unexercised muscle during an increase in the amount of resistance applied to isotonic exercise of the contralateral limb [18].

From biomechanical point of view, tension in a muscle varies with the type of contraction. Isometric contraction produces greater tension than do concentric contractions [19].For simple movements, the magnitude of the crossed cortical effects is related to the force of contraction. Thus, during isometric contraction the irradiation should be more, but this finding is not in agreement with our results. Conversely, in our study irradiation was better when PNF patterns were given isotonically (concentric) comparatively to isometric. The reason might be that, during isotonic training 3 sets of 10 repetitions of PNF pattern were performed but during isometric training only 3 repetitions of PNF pattern were performed. The effectiveness of a resistance training program is dependent upon several factors including frequency, volume of training (sets × repetition × resistance) and mode of training. Since, isotonically more repetitions were performed comparatively to isometric so the effectiveness of isotonic training was more than isometric training [10]. Another explanation for the above finding could be that, during simple movements like flexion or extension only one particular muscle group is activated whereas during PNF, more than one muscle groups are activated because PNF pattern are spiral in nature e.g. during hip extension only hip extensors are activated but during extension pattern of PNF (extension- abduction-internal rotation), hip extensor, abductor, internal rotators etc. gets activated. So, this biomechanical principle might not be valid for PNF pattern.

Within group

Irradiation by contralateral lower limb PNF patterns was better than contralateral upper limb PNF patterns:

On comparison between two combine groups of upper limb and lower limb, results shows that who were given isotonic pattern deferred significant difference between upper limb and lower limb patterns. The mean of lower limb pattern (27.33 ± 8.5) was higher than the mean of upper limb pattern (23.53 ± 10.3), so these data reveals that contralateral lower limb pattern causes greater improvement of strength, i.e., MVIC than contralateral upper limb pattern.

Many researches support this finding and according to them cross education occurs homologous muscle to homologous muscle, i.e., homologous limb to homologous limb. Hortobágyi [10]. Determined that 6 weeks of knee extension training increased strength in both the trained and untrained knee extensors, but found no increase in handgrip strength [17].

Evidently, irradiation from each entrant path tends to run in certain direction and not in all. This sometimes stated in the form that grey matter offers to the entrant path lines of conduction possessing different degree of resistance. The difference in conductive resistance was attributed mainly to differences in the length of the network to be traversed by some reflexes as compared with others. The longer that path in the grey matter the higher was thought to be the resistance. Evidence indicating slow travel of impulses in grey matter was taken as evidence of resistance in grey matter [20]. This statement by Sherrington might be the possible reason for the above finding. During upper limb PNF pattern, the impulses of irradiation has to travel a longer distance in grey matter compared to the lower limb PNF pattern [20]. Thus, the irradiation from upper limb to opposite lower limb has to encounter a greater resistance compared to irradiation from lower limb to opposite lower limb. Thus, the intensity of the stimulus would have reduced much more in upper limb pattern compared to lower limb pattern. According philosophy of PNF, irradiation is dependent on intensity of stimulus. So we can assume that due to following reasons irradiation by lower limb PNF patterns was effective than upper limb PNF patterns.

Effective irradiation by both flexion and extension PNF patterns of contralateral lower limb: Within group comparison of pre-test and post-test readings for group C and group D have shown significant ($p<0.0001$) increase in MVIC of opposite limb, when PNF patterns were performed both isotonically. This implies that when PNF is given in lower limb then we can expect greater improvement in strength of contralateral lower limb compared when the same pattern is given in upper limb.

Research by Sariyildiz et al. supports our findings. They examined whether unilateral strength training would increase strength in the opposite untrained agonist and antagonist muscles. The study used electrical muscle stimulation training on the wrist flexors to determine if the wrist extensors would increase strength. The trained limb wrist flexors increased strength by 50%, and the untrained limb wrist flexors increased strength by 44%. The untrained limb wrist extensors (i.e., the antagonist muscle) also increased strength by 46%, demonstrating that cross-education was not confined to the homologous muscle. The results suggest cross-education may also influence the antagonist muscles of the homologous joint that would be involved in a strength movement in opposition to the training task [17].

Similarly, Gregg and associates monitored electrical activity in the non-exercised biceps brachii and triceps brachii muscles as the contralateral biceps brachii muscle was exercised. They observed that overflow only occurred with resistive exercise and that such activity was confined to the triceps brachii muscle initially, spreading to the biceps brachii muscle only with greater contralateral exertion [14].

During flexion PNF pattern (flexion- adduction - external rotation), muscles activated at ipsilateral side at hip were psoas major, iliacus, adductor muscles, sartorius, pectineus, rectus femoris, at knee were hamstrings, gracilis, gastrocnemius, and at ankle was tibialis anterior. According to above stated research findings, the agonists and antagonists i.e. flexor and extensor muscles should also be activated around the contralateral homologous joint during ipsilateral training. This similar effect was seen in our study, the extension muscle force of the contralateral limb was increased after ipsilateral limb was given flexion pattern.

The possible mechanisms for the above findings can be explained by "cross-activation" hypothesis. This hypothesis is based on the observation that the execution of many unilateral tasks generates cortical activity both contralateral and ipsilateral to the trained limb (i.e., crossed activation). According to the "cross-activation" hypothesis, the bilateral cortical activity produced by unilateral training leads to adaptations in both hemispheres [13]. Thus, unilateral training causes task-specific changes in the organization of motor circuits normally associated with the control of the opposite, homologous muscles.

During extension-abduction-internal rotation pattern of lower limb, muscles activated at hip were gluteus medius, gluteus maximus (upper), and hamstrings, at knee are quadriceps, at ankle are gastrocnemius, soleus, peroneus longus and brevis. According the above mechanism ("cross activation" hypothesis) and other researches, in contralateral limb also the opposite and homologous muscle should be activated during ipsilateral training. This similar effect was seen in our study, the extension muscle force of the contralateral limb was increased after ipsilateral limb was given extension pattern.

Between groups

In lower limb, irradiation by extension PNF pattern (homologous pattern) was better than flexion PNF pattern (non-homologous pattern): Comparison of MVIC during pre-test have shown that there was no significant (p=1.0) difference between group C and group D but between group comparison shows significant (p=0.002) difference among them and within group comparison shows that the mean of group D (30.5) was higher than group C (24.0). This signifies that, at baseline there was no difference between group C and group D and more improvement was seen in group D comparatively to group C. Thus we can infer from the results that irradiation by extension PNF pattern was better than flexion PNF patterned [3].

The possible mechanisms for the above findings can be explained by "cross-activation" hypothesis. Hortobagayi [10] also supports this finding that cross education is specific to the homologous muscle in contralateral limb [16].

Some researchers believe that a neuroanatomical basis for cross-transfer may exist. A popular hypothesis of cross education has been that unilateral muscle contractions increase the excitability of non-decussated descending motor fibres the homologous ipsilateral muscle [21]. For instance, about 85% to 90% of the corticospinal tract crosses in the medulla so that the left primary motor cortex controls the right voluntary muscles and vice versa. The 10% to 15% of the axons that do not cross continue to travel through the medulla. The majority of these pathways eventually cross at several spinal cord levels and thus serve the contralateral muscles. However, not all of the anterior corticospinal tracts cross; some (up to 3%) serve the ipsilateral [22]. Hence, motor impulses arising from one of the cerebral hemispheres innervates both the contralateral and, to a lesser extent, the ipsilateral sides. 15% of corticospinal fibres cross to the contralateral side, and thus co-activation of homologous muscles has been suggested to be caused by an overflow of descending signals from the ipsilateral motor cortex [13].

This effect in the unexercised muscle group may be due to repeated contractions of the unexercised extremity in an attempt to stabilize the body during high-effort exercise [23].

Research by Brussock CM [18] supports these findings. They studied the lectromyographic activity recorded from an unexercised muscle during maximal isometric exercise of the contralateral agonists and antagonists and they demonstrated that the motion of the right unexercised knee paralleled the attempted motion of the left exercised knee. This associated motion may also be related to stabilization of the body. Maximal isometric contractions of the left knee flexor and extensor muscles appeared to produce a rotational force in the direction of the muscle contraction. A counter rotational force produced by the same knee motion on the contralateral side would help stabilize the body. So, the contralateral agonist and not the contralateral antagonist produced the greater IEMG activity. This can also be possible explanation for the above findings.

The effect of age and gender was insignificant as the subject group was very homogenous with less variability among these different characteristics.

Limitation of the Study

Long duration effects of PNF are not documented after training is completed. Individual effects of PNF pattern on subjects are not seen.

Future Recommendation

Same study using different protocols and different type of exercise form like isokinetic can be used. Same study can be used in different neurological conditions like stroke and can be validated.

Conclusion

Our results showed that the strength (MVIC) of opposite lower limb increased more during contralateral lower limb PNF patterns than contralateral upper limb PNF patterns.

So, we can conclude that there is significant difference in effect of irradiation by Proprioceptive neuromuscular facilitation by upper extremity and lower extremity on opposite lower limb extensor muscle force in adults.

The study thus concludes by rejecting the null hypothesis and accepting the experimental hypothesis.

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